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Biofuel Production Potential of *Anacardium occidentale* (Cashew)

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ABSTRACT

Mature and ripe cashew fruits were harvested, washed and the apples separated from the nuts. The apples were crushed and the juice extracted and treated with potassium metabisulphite to check the activities of undesirable microorganisms. A 3-spatula full of *Saccharomyces cerevisiae var. ellipsoideus*, was rehydrated and inoculated into the treated juice and allowed for 5 days in a room temperature of 32.5^{0}C to ferment. After fermentation, initial ethanol content of 7.5% was obtained. This ethanol could not be used as biofuel due to its impurities and high percentage of water. A distillation and re-distillation were performed to obtain a purer form of ethanol of 95%. The 95% ethanol was tested in a small 950-watts-capacity gasoline engine generating set and the engine ignited and ran successfully. The study could establish the use of cashew apple in the production of biofuel, a move that will diversify the oil sector and preserve our ecosystem.

Keywords: Cashew Apple Juice; Fermentation; Ethanol (Biofuel); *Saccharomyces cerevisiae var. ellipsoideus*; Distillation.

INTRODUCTION

Bioethanol is the most commonly known biofuel worldwide. It is the same type of alcohol found in alcoholic beverages and can be used as a biofuel alternative to gasoline. These fuels are produced by fermentation of sugars derived from wheat, corn, sugar beets, sugar cane, molasses, sorghum, cassava, potato, fruits and any sugar or starch materials that alcoholic beverages can be made from. The ethanol production methods used are enzyme digestion, fermentation of the sugar into alcohol, distillation and drying of the ethanol. Other biofuel types include vegetable oil, biodiesel, bioethers, biogas, syngas, oilgae and other biologically produced fuels. The use of fossil fuels, unlike the renewable energies, have contributed greatly to the environmental degradation and pollution of the atmosphere which include global warming and climate change through the release of harmful emissions and green house gases (GHG) into the atmosphere. The activities of oil exploration, spillage, gas flaring, and increasing concern for the security of oil supply have also necessitated interests in the diversification and provision of alternative energy to crude oil production, especially in the area of renewable energy. Fig. 1 shows a consistent increase in biofuel production over a ten-year period, while Fig. 2 shows a forecast of bioethanol production up to 2025.

Ethanol has both advantages and disadvantages over petrol and diesel. Graham-Solomon and Fryhle (2016) observed that ethanol has a high octane rating of 129 RON (Research Octane Test) and 102 MON (Motor Octane Test) which equates to 116 AKI (Anti-Knock-Index). Ordinarily European petrol is typically 95RON, 85 MON, equal to 90 AKI. It should be noted that AKI averages the RON and MON ratings and is used on US gas station pumps.

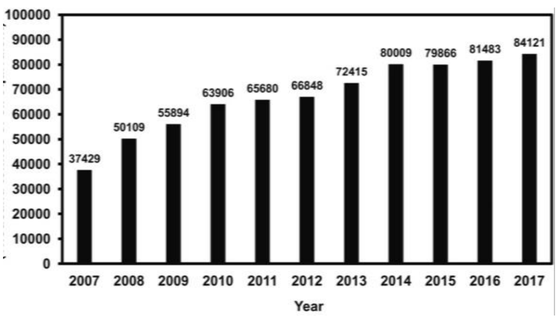

Fig. 1: Global Biofuel Production Showing a Consistent Increase In Its Production Thousands (Tonnes)

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Source: BP (2018, June).

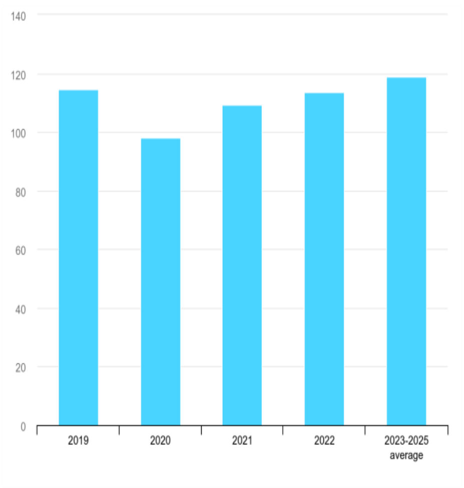

Fig. 2: Global Bioethanol Production in 2019 and Forecast to 2025 Billion (L)

Source: International Energy Agency (2020, November 10).

Utilization of food crops such as maize, wheat, sugarcane, rice, sorghum, cassava, potato etc., could become a serious threat to world food security. However cashew apple (*Anacardium occidentale*), an important organic resource generated in cashew plantations and wasted in large quantities becomes very attractive substrate to produce bioethanol. Cashew industry uses only the raw nuts for the manufacture of cashew kernels and almost the entire quantity of the cashew apple remains wasted in the plantation itself. Pinheiro *et al*. (2008) show that 40.11 lakh tonnes (1lakh tonne equals x10^5 metric tonnes) of cashew apple has a potential to produce 3.21 lakh tonnes of ethanol. Cashew apple yields 8 -10% of ethanol and every kg of raw nut generates apple equivalent to produce 500 - 600ml of ethanol of about 70% purity. This indicates the huge potential of generating ethanol from cashew apple. Fig. 3 shows a schematic flowchart of ethanol production processes from cashew apple.

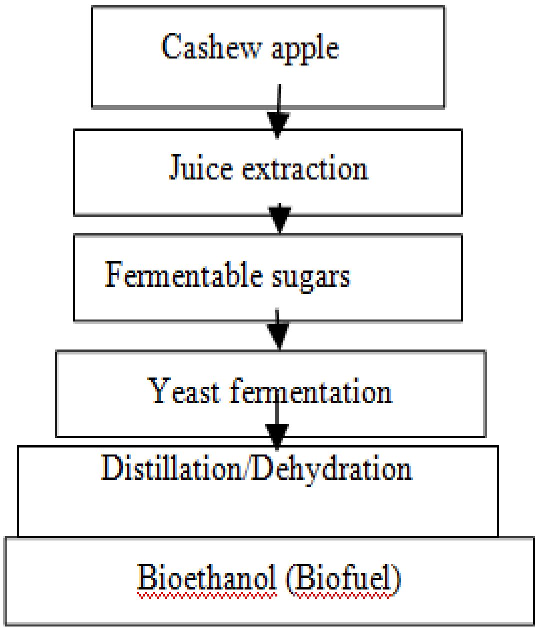

Fig. 3: A Flowchart of Bioethanol Production from Cashew Apple

The aim of the study was to determine the potentials of cashew apple in the production of bioethanol which is a biofuel alternative to gasoline. The combustion rate of the ethanol was, however, compared to that of gasoline in a gasoline engine.

DETAILS EXPERIMENTAL

Materials and Procedures

Mature and ripe cashew fruits were freshly harvested from a Nigerian farm and washed by submerging them in chlorinated water for about 30 minutes, then rinsed in a distilled water to remove the residual chlorine.

Processing and Treatment of Cashew Apple Juice

The cashew apples were separated from the nuts and 5kg of the apples weighed out for the experiment. The apple juice known as '**Must**' was obtained by crushing and extracting the juice using a simple milling machine. The extract was sieved to remove the suspension of undesirable cashew materials. The must was heated in a stainless steel pot at a temperature of 64.9^0C for 15 minutes for sterilization and allowed to cool to a room temperature, then it was treated with potassium metabisulphite to check the activities of undesirable microorganisms. Thereafter, the juice was 'Chaptalized' by addition of 20 grams per litre (g/L) of sugar into it to increase the quantity of the fermentable extract. A 5-litre of the treated juice was obtained. The chemical composition of a cashew apple juice is found in Table 1 below.

Table 1: Chemical Composition of Cashew Apple Juice

Compounds	**Qty (mg/100mL)**
Phenols	269.5
Tannins	266.0
Vitamin C	231.4
Sugars	12.05 (in mg /mL^{-1}).
Potassium (K)	76.0
Calcium (Ca)	43.0
Magnesium (Mg)	10.92
Phosphorous (P)	0.79
Sodium (Na)	0.41
Zinc (Zn)	0.05
Copper (Cu)	0.065
Iron (Fe)	0.08

Source: Lowor and Agyente-Badu (2009)

Fermentation of Cashew Apple Juice (Must)

A 3-spatula full of true wine yeast, *Saccharomyces cerevisiae var. ellipsoideus,* was measured into a conical flask and rehydrated. The rehydration process involved the addition of 0.1% Nacl, 0.1% K_2HPO_4, 0.5% yeast extract and 0.1% $MgSO_4$ into 400ml of distilled H_2O. Producing a 500ml of inoculum, a 400ml part of the inoculum was thoroughly shaken and inoculated into the treated must and kept in room temperature of 32.5^0C for 5 days. Thereafter, the fermented juice [cashew wine (alcohol)] was aerated into another container and the sediment at the bottom of the wine, which contained a large amount of reproducing yeasts, was collected and preserved for another round of fermentation. Optimum fermentation parameters as enlisted in Table 2 were used for an effective utilization of the cashew apple juice for the ethanol production.

Table 2: Fermentation parameters used on ethanol production from cashew wine

Parameters	**Value**
Substrate Concentration	10% (v/v)
pH	6.0
Temperature	32.5^{0}C(room temp)
Inoculum Concentration	8% (v/v)

Using alcohol meter, the alcoholic content of the cashew wine was found to be 7.5% which cannot be used as biofuel due its impurities and higher percentage of water, and as such, cannot burn in a combustion engine. The cashew wine was then put in a mini/laboratory biorefinery for distillation. The alcohol was distilled and re-distilled several times to obtain a purer form of ethanol (95%). The alcoholic strength of each distillate and its boiling point-temperature was intermittently determined until a satisfactory ethanol content of 95% was obtained, after eight (8) distillations. Using a Barometer, the vapour pressure of the anhydrous ethanol was also measured and found to be 47kPa.

Testing of the Ethanol in a Gasoline Engine

A liter of the 95% ethanol was poured inside a 5-litre-tank gasoline generating set of 950 watts capacity and turned on. The generator ignited and ran continuously for 30 minutes until the ethanol became exhausted. After an hour interval, a 1 litre of gasoline fuel (petrol) was introduced into the tank of the same generator and turned on. This too was allowed to run until the gasoline became exhausted after 1 hour. This was used as a control of the experiment. The ethanol was tested again in a low temperature environment of 10^{0}C using the same generating set, but it could not ignite the engine.

RESULTS AND DISCUSSION

The Fermented Must and the 95% Ethanol Obtained.

After incubating the must for 5 days, a 7.5% cashew wine was obtained. Upon distillation, an initial distillate of 46.7% alcohol was obtained at 94.5^{0}C. The distillate was re-distilled for eight (8) times before a 95% ethanol was obtained at a temperature of 78.2^{0}C. Further distillation to obtain 100% ethanol could not be achieved using this simple/laboratory distillation method, as the solution forms an azeotrope which can only be separated through sophisticated methods. Table 3 below shows the number of times the cashew wine was distilled, their various boiling points, and the respective percentages of ethanol obtained at each boling point. Fig. 2 also shows the graphical representation of the distillation stage. A 2-liter final ethanol distillate of 95% was obtained.

Table 3: Different percentages of ethanol obtained during distillation

Number of distillatins	Boiling points of each distillates (^{0}C)	Percentages (%) of ethanol obtained
1st	94.5	46.7
2nd	84.2	77.6
3rd	82.0	86.6
4th	80.7	89.8
5th	80.0	91.6
7th	78.8	93.7
8th	78.4	94.4
9th	78.2	95.0

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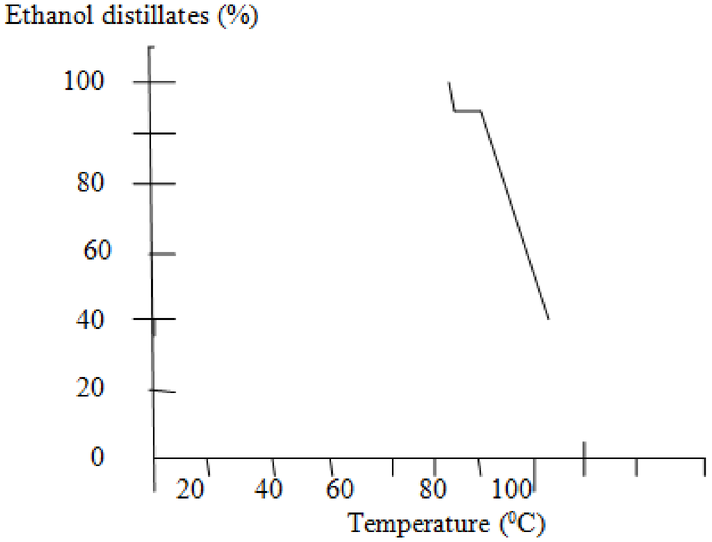

Fig. 2: A Graph showing ethanol distillates and their boiling points

Using the Ethanol (Biofuel) in a Gasoline Engine

The 95% ethanol when tested in the small gasoline engine generator, powered and ran the engine successfully. It ran until the ethanol in the tank exhausted. However, the combustion rate of the ethanol (biofuel) was found to be higher than that of gasoline, as the 1 litre ethanol exhausted in the gasoline tank after 30minutes of combustion, whereas the 1 litre of petrol exhausted after 1 hour of burning. Table 4 shows the different combustion rates of ethanol and gasoline fuel. Also the ethanol could not ignite a spark in the engine of the same generator under a cold weather condition because of the drop in the vapour pressure which was found to be 35kPa. It fell below the minimum standard of 45kpa required to ignite a spark in an engine.

Table 4: Combustion rate of ethanol and gasoline in a 0.95kv-capacity generator

Fuel Type	Quantity (l)	Combustion rate (mins)
Ethanol	2	60
Gasoline	2	120

The Chemistry of Biofuel Production and Combustion

Ethanol is produced by the action of microorganisms and enzymes through the fermentation of sugars. The ethanol during combustion reacts with oxygen to produce carbondioxide, water and heat. It is the heat of combustion of ethanol that is used to drive the piston of the engine by expanding heated gases. These can be seen in Equations 1-3.

Biobutanol, another form of ethanol, is a direct replacement for gasoline as it can be used directly in a gasoline engine, in a similar way biodiesel is used in diesel engines. The chemical formula for alcohol fuel is:

$C_n H_{2n+1} OH$.

Equation 1: During photosynthesis, glucose is created in the plant:

$6CO_2 + 6H_2O + \text{light} \longrightarrow C_6H_{12}O_6 + 6O_2$

Equation 2: The glucose is decomposed into ethanol and carbondioxide during fermentation:

$C_6H_{12}O_6 \quad \text{yeast} \longrightarrow 2C_2H_5OH + 2CO_2 + \text{heat}$

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*Equation **3**:* The ethanol, during combustion, reacts with oxygen to produce carbondioxide, water, and heat.

$$C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O + heat$$

CONCLUSIONS

The potentials of cashew (*Anacardium occidentale*) to produce biofuel was studied and major conclusions are as follows:

1. The cashew apple can be used in the production of bioethanol - a biofuel alternative to gasoline fuel.
2. Ethanol is very corrosive to fuel systems. In very low temperatures of less than 11^0C, ethanol due to its corrosive nature absorbs moisture from the atmosphere which makes the engines harder to start by bringing down the vapour pressure required to ignite a spark to less than 45kpa, and causing intermittent operation (sputtering), aluminum (carburetors), and steel components oxidation.

RECOMMENDATIONS

Since high ethanol blend (E95 or 95% and above), is corrosive and, causes the vapor pressure to drop faster during cold weather, it is recommended that E85 or 85% ethanol as maximum blend be used. E85 is 85% ethanol mixed with 15% fuel.

For 100% ethanol and higher blends (E95), engine modifications are required in vehicles for optimum ethanol efficiency. These modifications include: Adjusting the engine control unit (ECU) such as using a larger fuel injector to accommodate the fuel's lower energy density; altering the ignition timing to exploit ethanol's higher octane rating; and adjusting the air-to-fuel ratio to cater for ethanol's higher oxygen content. Engine materials that are resistant to ethanol's corrosion should also be used. Some flexible-fuel vehicles (FFV's) already have these modifications and can safely run on any combination of bioethanol and petrol - up to 100% bioethanol. These FFVs dynamically sense exhaust oxygen content, adjust the engine's computer systems, spark, and fuel injection accordingly.

An over the road stainless-steel tank trucks are also needed to deliver ethanol to the pump stations. Before the existing petroleum pipelines could be used, a corrosive-resistant material such as stainless steel should be laced on them.

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