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## Comparative study of bioethanol yield from yam, potato, watermelon, and pineapple peels using different concentrations of hydrochloric acid

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### ABSTRACT

This study was aimed at determining the optimum yield of bioethanol (as biofuel and industrial chemical) from yam, potato, watermelon, and pineapple peels using different concentrations of hydrochloric acid (HCl). Results obtained from acid hydrolysis, fermentation and distillation revealed that yam peel gave the highest quantity of glucose ( $38.7 \pm 0.90\%$ ) and ethanol ( $18.40 \pm 0.18\%$ ) at an acid concentration of 1.5 M, watermelon peel equally recorded the highest yield of glucose ( $18.3 \pm 0.50\%$ ) and ethanol ( $8.35 \pm 0.14\%$ ) at 1.5 M. For potato peel, the highest quantity of glucose ( $33.8 \pm 1.10\%$ ), and ethanol ( $18.23 \pm 0.04\%$ ) was at 2.0 M; this concentration (2.0 M) was equally the optimum for pineapple peel, the highest glucose concentration and ethanol yield of which was  $24.5 \pm 0.62\%$  and  $11.44 \pm 0.29\%$ , respectively. Utilizing these agro-wastes for the production of bioethanol provides a means of recycling these biological wastes which are normally prone to rapid microbial spoilage.

**Keywords:** Waste recycling, Bioethanol production, yam peel, potato peel, watermelon peel and pineapple peel

## **1. INTRODUCTION**

Food remains a basic human need and producing enough to feed the growing population of developing countries is a major challenge facing a large proportion of nations. Hence, there should be greater intervention in the form of environment friendly science and technology in food production. One of such environment friendly intervention is an effective management of wastes, particularly as it concerns agricultural and food processing wastes. The quality of the total environment and health status of the inhabitants is related to the quality and quantity of wastes generated in those areas, as partly defined by the nature of activities carried out by the populace. The evidence of this environment-health relationship is seen in most tropical environments where the environment is loaded with pollutants as a result of abandoned wastes. In Nigeria for instance, municipal waste is a major and serious environmental problem, due to refuse dump sites which are seen all round its cities, where they constitute nuisance and eye sore with corresponding health implications.

Many wastes are generated on daily basis as a result of agricultural activities. These wastes are either biological, solid, hazardous wastes or even waste water. They ought to be identified and managed properly in order to protect the health of people who dwell nearby as well as the environment. The compositions of these wastes vary over time and location, with anthropogenic activities. Managing these wastes therefore creates a room for worry in the agricultural and food processing industries. This is attributed to the weird nature of these industrial sectors because they deal with biological materials which have great potentials for spoilage and bio-deterioration. The tendency for odor, rat and fly infestation with consequent health implications resulting from food spoilage and related food-borne diseases, all are facilitated by wastes particularly from food wastes.

Overtime, the concept of waste as a “useless material” is gradually changing to that of seeing the wastes as resources by converting them into usable materials with modifications. Wastes can therefore be converted into resources or materials used at home or even sold for wealth. Recycling wastes involves collecting discarded materials, such as husks, peels, poultry droppings, cow dung, biomass, etc., and processing them, turning them into new products. This is done to minimize the amount of waste exposed to our environment and its consequent health implications [1-12].

Presently, there is energy crisis in the world not only in terms of food or feeds for man and livestock but also in terms of fuels to drive various sectors of the economy. The world has continued to depend on petroleum for this purpose. However, due to the politics involved in the distribution of natural resources as well as inequalities in technological developments across nations, there has been involvement of politics in the distribution of this important resource. It therefore becomes necessary to search for other energy sources which would not only be renewable but equally inexpensive. Furthermore, while petroleum serves various purposes, its use has other adverse effects, such as increasing trace gas concentrations in the atmosphere.

Yams (*Dioscorea* spp.) are among the most important staple foods in the world, especially in most parts of the tropics and subtropics. It is one of the most important dietary sources of energy produced within the tropics. Significantly, yam contributes to food security and its availability in the market for a considerable part of the year helps prevent food shortages, particularly in the urban communities because it stores relatively longer than other root crops.

Wastes from the peels are often fed to livestock especially goats, pigs, and sheep. In most instances, however, it constitutes nuisance. The peels of white yam, *Dioscorea rotundata* which

form about 10% of the total root, are a valuable food for ruminants. White yam and its peels do not contain cyanogenic glycosides. Apart from being a staple food, yams are equally used for medicinal purposes because they contain saponins. Saponins are significant mainly because of their steroidal structure. They serve as precursors for the hemisynthesis of birth control pills (with progesterone and estrogen) and other related hormones and corticosteroids. Like other higher plants, yams have complex phytochemical profile. Prominent among these are dioscorine alkaloid and diosgenin saponin. Although these two are usually considered toxic, the toxicity is destroyed by washing, boiling, and cooking.

Potatoes (*Solanum tuberosum*) are one of the most important crops for human consumption. Over centuries, its nutritional quality has been established and documented and considered a source for many nutrients. They represent a source of dietary energy due to their carbohydrate and protein contents and equally contain other organic micronutrients, such as vitamin C, some B vitamins and also contain appreciable levels of minerals. The fat content of raw and cooked potatoes is very low, whereas in fried products, the caloric value is significantly increased.

Potatoes are processed into a variety of products such as mashed potatoes, chips, fries and deep frozen dehydrated products like granules and flakes. Furthermore, starch is an economically important product obtained in large quantities from the tubers. Utilizing waste products of potato reduces the amount of waste and leads to sustainable production. Potato peel is the major waste of this particular crop. The peels contain sufficient quantities of starch, cellulose, hemicelluloses, and fermentable sugars which can serve as raw materials for the production of bioethanol.

The watermelon plant (*Citrullus lanatus*), a member of the family *Cucurbitaceae*, is monoecious and bears fruit annually. The seeds are a source of edible oil. Watermelons are now majorly eaten as a sweet and juicy fruit. Accordingly, fruits and vegetables contain substantial quantities of vitamins, fibre, antioxidants and phytochemicals, and their frequent consumption helps in reducing chronic diseases and maintains a healthy living. The fruits can be consumed fresh, canned, or processed. This processing and consumption result in the production of massive wastes from the seeds and rind. Despite of the nutritional benefits derived from fruits, only a small portion is utilized directly for human consumption, the rest may be used as a feed or fertilizer. The pineapple (*Ananas comosus*) is one of the most widely eaten fruits in the world and is the leading edible member of the family *Bromeliaceae*. The fruit juice is mostly preferred by many just like orange and apple juices. Harvesting, transportation and storage of the fruits can generate up to 55% of waste [20]. These wastes have potentials for quick microbial spoilage which prevents further utilization. These discarded fruits can possibly be used for further industrial processes like fermentation, bioactive component extraction, etc. Several efforts have been made to investigate how pineapple wastes can be reused. The wastes from pineapple canneries have been used as the substrate for bromelain, organic acids, ethanol, etc. since these are potential source of sugars, vitamins and growth factors.

## **2. MATERIALS AND METHODS**

### **2. 1. Sample collection and processing**

All the agro-wastes were collected from household kitchen wastes, sorted, washed with distilled water to remove sand and other dirt and cut into pieces before sun-drying. The samples

were sun-dried for three weeks with constant turning to ensure proper drying. They were then milled using a laboratory milling machine. Thereafter, the samples were then sieved using a 500  $\mu\text{m}$  sieve in order to get a smooth sample of uniform size, then stored in properly washed, dried and labeled containers for further analyses [13-20].

## **2. 2. Acid Hydrolysis**

Hydrolysis was carried out according to the method of 10 g each of the agro-wastes, yam, potato, watermelon and pineapple peels were first pretreated with 50 ml of 0.1 M HCl at 50 °C for 20 minutes. These were then hydrolysed with 100 ml of five different concentrations (0.8 M, 1.0 M, 1.5 M, 2.0 M, and 2.5 M) of Hydrochloric acid (HCl) and hydrolyzed at 100 °C.

The wastes were hydrolyzed with different concentrations of acid to determine the concentration of acid that will give the maximum yield of reducing sugar for fermentation. Hydrolysis was carried out by boiling the samples with 100 ml each of the different concentrations of acid at 100 °C.

The boiling samples were reacted at intervals on a white tile with iodine solution to monitor the progress of hydrolysis. This gave a blue black colouration which kept reducing in intensity until the blue black colour totally disappeared to give an orange colour, indicating complete hydrolysis.

The boiled samples were then allowed to cool and neutralized with equal concentrations of NaOH to a pH of 5.0. This was followed by filtration using Whatman filter paper. The filtrates were then subjected to Benedict's test for the presence of reducing sugar. The quantity of reducing sugar produced after hydrolysis with different concentrations of acid was measured using a refractometer.

## **2. 3. Preparation of yeast culture**

10 g of *Sacharomyces cerevisiae* (Bakers' yeast) was added to 50 ml of distilled water at room temperature. The solution was stirred for five minutes and allowed to stand for two hours before adding it to the hydrolysates.

## **2. 4. Fermentation**

The activated yeast was aseptically inoculated into the hydrolysates from the wastes. The solutions were properly mixed before covering the flasks with aluminium foil and left at room temperature for seven days. The flasks were shaken on daily basis till the seventh day. The pH of the solutions were also monitored on daily basis until the seventh day. This was to ensure that they remained within the pH range of fermentation.

## **2. 5. Distillation**

After fermentation, distillation was carried out on the various hydrolysates. This involved removing ethanol from the mixture of ethanol, water and other impurities. Ethanol was boiled off from the mixture of water and other impurities in a distillation column where it was monitored from a temperature of 78 °C. The bioethanol produced from distillation was assessed for quality with the following parameters: colour, odour, boiling point, volatility, and specific gravity.

## 2. 6. Distinguishing Test for Ethanol

Five drops of the distillate were added to 5 ml of iodine solution in a test tube, sodium hydroxide was carefully added until the colour of the iodine disappeared. The test tube was then placed in a water bath at 70 °C for 3 minutes. It was removed and allowed to cool. Yellow crystals of iodoform were formed and the smell was reminiscent of antiseptic. Quantity of ethanol produced was measured using a 100 ml pyrex measuring cylinder.

Specific gravity of the distillate was measured using the specific gravity bottle (density bottle). The specific gravity bottle was filled with ethanol sample, weighed, and recorded. The bottle was also filled with distilled water, weighed and recorded. Specific gravity was calculated thus:

$$\text{Specific gravity} = \frac{\text{Weight of ethanol sample}}{\text{Weight of equal volume of water}}$$

Percentage by volume of the alcohol (ethanol) corresponding to apparent specific gravity at 30 °C was read from.

## 2. 7. Statistical analysis

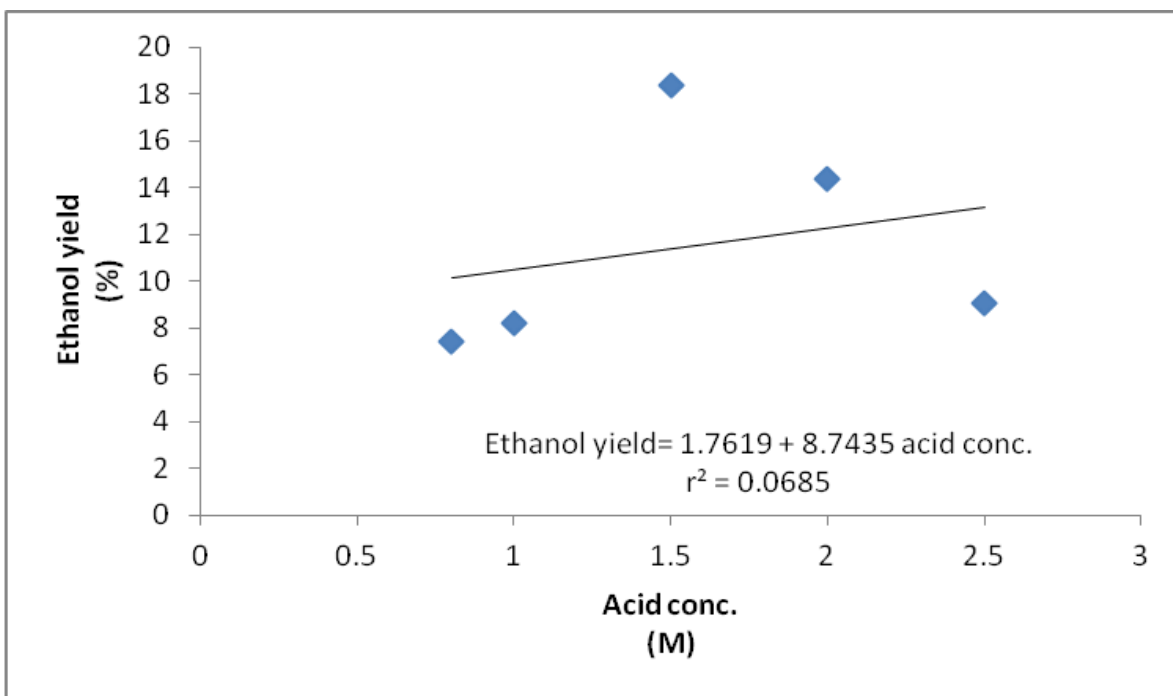
Statistical tools used in this study included descriptive statistics, e.g. standard deviation, bar chart, and coefficient of simple determinant.

## 3. RESULT AND DISCUSSION

The results of the studies have been presented in the following **Tables 1** through **4**, and **Figures 1** through **4**, and next **Figures 5** through **8** concerning glucose concentration effect.

**Table 1.** Effects of different concentrations of HCl on bioethanol production from yam peel by *Saccharomyces cerevisiae*.

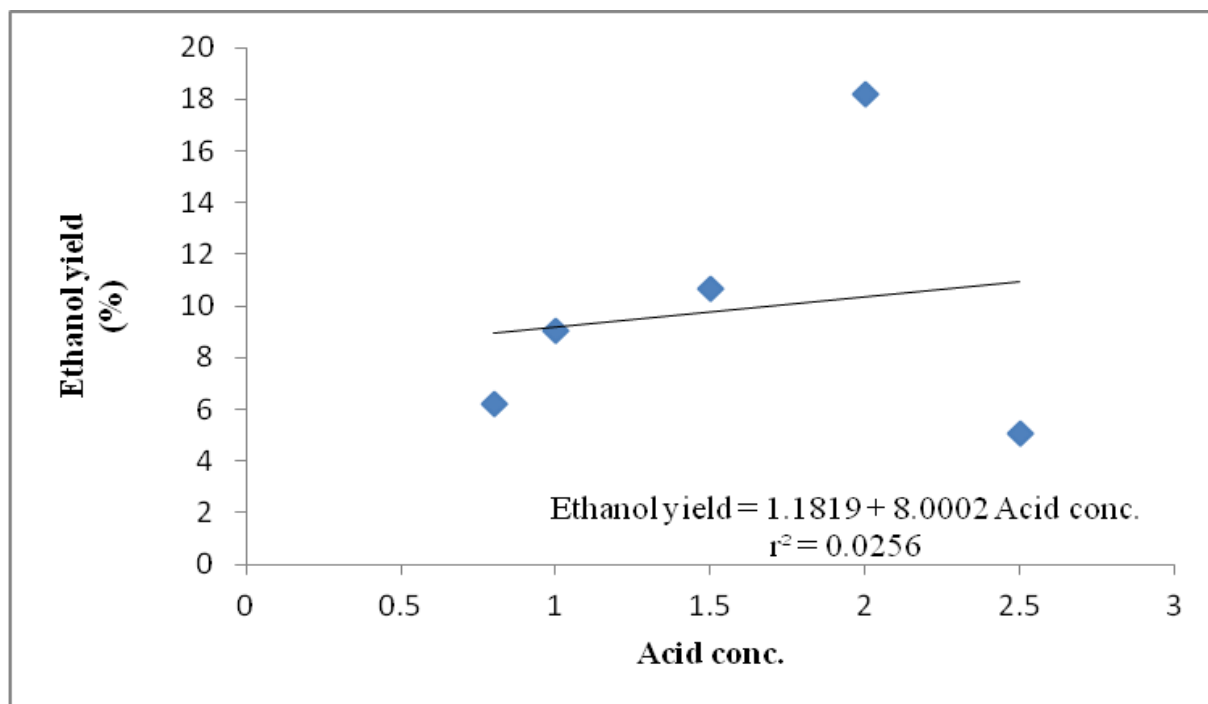
Acid conc. (M)	Glucose conc., % (after hydrolysis)	Quantity of ethanol mixture ( cm <sup>3</sup> )	Ethanol conc. (vol%)	Specific gravity at 30 °C	Mass of ethanol produced (g/cm <sup>3</sup> /cm <sup>3</sup> )	Boiling point
0.8	13.2±0.50	12.0±1.15	7.44±0.79	0.9894	9.64±0.17	83±2 °C
1.0	15.1±0.70	17.0±1.51	8.20±0.13	0.9884	13.66±0.36	83±1 °C
1.5	38.7±0.90	38.0±1.00	18.40±0.18	0.9756	30.53±0.22	80±1 °C
2.0	28.0±1.50	26.0±0.43	14.38±1.11	0.9805	20.89±0.15	81±2 °C
2.5	17.6±1.11	21.0±1.73	9.04±0.99	0.9873	16.87±2.07	82±2 °C



**Figure 1.** Plot of Ethanol yield (vol %) versus HCl concentration (M) for Yam peel

**Table 2.** Effects of different concentrations of HCl on bioethanol production from potato peel by *Saccharomyces cerevisiae*.

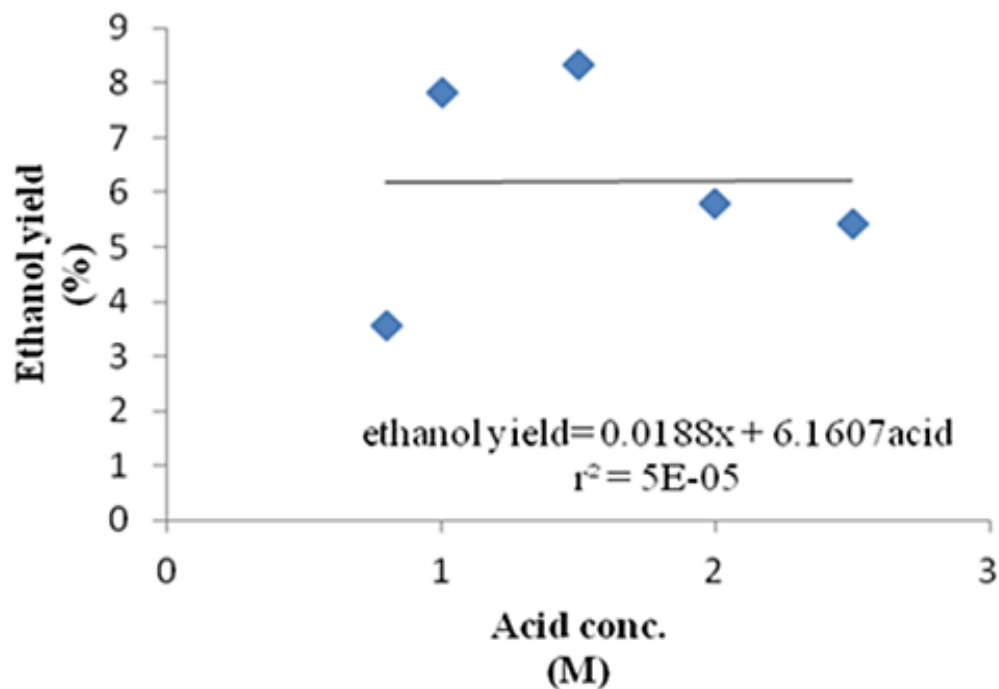
Acid conc. (M)	Glucose conc. % (after hydrolysis)	Quantity of ethanol mixture (cm <sup>3</sup> )	Ethanol conc. (vol%)	Specific gravity at 30 °C	Mass of ethanol produced (g/cm <sup>3</sup> /cm <sup>3</sup> )	Boiling point
0.8	10.6±1.60	17.0±1.73	6.23±0.36	0.9910	13.66±0.13	84±1 °C
1.0	15.5±0.33	27.0±1.00	9.04±0.78	0.9873	21.69±0.17	82±2 °C
1.5	18.9±0.35	25.0±1.80	10.67±0.24	0.9852	20.08±0.33	81±3 °C
2.0	33.8±1.10	34.0±0.35	18.23±0.04	0.9758	27.31±0.21	80±1 °C
2.5	8.7±0.70	18.0±1.73	5.05±0.04	0.9926	14.46±0.18	85±1 °C



**Figure 2.** Plot of ethanol conc. (vol%) vs HCl concentration (M) for potato peel

**Table 3.** Effects of different concentrations of HCl on Bioethanol production from watermelon peels by *Saccharomyces cerevisiae*

Acid conc. (M)	Glucose conc. (%) after hydrolysis	Quantity of ethanol mixture in (cm <sup>3</sup> )	Ethanol conc. (vol%)	Specific gravity at 30 °C	Mass of ethanol produced (g/cm <sup>3</sup> /cm <sup>3</sup> )	Boiling point
0.8	4.8±0.60	7.0±0.26	3.58±0.31	0.9947	5.62±0.32	86±2 °C
1.0	13.6±0.20	11.0±0.17	7.82±0.22	0.9889	8.84±0.14	83±1 °C
1.5	18.3±0.50	21.0±1.73	8.35±0.14	0.9882	16.87±0.24	83±1 °C
2.0	10.4±0.36	16.0±0.36	5.78±0.02	0.9916	12.85±0.36	84±3 °C
2.5	9.6±0.35	14.0±1.73	5.42±0.22	0.9921	11.25±0.13	84±2 °C

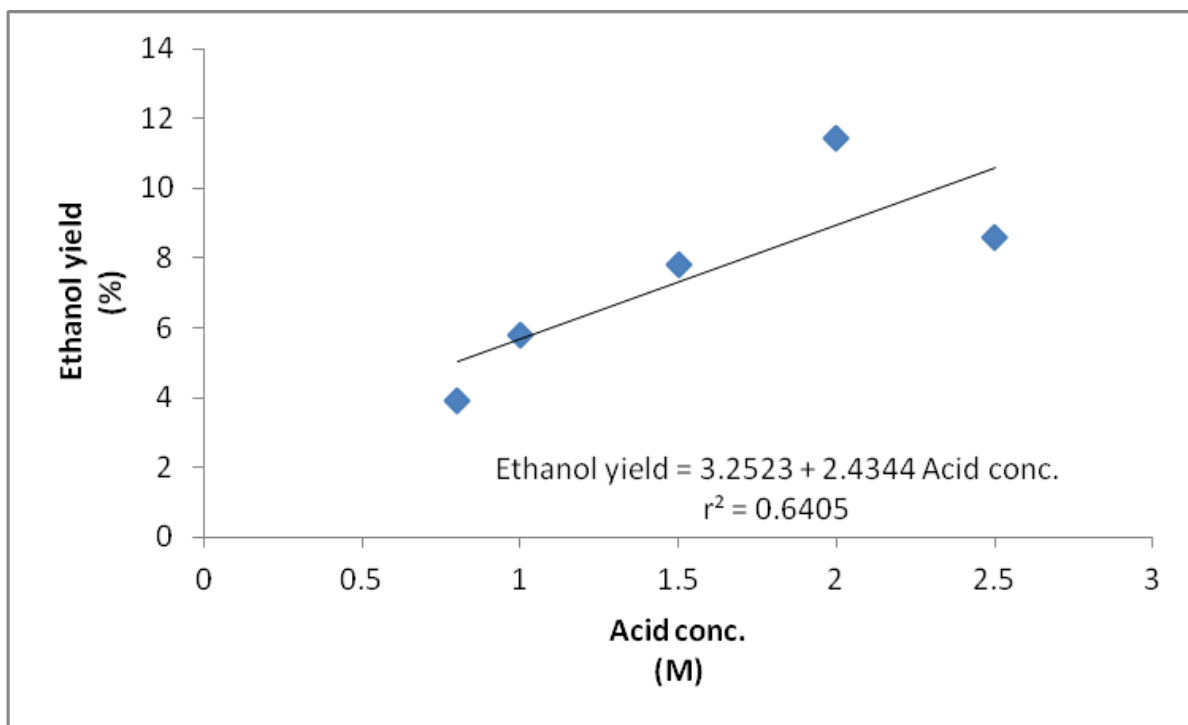


**Figure 3.** Plot of ethanol conc. (vol%) vs HCl concentration (M) for watermelon peel

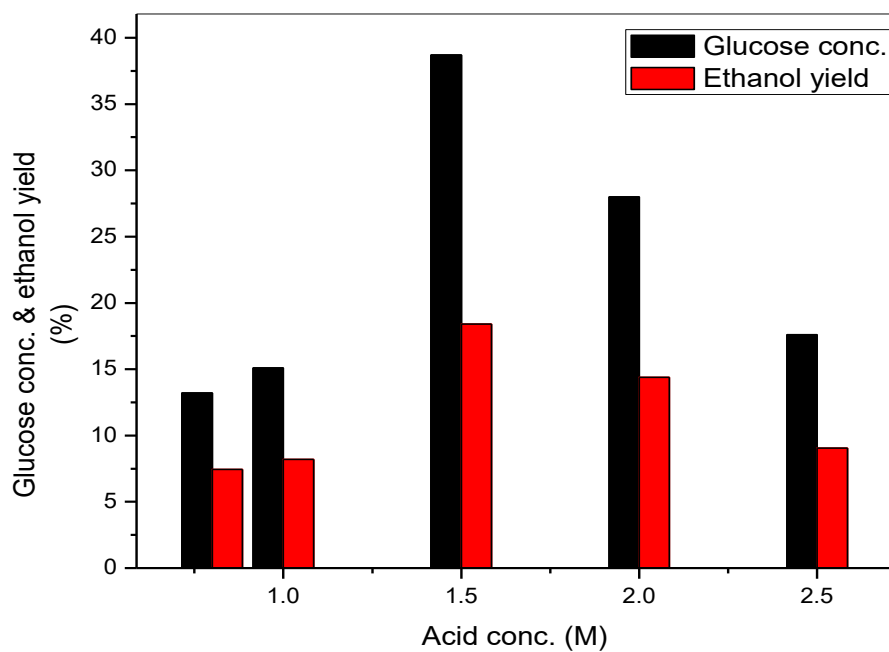
**Table 4.** Effects of different concentrations of HCl on bioethanol production from pineapple peel by *Saccharomyces cerevisiae*.

Acid conc. (M)	Glucose conc.% (after hydrolysis)	Quantity of ethanol mixture	Ethanol conc. (vol%)	Specific gravity at 30 °C	Mass of ethanol produced (g/cm <sup>3</sup> /cm <sup>3</sup> )	Boiling point
0.8	6.2±0.36	11.0±1.73	3.92±0.22	0.9942	8.84±0.34	85±2 °C
1.0	10.5±0.46	17.0±0.44	5.78±0.28	0.9916	13.66±0.22	84±1 °C
1.5	13.3±0.50	23.0±1.00	7.82±0.04	0.9889	18.48±0.24	83±2 °C
2.0	24.5±0.62	28.0±0.62	11.44±0.29	0.9842	22.49±0.23	81±1 °C
2.5	17.0±2.00	30.0±1.04	8.58±0.23	0.9879	24.09±0.52	83±3 °C

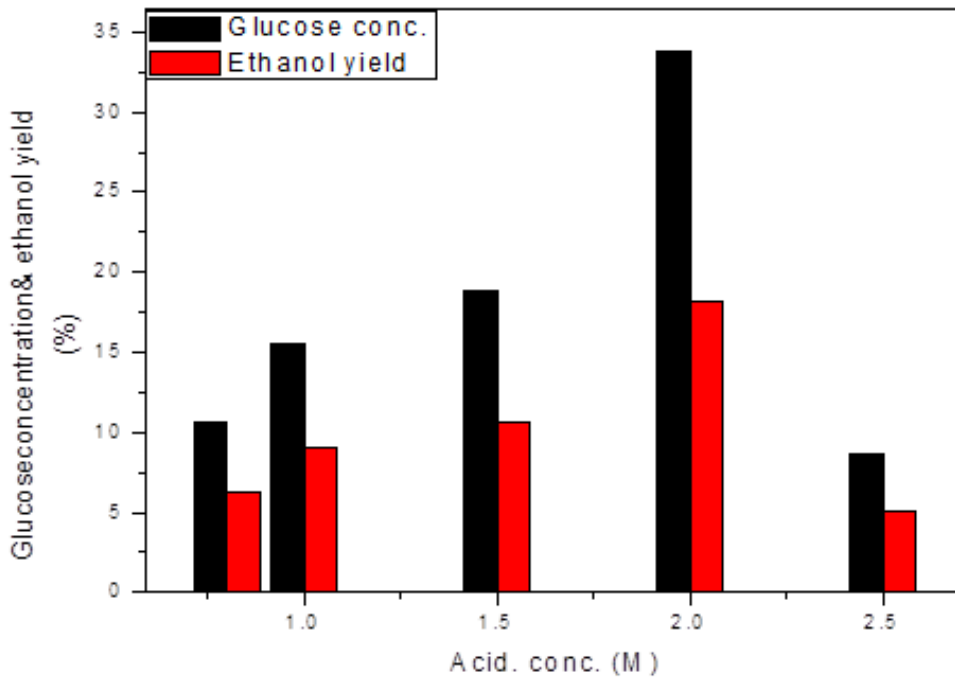




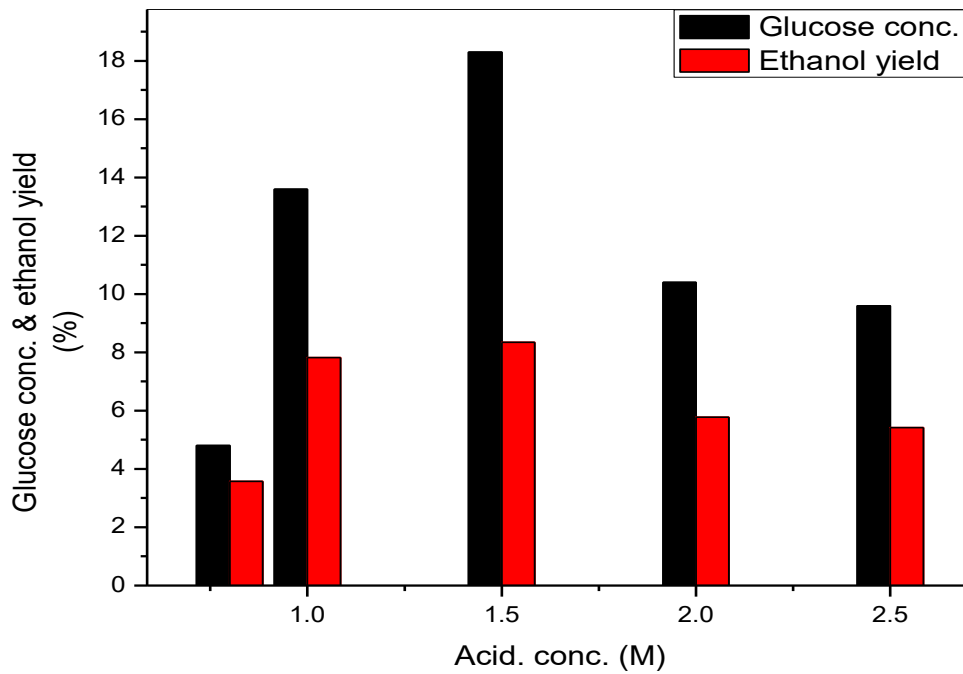
**Figure 4.** Plot of Ethanol yield (vol %) versus Acid (HCl) concentration (M) for Pineapple peel



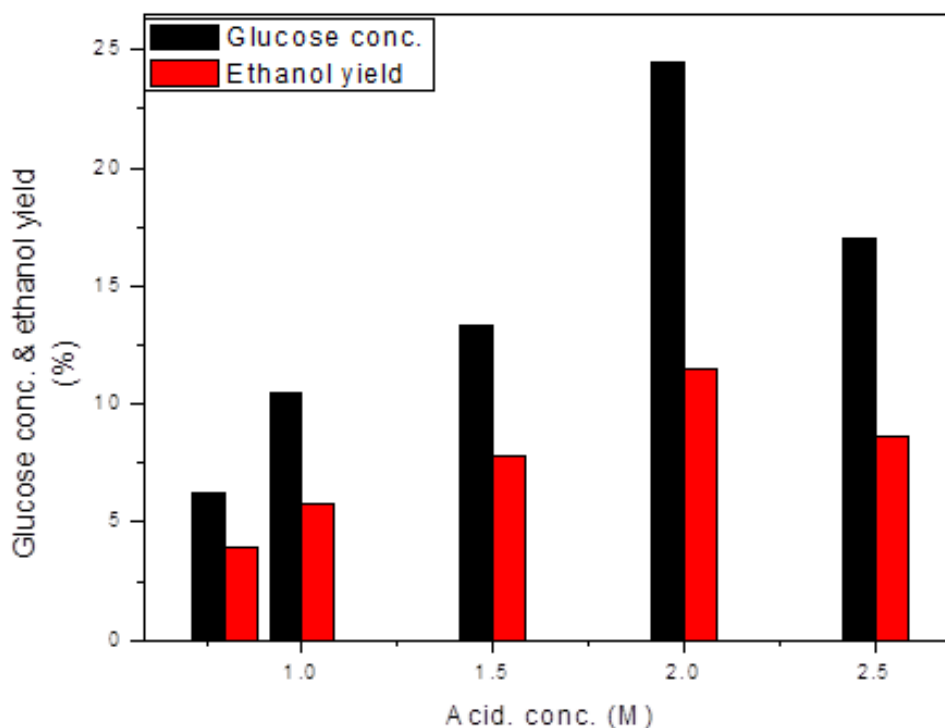
**Figure 5.** Glucose concentrations and ethanol yields of yam peel at different acid concentrations



**Figure 6.** Glucose concentrations and ethanol yields of potato peel at different acid concentrations



**Figure 7.** Glucose concentrations and ethanol yields of watermelon peel at different acid concentrations



**Figure 8.** Glucose concentrations and ethanol yield of pineapple peel at different acid concentrations

The results obtained from acid hydrolysis showed that reducing sugar concentrations varied with the different concentrations of hydrochloric acid. The trend also showed that the concentration of glucose in the hydrolysates was higher for yam and potato peels but lower for watermelon and pineapple peels. This tallied with who reported that energy crops are better alternatives for biofuel production.

The maximum sugar concentration of yam peel  $38.7 \pm 1.00\%$  was recorded at 1.5 M HCl, this subsequently yielded  $18.40 \pm 0.18\%$  of ethanol concentration (**Fig. 5**). At 2.0 M and 2.5 M concentrations, there was a significant decrease in reducing sugar concentration. This affected their ethanol yield. When compared with potato peel, the highest glucose concentration and ethanol yield of yam peel was slightly higher. This may be attributed to the difference in the nature of substrates. Maximum ethanol concentration of  $18.40 \pm 0.18\%$  was higher than 2.15% and 1.90% which were reported by as the maximum ethanol concentrations from beet waste and banana peel respectively.

This can be attributed to higher content of carbohydrate in yam peel than that in beet and banana wastes. This attribute makes yam peel a good source of bioethanol.

The hydrolysates obtained from yam peel were dark-brown in colour. This type of browning is due to the oxidation of phenolic constituents, especially O-hydroxy or trihydroxy phenolics by a phenol oxidase present in the tissue of yam. It was observed that all the liquid obtained after distillation was colourless, volatile, miscible with water, and had a characteristic odour. A 6.85% variation on the ethanol yield of yam peel used in this study was due to different acid concentrations used (Fig. 1).

For potato peel, 2.0 M HCl gave the highest quantity of reducing sugar ( $33.8 \pm 0.1.10\%$ ), while 2.5 M HCl gave the least quantity ( $8.7 \pm 0.70\%$ ), as seen in Fig.6. 1.0 M gave  $15.5 \pm 0.33\%$  of sugar, while 0.8 M gave  $10.6 \pm 1.60\%$  of reducing sugar. The reducing sugar concentration obtained for 1.5 M acid was  $18.9 \pm 0.0.35\%$ . Potato, which is a principal rotation crop in Nigeria, generates many by-products during its processing. One of the products that can be obtained from these wastes is bioethanol. The boiling points of the ethanol samples from different acid concentrations were as follows:  $84 \pm 1$  °C,  $82 \pm 2$  °C,  $81 \pm 3$  °C,  $80 \pm 1$  °C, and  $85 \pm 1$  °C for 0.8, 1.0, 1.5, 2.0, and 2.5 M acid concentration, respectively. All the ethanol samples were colourless, volatile and had a characteristic odour especially the sample obtained from 2.0 M HCl. From the graph in Fig. 2, differences in acid concentration were responsible for 2.56% variation on the bioethanol yields obtained from potato peel. It was observed that the brown colour of the sample hydrolysed with 2.5 M HCl remained darker than the other samples whose brown colours were lighter. The maximum ethanol yield for potato peel was  $18.23 \pm 0.04\%$  at 2.0 M HCl with a boiling point of  $80 \pm 1$  °C.

This yield was higher than that reported by, who reported maximum ethanol yield of 12.9% from rotten pineapple when inoculated with 10% culture of *S.cerevisiae*. The yield is also high when compared with the results of those who observed maximum ethanol yield of 8.8% from waste potato tubers. The difference in results might be as a result of reaction time, concentration of acid used, quantity of sample, or type of treatment. The yield is equally lower than that reported by those who reported ethanol concentration of 67.7%, as observed when *A. niger* and *Z.mobilis* were used simultaneously on guinea corn husk. This could be as a result of more lignin and hemicelluloses content of guinea corn husks than in other agricultural wastes. This result is slightly higher than the theoretical 17% maximum from agricultural wastes and 15-16% reported by.

For watermelon peel, increase in concentration of acid increased the yield of ethanol, as observed in the other agro-wastes. 1.5 M concentration of acid gave the highest quantity of reduced sugar ( $18.3 \pm 0.50\%$ ) and consequently the highest yield of ethanol ( $8.35 \pm 0.14\%$ ), as seen in Fig. 7. Glucose concentration decreased with further increase in the concentration of HCl. This may be due to the fact that at a higher concentration of acid, hydrolysis produces a lot of charring and dehydrating reactions. The highest quantity of ethanol obtained from this sample study was  $8.35 \pm 0.14\%$  which was boiled off from the mixture at a temperature of  $83 \pm 1$  °C. The temperature may have been high because the concentration of ethanol in the mixture was low. This concentration is greater than 2.15% reported by as the maximum alcohol production from beet waste using a dextrose-containing media. This could be as a result of differences in the methods adopted for ethanol production. The highest ethanol yield in this sample is also more than 5.14 vol% reported by as the quantity of ethanol obtained from a direct fermentation of mango peels.

However, when these media were supplemented with yeast extract alone and in combination with peptone, the yields were increased to 7.0% and 7.14 vol%, respectively instead of 5.14 obtained from non-supplemented media. These results were however slightly lower than what was obtained as the maximum ethanol yield from watermelon peels ( $8.35 \pm 0.14\%$ ) in this study. This could be attributed to more fermentable sugars in watermelon peels. From the regression graph in Fig. 4, the different acid concentrations did not have a significant effect on the bioethanol yield of watermelon peel.

From the results in Table 2, the amount of glucose present in pineapple peel was sufficient to undergo fermentation. This agrees with those who studied bioethanol production from

pineapple waste water. After hydrolysis with different concentrations of HCl, 2.0 M gave the highest quantity of reducing sugar ( $24.5 \pm 0.62\%$ ), as evident in Fig. 8. Results showed that the increase in concentration of acid increased the concentration of glucose, however at 2.5 M, the concentration of glucose was reduced.

Increase in acid concentration, which led to the increase in concentration of glucose, may be due to a great random collision between the acid and substrate molecules [38]. The highest ethanol yield ( $11.44 \pm 0.29\%$ ) obtained with pineapple peel in this study was higher than 5% reported as the highest ethanol yield obtained from fermentation of orange peel hydrolysates.

The yields were also higher than 7.0% and 7.14% reported when they studied ethanol production from *Mangifera indica* peels by *Saccharomyces cerevisiae* CFTR1101 using yeast extract alone and in combination with peptone supplement. However, their result was higher than 3.92% obtained for 0.8 M HCl. The highest yield obtained in this study, however, corresponds with the results, who reported an ethanol yield of 11.27% from discarded sweet orange juice. The ethanol samples obtained for 0.8 and 1.0 M concentrations of acid though were colourless but their volatility was not as high as in the other concentrations. From the regression graph in Fig.4, 64.05% variation occurred on the ethanol yield of this agro-waste due to a difference in acid concentration.

#### **4. CONCLUSIONS**

This study compared the bioethanol yield from selected agricultural wastes (yam, potato, watermelon, and pineapple peels) using different concentrations of Hydrochloric acid. From the results, the concentration of acid used in hydrolysis affected the concentration of reducing sugar as well as yield of bioethanol. The yield from yam peel, in terms of quantity and concentration of bioethanol, was slightly higher than that of potato peel. Pineapple and watermelon peels recorded lower amounts of fermentable sugar and ethanol. In terms of volatility, the ethanol samples from yam and potato peels were higher and the odour was stronger when compared with the samples from watermelon and pineapple peels. This implies that yam and potato peels are better substrates for the production of bioethanol when compared with the other agro-wastes.

Although ethanol produced from acid hydrolysates of yam and potato peels were higher than that of watermelon and pineapple peels, the study showed that the ethanol yield from the later were appreciable and if the process is optimized, the method could be adopted as a cost-effective alternative in the pursuit of fuel ethanol production protocol. These peels could therefore serve as cheap sources of glucose which can be fermented locally for bioethanol production, especially in the areas where they are in abundance. Utilizing these wastes to produce other value added products like bioethanol will also result in a healthy environment since recycling them automatically clears them from the environment where they would have otherwise caused environmental degradation and related health hazards [21-33].

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