Traditional Fermentation and Distillation of Raffia Palm Sap for the Production of Bioethanol in Bayelsa State, Nigeria

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Abstract: The production of alcoholic beverages from the sap of raffia palm, *Raphia hookeri,* has continued for decades in West Africa, but the detailed processes had never been documented before. The objective of this study is to document the traditional process of ethanol production, with the aim of scaling up the process for the production of fuel ethanol. Ten smallholder ethanol production facilities were randomly selected, and triplicate samples of the process intermediates were collected and analysed, including fermented palm sap, first and second distillate, first and second stillage. Results show that the percentage of ethanol was significantly different ($P<0.05$) among the different intermediates. The highest ethanol presence was recorded in the second distillate (39-61.5%), followed by the first distillate (18.83-39%), then the first stillage (5.80-10.20%), the palm sap (10.50-15.30%) and finally the second stillage (3.40-5.80%).Yeast population, pH, sugar, specific gravity and electrical conductivity differed significantly among the various sites and intermediates. Wood (105-155kg) was used as fuel to boil 280-480L of fermented palm sap producing 20L of 39-61.5% ethanol. The smallholder processors are however challenged by the poor distillation apparatus and the lack of ethanol dehydration facilities. The study concludes by recommending the modification of the Nigerian Biofuel Policy (2007) to allow the use of hydrous ethanol in automobiles and low concentration ethanol for household cooking.

Keywords: Biofuel conversion, distillate, fuel ethanol, innovation, stillage, sugar.

INTRODUCTION

The production of ethanol from agricultural feedstock for use as alternative fuel has attracted worldwide attention because of the depleting fossil fuel sources and volatile petroleum prices in the international market [1]. Many countries are seeking alternative sources of energy that can be produced locally [2]. Palm wine is an alcoholic beverage that is widely consumed in the tropical world, especially in West Africa. Palm wine is produced *via* natural fermentation of the sap of raffia palm, *Raphia hookeri* and oil palm, *Elaeis guineensis* [3-5]. Nwachukwu *et al.* [6] reported that palm wine is consumed by over 10 million people in Africa. The saps of raffia and oil palm have been widely reported to contain sugars - mostly glucose and sucrose - which are excellent substrates for yeast and bacteria fermentation. Obahiagbon [7] indicates that the sweet taste of raffia palm sap is due to the presence of sucrose. Obahiagbon and Osagie [8] report a maximum of 9.5% sucrose content of raffia palm sap. The study also reveals that raffia palm sap contains several other sugars such as glucose, fructose and raffinose, but concludes that sucrose contributed over 95% of the sugar in raffia palm sap. Similarly, Eze and Ogan [9] report that the sap of oil palm contain sucrose as the dominant sugar, accounting for 10% w/v, whereas glucose and fructose account for <1.0% w/v. However, a study in Malaysia shows that glucose is the dominant sugar in oil palm sap [10]. Several other studies show that the unfermented palm sap contains about 10-20 % sugar dominated by sucrose, whereas upon fermentation sucrose is first broken down to glucose and fructose, which are then converted to ethanol, lactic acid and other products *via* fermentation [3, 8, 10, 11].

Studies have shown that the microbial infestation of palm sap, which promotes the proliferation of yeast and bacteria for the conversion of the sugary sap into ethanol, is a spontaneous process [12, 13]. Several other studies have shown that the alcohol fermenting yeast *Saccharomyces cerevisiae* naturally colonizes palm wine sap [6, 14-18]. Ezeronye and Okerentugba [16] report that palm wine yeast produces alcohol in the range of 5.8-8.8%. Alcohol tolerance of fermenting yeast has been generally reported to be in the order of 12% [19], but Nwachukwu *et al.* [14] reports some stains of palm wine yeast that tolerated 10-20% ethanol.

The distillate that is produced from the fermented palm sap is called in various ways in West Africa: ‘ogogoro’, ‘kaikai’or‘apeteshi’ [5, 20, 21]. The aqueous by-product from the distillation of ethanol from fermented broth is called stillage, spent wash, distillery wastewater, or vinasse [1, 2, 22]. Stillage production and handling are typically challenging processes in all ethanol production facilities in the world. It has been

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reported that a typical distillery produces about 13 litres of stillage per litre of ethanol produced [2, 23]. Other authors report 15 litres of stillage is generated per litre of ethanol [1, 24]. A few authors report 20 litres of stillage per litre of ethanol produced [22, 25]. It therefore follows that stillage may account for 80-87% of the fermented broth. This presents a huge volume of wastewater. Stillage is known to be an environmental hazard because of its high content of BOD (35-50g/l), COD (100-150g/l) among other parameters [26].

The alcohol content of fermented sap is dependent on the ethanol productivity and tolerance of the fermenting yeast, and on the efficiency of the distillation. However in most cases, middlemen dilute the ethanol beverage before selling it to customers. Notwithstanding this, ogogoro have been variously reported to have alcohol content of 37.6% [21], > 40% [20], 30-60% [27, 28]. This high concentration of ethanol produced *via* rudimentary equipment [29] suggests the possibility of scaling up the traditional beverage ethanol produced from raffia palm as a possible source of fuel ethanol. Besides, raffia palm has been described as hapazanthic i.e. after a period of vegetative growth, it produces flower and fruits only once and dies [7, 8], thus resulting in the loss of important biomass/energy feedstock. Feedstock for ethanol production varies among countries. The US, the leading ethanol producing country in the world, produces ethanol mostly from corn [30], while the second leading ethanol producing country, Brazil produces ethanol mostly from sugarcane [31, 32]. However, the Nigerian biofuel policy recommends sugarcane, sweet sorghum and cassava [33] as feedstock. The use of these food crops for fuel ethanol production could potentially cause a conflict of use between food and fuel. Hence, alternative feedstock is being sought for ethanol production. Cellulosic feedstock is currently being promoted as viable alternative for fuel ethanol production. Ethanol produced from sugarcane, corn and raffia palm have been shown to exhibit good engine performance [34] hence, this study is aimed at scaling up the traditional raffia palm fermentation for fuel ethanol production. The traditional fermentation and production of ethanol has in fact been practiced for decades in West Africa, yet the detailed process has not been documented.

MATERIALS AND METHODS

Field Sampling

Ten traditional ethanol processing facilities were randomly selected in Bayelsa State, Nigeria for sample collection. Batch processes for ethanol production were carried out in all the sites. Triplicate samples of fermented raffia palm sap, first and second distillate, first and second stillage were collected for laboratory analysis. The volumes of each intermediate were measured in the field, while the amount of fire wood used for the distillation process was measured using spring dial weighing balance. Conductivity and pH were determined in situ using Hach's CO 150 conductivity/TDS meter and pH meter respectively. The number of personnel involved in the distillation of process was counted in each of the sites, while the duration of the distillation process was measured using a stop clock.

Laboratory Analysis

The specific gravity (SG) of the samples was determined with the use of specific gravity bottles. The specific gravity bottles with the glass stopper were filled to the brim i.e. overflowing with the various fractions of the palm wine products. All spillage on the body of the bottle was cleaned after the bottle had been stopped with the glass stopper. The weight of the bottle was measured with analytical balance (Metler Toledo) and the SG was calculated using the formula

$$SG = \frac{\text{Mass of SG bottle + samples - Mass of the empty bottle}}{\text{Volume of SG bottle}}$$

The percentage alcohol content of the various samples was determined with the $K_2Cr_2O_7$ method. An alcohol standard curve was prepared by diluting a 98% - 100% absolute ethanol, to give a series of standards, 20% - 80%. From each of these standard solutions, 1ml of alcohol was added into a test tube and 5ml of 0.1M $K_2Cr_2O_7$ was added and incubated for 30minutes at room temperature. The spectrophotometer (Jenway 6505 UV/VIS) was set up at a wavelength of 540nm. The blank used in this case was 1ml of distilled water in a test tube and 5ml of 0.1m $K_2Cr_2O_7$ added and incubated at room temperature for 30 minutes. This was used to zero the spectrophotometer, and absorption values were then taken, the curve obtained was linear. The samples were also treated in the same manner and their absorbances were measured. A standard graph of absorbance versus alcohol percentage was drawn, and alcohol percentage values were calculated by extrapolation from the curve [15].

The Percentage of sugar content in the various samples was determined with the use of potassium ferricyanate in the presence of NaOH. 1 ml of the filtered sample was put into a test tube followed by the additional of 5 ml of 0.1, potassium ferricyanate solution and 1 ml of 2M NaOH solution. The test tubes were then placed in a water bath at 100^0C and incubated for 10-15 min until the greenish yellow colour developed. A standard 100% sugar solution was prepared as the stock sugar solution from D-glucose crystals by weighing 100g of glucose into 100ml volumetric flask and making up to the mark with distilled water. By using the $M_1 V_1 = M_2 V_2$ relationship, various dilutions ranging from 20% - 80% were created. Using the same procedure as that of the samples, the standard glucose solution was treated. The spectrophotometer was set at 420nm after incubation. Absorbance values were taken and a calibration curve was drawn. The percentage of sugar was determined by extrapolation from the standard curve.

Yeast Counts and Identification

Serially diluted palm wine sap was plated on sabouraud dextrose agar containing 0.05 mg/ml

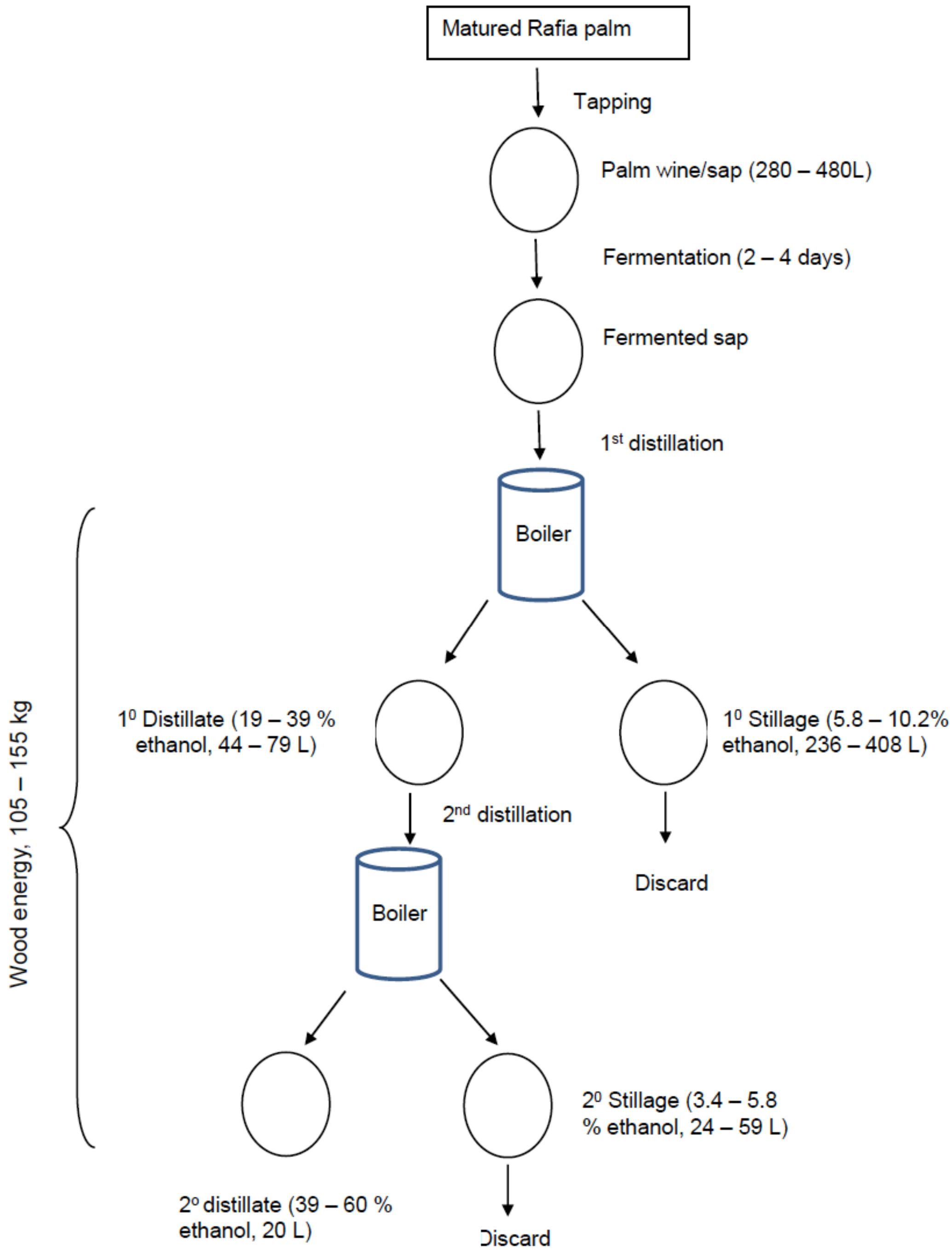

Figure 1: Batch process for the traditional fermentation and distillation of raffia palm sap for ethanol production.

chloramphenicol for yeast counts. The yeast was identified with morphological, cultural, and biochemical tests [14].

Statistical Analysis

SPSS software version 17 (SPSS Inc, Chicago) was used to carry out the statistical analysis. A one-way analysis of variance was carried out at $\alpha = 0.05$, and Duncan's multiple range test was used to discern the source of the observed differences.

RESULTS AND DISCUSSIONS

The traditional fermentation and distillation of raffia palm sap for the production of ethanol in Bayelsa State, Nigeria, is carried out in a batch process (Figure **1**). In the ten studied sites, 280-480 litres of fermented sap was distilled using makeshift rudimentary equipment (Figure **2**), the volume of the fermented sap being significantly different ($P<0.05$) in the different sites (Table **1**). After the first cycle of distillation, a diluted ethanol called primary or first distillate is produced, which is re-distilled to produce concentrated ethanol, often referred to as 'secondary or second distillate' or simply called ethanol. During both distillation processes, primary or first stillage and secondary or second stillage are produced as by-products. The volumes of the primary distillate (44-79L), primary stillage (236-408L) and secondary stillage (24-59L) are significantly different ($P<0.05$) among the various sites. The volume of ethanol produced, which is 20L per batch, is basically the same among the different sites ($P>0.05$), which forms the basis for comparison among the sites (for the purpose of normalization of the data), since the 20L is a common denominator among the various sites. Therefore, per litre of ethanol, 13-23.35 litres of stillage were produced, not including the recycling cooling water. This volume of stillage produced is within the range reported by various authors [1, 2, 7, 22-25]. The sap of raffia palm is made up of over 90% water [7]. Hence, using raffia palm sap as feedstock for ethanol production will expectedly yield large volume of stillage. Wilkie *et al*. [22] reported that ethanol production processes particularly hydrolysis, fermentation and distillation affect the quality and quantity of stillage produced and their possible utilization. For the production of ethanol to qualify as a sustainable 'green energy' process, consideration for treatment and utilization of the stillage by-product is essential [22].

Unlike sugar and starch-based crops, the relative abundance of cellulosic feedstock suggests that large-scale production of cellulosic ethanol has great potential to replace a major portion of imported fuel [22, 35]. However, large-scale ethanol production may have limited benefits [29, 36], hence a large number of small-scale ethanol production facilities is more desirable. Besides, large-scale ethanol refineries will require massive capital investments and long lead times and items [2]. The participation of smallholders is very important to the sustainability of biofuel.

The batch process of ethanol production is carried out by 2-5 workers in a period of time that differs greatly among the various sites, ranging from 5 hours 32 minutes to 12 hours 33 minutes. About 105-155kg of hard wood being significantly different ($P<0.05$) among the various sites, was the source of energy used for the distillation of 20 L of ethanol, which is done in open furnace (Figure **2**). Thus, this indicates that about 5.25-7.75 kg of wood is consumed to distil one litre of ethanol. Energy and labour related inputs are important issues in energy assessment and sustainability. Knowing that the gross energy content of most Nigerian hard wood is in the range of 18-22 MJ/kg [37, 38], it therefore appears that the traditional distillation process is energy inefficient because the energy content of pure ethanol and low concentration ethanol (39-61.5%) are 21.2 MJ/L and 13.9 MJ/L respectively. Igbinadolor [13] describes the process of traditional production of ethanol to involve pooling palm saps into metal drums where they are thoroughly mixed, and allowed to ferment for 24 hours with occasional stirring. The fermented sap is then distilled over fire; the vapour is condensed as ethanol. The first distillate is re-distilled to obtain a product with higher ethanol content.

Table **2** presents the yeast counts and physicochemical properties of the fermented sap prior to distillation. The yeast population is in the order of 0.75-185 x 10^8cfu/ml being significantly different in the various sites ($P<0.05$). Yeast, and to lesser extent bacteria, have been commonly associated with the fermentation of palm sap [3, 10, 18]. However, Karamoko *et al.* [12] report yeast/mould population of 3.2 x 10^3, 2.3 x 10^7, 1.2 x 10^8, 1.6 x $10^8$and 1.0 x 10^8cfu/ml for the first day, the first week, the second week, the third week, and the fourth week-old palm sap respectively.

The physicochemical properties of the fermented sap, of the first distillate, of the second distillate, of the first stillage, and of the second stillage are presented in Tables **2-6**. The pH of the fermented palm sap

Figure 2: Rudimentary ethanol distillation equipment used in the Niger Delta.

Table 1: Volumes of Process Intermediates, Wood Energy Utilized, Duration and Manpower Input for the Traditional Fermentation and Distillation of Raffia Palm Sap to Ethanol

	Palm Wine Sap volume, l	1st distillate volume, l	2nd distillate volume, l	1st stillage volume, l	2nd stillage volume, l	Wood energy, kg	Duration	Employees
1	280.000±0.289a	43.700±0.115a	20.000±0.577a	236.300±0.173a	23.700±0.115a	117.630±0.012b	5hr:32 Min.	3
2	480.000±2.887e	79.080±0.012h	20.000±0.520a	400.920±0.012i	59.080±0.012i	120.080±0.015c	7 hrs	2
3	480.000±5.774e	71.733±0.007g	20.240±0.012a	408.280±0.012j	51.480±0.012h	124.217±0.132e	9 hrs 41 min.	5
4	360.000±2.887d	56.163±1.318ef	20.000±0.058a	305.170±0.017f	34.830±0.017e	146.850±0.330f	7 hrs	4
5	360.000±2.309d	53.450±0.029bc	20.000±0.115a	306.550±0.012g	33.450±0.029c	160.173±0.139i	6hrs 47 min.	3
6	320.870±0.012c	54.817±0.007d	20.000±0.289a	266.040±0.012d	34.830±0.015e	104.597±0.101a	12hrs 33 min.	2
7	300.000±0.289b	56.550±0.029f	20.000±0.265a	243.450±0.029b	36.550±0.029g	153.080±0.072g	7hrs 54 min.	5
8	360.000±2.887d	54.140±0.012cd	20.000±0.520a	306.860±0.012h	34.140±0.012d	120.193±0.064c	5hrs 56 min.	2
9	300.000±0.289b	52.760±0.012b	20.000±0.115a	247.240±0.012c	32.760±0.012b	154.757±0.024h	7 hrs 50 minutes	3
10	360.000±2.887d	55.170±0.017de	20.000±0.404a	304.830±0.017e	35.170±0.012f	121.397±0.095d	6 hrs 30 min.	2

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at $P< 0.05$ according to the Duncan Statistics.

Table 2: Yeast Counts and Physicochemical Properties of Fermented Raffia Palm Sap

	pH	Electrical Conductivity, µS/cm	Specific Gravity	% Alcohol	% Sugar	Yeast x 10^8cfu/ml
1	6.72±0.012d	21100±5.774a	1.006±0.001c	12.00±0.058c	6.20±0.058ef	6.667±0.001b
2	6.59±0.006a	27100±5.774g	1.003±0.001ab	13.00±0.100e	12.60±0.058h	101.000±2.887f
3	6.67±0.012bc	26150±5.774f	1.019±0.001e	13.20±0.115e	4.60±0.100d	116.667±3.180g
4	6.60±0.020a	24050±0.000d	1.015±0.001d	15.30±0.058g	6.30±0.058f	185.637±0.052i
5	6.65±0.010b	24500±10.000e	1.007±0.001c	12.40±0.058d	3.00±0.100a	65.330±0.068d
6	6.77±0.010e	30100±5.774i	1.001±0.001a	11.50±0.100b	4.20±0.058c	1.653±0.001ab
7	6.70±0.010cd	23250±5.774c	1.005±0.001bc	12.40±0.058d	6.00±0.058e	49.333±0.007c
8	6.70±0.012cd	21600±11.547b	1.002±0.000a	12.50±0.100d	3.40±0.100b	71.333±4.096e
9	6.76±0.010e	28500±10.000h	1.007±0.001c	14.00±0.000f	7.20±0.058g	153.330±0.068h
10	6.70±0.000cd	36750±5.774j	1.017±0.001de	10.50±0.058a	3.60±0.058b	0.753±0.001a

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at *P*< 0.05 according to the Duncan Statistics.

Table 3: Physicochemical Properties of First Distillate Produced During the Distillation of Raffia Palm Sap

	pH	Electrical Conductivity, µS/cm	Specific Gravity	% Alcohol	% Sugar
1	7.060±0.006a	768.00±0.577d	0.968±0.001c	18.833±0.441a	3.567±0.120c
2	7.130±0.010a	765.00±1.155d	0.976±0.001e	20.000±0.000ab	6.433±0.033f
3	7.250±0.010ab	647.00±0.000a	0.977±0.001ef	20.167±0.333b	3.600±0.100c
4	7.437±0.012ab	1898.33±1.202i	0.974±0.001de	39.000±0.577d	4.300±0.115d
5	7.080±0.012a	681.00±1.155b	0.963±0.001b	19.800±0.651ab	2.200±0.100a
6	7.100±0.010a	1823.00±1.528h	0.976±0.001e	19.000±0.000ab	3.400±0.000c
7	7.377±0.212ab	793.00±1.528e	0.979±0.000f	19.500±0.289ab	4.400±0.100d
8	7.380±0.260ab	1133.00±1.000g	0.778±0.001a	20.000±0.289ab	2.367±0.067ab
9	7.217±0.015ab	1022.00±1.155f	0.972±0.001d	23.000±0.289c	5.100±0.058e
10	7.570±0.230b	745.00±0.577c	0.974±0.002de	19.000±0.289ab	2.600±0.058b

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at *P*< 0.05 according to the Duncan Statistics.

Table 4: Physicochemical Properties of Second Distillate Produced During the Distillation of Raffia Palm Sap

	pH	Electrical Conductivity, µS/cm	Specific Gravity	% Alcohol	% Sugar
1	6.650±0.015f	230.000±3.606e	0.938±0.002abc	50.667±0.441b	2.800±0.029b
2	6.503±0.055abc	219.000±1.000d	0.940±0.002bc	59.500±0.764d	3.500±0.100f
3	6.630±0.006ef	172.000±1.155c	0.959±0.012d	60.500±0.764de	3.120±0.032c
4	6.450±0.006a	100.000±1.732a	0.928±0.001ab	61.500±0.289e	3.400±0.058ef
5	6.460±0.012ab	217.000±1.528d	0.973±0.001e	53.367±0.088c	1.900±0.050a
6	6.550±0.012cd	105.333±2.333a	0.926±0.001a	40.000±0.289a	3.100±0.029c
7	6.570±0.010de	280.000±2.887f	0.947±0.002c	53.000±0.289c	3.300±0.050de
8	6.490±0.015abc	232.333±1.202e	0.931±0.002ab	53.500±0.289c	2.000±0.029a
9	6.520±0.010bcd	130.000±1.528b	0.937±0.002abc	61.000±0.289e	3.200±0.076cd
10	6.450±0.010a	464.667±1.202g	0.962±0.001de	39.000±0.289a	2.030±0.021a

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at *P*< 0.05 according to the Duncan Statistics.

Table 5: Physicochemical Properties of First Stillage Produced During the Distillation of Raffia Palm Sap

	pH	Electrical Conductivity, µS/cm	Specific Gravity	% Alcohol	% Sugar
1	7.200±0.029b	12400±7.638b	0.999±0.002a	10.200±0.058g	0.800±0.058bc
2	7.107±0.015a	16900±2.887f	1.008±0.001c	8.000±0.058d	1.200±0.058d
3	7.160±0.006ab	16350±5.000e	1.002±0.001ab	6.467±0.067c	1.000±0.058c
4	7.200±0.010b	13700±2.887c	1.007±0.001c	5.800±0.058a	1.500±0.058e
5	7.180±0.006b	11150±2.887a	1.005±0.001bc	6.200±0.058b	0.800±0.000bc
6	7.200±0.010b	17710±2.887i	1.000±0.003a	9.400±0.058e	0.500±0.058a
7	7.260±0.010c	29500±5.774j	0.999±0.001a	9.600±0.000f	0.700±0.100ab
8	7.270±0.015c	17350±2.887h	0.999±0.001a	9.400±0.058e	0.600±0.100ab
9	7.290±0.017c	15350±7.638d	1.000±0.002a	9.500±0.100ef	0.500±0.058a
10	7.270±0.012c	16960±25.166g	1.001±0.001ab	6.600±0.058c	0.800±0.058bc

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at *P*< 0.05 according to the Duncan Statistics.

Table 6: Physicochemical Properties of Second Stillage Produced During the Distillation of Raffia Palm Sap

	pH	Electrical Conductivity, µS/cm	Specific Gravity	% Alcohol	% Sugar
1	6.440±0.015f	12105±2.887b	1.001±0.001a	5.800±0.058f	0.300±0.058bc
2	6.340±0.006cd	19805±2.887i	1.001±0.001a	4.200±0.058cd	0.200±0.000ab
3	6.360±0.006d	16700±30.503f	1.007±0.001b	4.000±0.000bc	0.300±0.058bc
4	6.290±0.010b	18430±2.887h	1.001±0.001a	4.100±0.058cd	0.300±0.058bc
5	6.320±0.010c	18030±2.887g	1.001±0.001a	4.300±0.058d	0.200±0.058ab
6	6.430±0.006f	11360±2.887a	1.003±0.001a	5.200±0.058e	0.100±0.000a
7	6.360±0.010d	15333±30.867d	1.001±0.001a	4.100±0.058cd	0.300±0.058bc
8	6.390±0.006e	13650±5.774c	1.003±0.001a	3.400±0.000a	0.400±0.058c
9	6.200±0.010a	15600±7.638d	1.001±0.001a	3.800±0.153b	0.200±0.058ab
10	6.537±0.012g	16250±2.887e	1.001±0.000a	5.400±0.058e	0.400±0.058c

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at *P*< 0.05 according to the Duncan Statistics.

(6.59-6.77), of the second distillate (6.45-6.65), and of the second stillage (6.20-6.54) were slightly acidic, while that of the first distillate (7.10-7.57) and of the first stillage (7.11-7.29) were neutral. Stillage from molasses and sugarcane juice have been reported to have a pH of 4.8 and 3.7-5.9 respectively [2]. Adeleke and Abiodun [21] report a pH of 4.3 and 6.3 for palm sap and ethanol respectively. Nwanchukwu *et al*. [14] revealed that the pH of palm sap decreases with age i.e. the length of fermentation. Several authors have reported a concurrent alcoholic, acetic and lactic acid fermentation of palm sap, which is responsible for the rapid acidification of the palm sap [10, 12, 13, 17, 39].

The specific gravity was significantly different in the studied sites and among the various intermediates (P<0.05). The specific gravity of the fermented sap, of the first and second stillage were slightly greater than 1, while that of the first and second distillates were slightly lesser than 1. Adeleke and Abiodun [21] report specific gravity of 0.9897 for ethanol and 1.0387 for fermented palm sap. Willington and Marten [2] report a specific gravity of 1.05 for molasses. The electrical conductivity was highest in the palm sap (21,100 - 36,750 µS/cm), of the first stillage (11,150-29,500 µS/cm) and of the second stillage (11,360-19,805 µS/cm), and least in the first distillate (647-1898 µS/cm) and second distillate (100-464 µS/cm).

The total sugar percentage was highest in the fermented sap (3.00-12.60%), followed by the first distillate (2.20 –6.43%), the second distillate (1.90-

3.50%) and least in the first stillage (0.50-1.50%) and second stillage (0.10-0.40%), though significantly different in the various sites (P<0.05). Several authors have reported the total sugar of unfermented palm sap to be in the order of 10-12% [3, 12, 40]. Rokosu and Nwisienyi [17] report 4-7% total sugar in unfermented palm sap. Being a substrate for the production of ethanol, expectedly the palm sap had the highest sugar level, which declined afterwards.

The percentage of ethanol was significantly different (P<0.05) among the different intermediates. The highest ethanol percentage was recorded in the second distillate (39-61.5%), followed by the first distillate (18.83-39%), the first stillage (5.80-10.20%), the palm sap (10.50-15.30%), and the second stillage (3.40-5.80%). Several authors have reported various levels of ethanol in fermented palm sap, including 2-8% [27], 3.25% [17], 3.1% [21], 0.5-7.1% [13], 8.2% [6, 14], 3-4% [20]. Similarly, several authors have reported the ethanol level produced from sap distillation to be >40% [20], 26.8-39.9% [13], 37.6% [21], 40% [27].

On the positive side, the production of ethanol fuel from raffia palm would allow the indigenous people to participate in the energy sector, which has long been dominated by multinationals. Indigenous people could participate in the entire value chain of fuel ethanol production, including palm wine tapping, transportation, fermentation, distillation and distribution, unlike multinational biofuel companies that engage indigenous people only in farm-related activities. However, there are several challenges associated with the traditional fermentation and distillation of palm sap for ethanol production that must be addressed in order to scale up the process. Some of the limiting factors include microbial contamination, poor distillation apparatus, inefficient energy utilization, and lack of ethanol dehydration technology and the production of large volume of stillage.

For the traditional fermentation and distillation of raffia palm to be used for the production of fuel ethanol, the process must first be upgraded. For instance, inoculation of fresh palm sap is spontaneous i.e. left to chance inoculation, which is prone to contamination by other microbes, producing competing products such as lactic and acetic acid [10, 12, 13, 17, 39]. In order to prevent or reduce microbial contamination, it is suggested that the ethanol fermenting yeast be isolated, developed, and used under sterile conditions. Yeast strain with high ethanol yield and tolerance was recorded in this study, which agreed with other findings in literature [12, 14].

The ethanol produced by the smallholders is of low concentration, typically in the range of 39-61.5% ethanol. The smallholders lacked the technology for ethanol dehydration such as the use of molecular sieves, azeotropic distillation, counter current distillation etc. This challenge can be overcome by modifying the Nigerian Biofuel Policy [41] to permit the use of low concentration ethanol cooking fuel [42] as practiced in India [43-45] and hydrous ethanol for automobiles, as commonly practiced in Brazil [31, 32].

Another problem faced by the smallholder distillers is the poor energy efficiency of rudimentary distillation apparatus (Figure **2**) used for distillation, which has resulted in large energy input. The Nigerian government, through its research institutions like the Nigeria Institute for Oil Palm Research (NIFOR), the Federal Institute of Industrial Research (FIIRO), the National Centre for Agricultural Mechanization (NCAM), and the Project Development Agency (PRODA),are encouraged to modernize the distillers and equip them with process-control features. Meanwhile, it has been reported that raffia palm is hapazanthic i.e. the palm would die after fruiting once [7, 8], thus resulting in the loss of biomass and the release of carbon into the environment. It is therefore recommended that raffia palm wood and fronds be used as energy source for distillation, which could offset the potentially negative energy balance associated with the poor distillation process. The practice of using raffia stems, trunk and fronds from tapped trees is currently being practiced by some smallholders. These lignocellulosic biomass can be converted to ethanol by dilute-acid pretreatment, enzymatic saccharification, and co-fermentation [46]. Also, excess raffia palm stem and fronds can be used as fuel for power generation *via* steam cycle or for advanced fuel and power generation *via* gasification and the Fischer-Tropsch synthesis. The ripe fruit can be harvested, oil extracted and used for biodiesel production. The seeds can be used for the propagation of raffia palm or as fuel for steam boilers for electricity generation. All these innovations could increase the energy efficiency of biofuel production from raffia palm.

Stillage and yeast are by-products from any ethanol production facility. In Nigeria, the smallholder ethanol distillers typically dispose these by-products into the environment, which potentially pollute the ecosystem [26]. The sustainability of the smallholder ethanol process is largely dependent on the distillation and recycling of these waste by-products [22]. Ethanol fermenting yeasts have been successfully used as animal feeds. From this study, primary stillage has a considerable level of ethanol (5.8-10.2%) and sugars (0.5-1.5%), while the secondary stillage has lesser levels of alcohol (3.4-5.8%) and sugar (0.2-0.4%). Hence, these by-products could be recycled to recover more ethanol. They could also be used as ferti-irrigation. The use of ethanol fermentation by-products for animal feed and ferti-irrigation could further increase the energy efficiency and sustainability of the process. Finally, the use state-of-the-art technology such as dilute-acid pretreatment, enzymatic saccharification, and fermentation, optimization of product recovery, and wastewater utilization could significantly improve the traditional ethanol production process [46]. However, these high technologies may be unavailable to the rural processors in the near future.

CONCLUSION

This research was designed to present the process of traditional fermentation and distillation of beverage ethanol in Bayelsa State, Nigeria, and to investigate the possibility of scaling up the process for the production of fuel ethanol. Ten smallholder ethanol production facilities were randomly selected and triplicate samples of the process intermediates were collected and analysed including fermented palm sap, first and second distillate, first and second stillage. Results show that the ethanol percentage was significantly different ($P<0.05$) among the different intermediates. The highest ethanol was recorded in the second distillate (39-61.5%), followed by the first distillate (18.83-39%), first stillage (5.80-10.20%), palm sap (10.50-15.30%) and second stillage (3.40-5.80%).

The smallholder ethanol production facilities are challenged by;

- the entire process is not done under aseptic conditions but is dependent on spontaneous (i.e. chance) inoculation, which is prone to contamination by competing microorganisms catalyzing the production of other products such as lactic and acetic acid,
- the use of makeshift distillation apparatus, which is energy inefficient and lacked process control,
- production of large volume of stillage, which is typically disposed into the environment, without any form of treatment,
- production of low concentration ethanol (39-61.5%) that cannot be blended with gasoline to comply with Nigeria's E10 gasoline/ethanol blend policy.

These challenges could be overcome by modernization of the distillation apparatus, and upgrading of the Nigerian Biofuel Policy to permit the use of hydrous ethanol in automobiles and low concentration ethanol for domestic/household cooking. The study concludes that it is feasible to scale up the traditional process for fuel ethanol production, which has the added benefit of engaging indigenous people in the entire value chain of fuel ethanol production.

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