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Conversion of Three Types of Waste Biomass in Ghana (Coconut Shell, Coconut Husk and Mahogany) into Liquid Smokes and Determination of the Sensory Profiles

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***Abstract* - The disposal of large amounts of waste biomass generally regarded as rubbish and pollutants is a major environmental management problem in Ghana. The challenge, therefore, was to convert the large amounts of waste biomass into useful products. In developed countries, plant based waste biomass are converted into Liquid Smoke which is used as a substitute to wood smoke during the traditional smoking of fish. In this study, liquid smoke was produced from coconut shell, coconut husk and mahogany wood by pyrolysing separately known weights of each biomass in a closed system, and absorbing the smoke in water by passing the condensed smoke vapours at 6°C through three flasks filled with distilled water and connected in series ($Flask_1-Flask_2-Flask_3$) to obtain a liquid smoke fraction in each flask. Yields of liquid smoke from coconut husk, Mahogany and coconut shell were 40.0%(v/w), 23.25%(v/w) and 15.6%(v/w) respectively. The yields, pH, colour, and flavour profiles of the Liquid smokes depended significantly ($p \leq 0.05$) on the type of biomass, and the liquid smoke fraction. However, Liquid smokes from different batches of the same biomass did not differ significantly ($p > 0.05$) in yields, pH, colour, and flavour profiles. The production setup could easily be scaled up into a simple, affordable, and easy to maintain form for community - level liquid smoke production ventures to convert waste biomass into Liquid smoke. This would be a more productive, sustainable and cleaner way to manage waste biomass in Ghana than the current practices of burning and prolonged decomposition.**

Keywords: Waste Biomass, Pollution, Pyrolysis, Condensation, Liquid smoke, Biochar, Tar.

1. INTRODUCTION

1.1. Background

Agriculture alone generates globally every year 140 billion metric tons of biomass (UNEP, 2009). In addition, the amount of biomass used globally as wood fuel in 1999 was 3.3 billion metric tons (Parikka, 2004).

Biomass is a renewable and readily available resource and it has a huge potential for energy production or conversion into other forms of raw materials which could be especially useful in community-level ventures (UNEP, 2009).

Biomass wastes from agriculture include animal husbandry waste, plant waste such as corn stalks, straw, sugarcane leavings, sugarcane bagasse, cereal husk, and nutshells.

Biomass wastes derived from the forest include leaves, twigs, small branches and roots, straw, husk, nuts and seeds, wood chips, bark, sawdust, timber slash, and mill scrap (UNEP, 2009).

Due to the very large amounts generated, waste biomass which is not converted into energy and other useful products create environmental management problems.

Decomposing biomass contaminate water systems with leachates (Tao, 2005) which are toxic to fish and other aquatic life (Hughes-Games, 1992).

Burning of biomass pollutes the atmosphere with major air pollutants like carbon monoxide, nitrogen dioxide, nitrogen oxide, Inhalable Particulate Matter (IMP) consisting of droplets of condensed organic vapors, soot, and ash, and toxic and cancer-causing substances such as benzene, formaldehyde, and benzopyrene.

In some countries, plant based waste biomass like sawdust is converted into a product called Liquid smoke through pyrolysis followed by condensation of the smoke (Martinez et al, 2011). Liquid smoke can also be produced from biomass from agricultural wastes and forestry residues, and any plant material which contain cellulose, hemicellulose and lignin, the three main compounds from which the components of liquid smoke are derived (Milly and Toledo, 2003).

Liquid smoke has been produced from coconut shell (Zuraida et al, 2011), Lamtoro Wood (Swastawati et al, 2007) Corn Cob (Swastawati et al, 2007), and chaff from paddy rice (Swastawati et al, 2008).

Liquid smoke is used to substitute the traditional wood smoking methods in the processing of fish in developed countries (Martinez et al, 2011). According to Ruitenberg (2014) there are wide ranges of environmental, health, and production benefits from the use of liquid smoke compared to traditional smoke.

During the traditional smoking process the smoke containing all the carcinogenic and potentially unsafe elements, gases and solid elements like tar and char is deposited directly on the food (Martinez et al, 2011). During the production of liquid smoke, all the carcinogenic and potentially unsafe elements from the natural smoke are removed during processing. The tar extracted from the smoke is recycled as fuel back into the process (Ruitenberg, 2014).

1.2. Problem Statement

Large amount of biomass like sawings and sawdust from sawmill activities, and coconut husk, sugarcane chaff, and palm kernel shells generated every year from agricultural activities are generally regarded as rubbish and pollutants in Ghana (Sekyere and Okyere, 2007). Their disposal is a major environmental management problem (Kukogho et al, 2011). They are either disposed through burning (Kürsten, 2012) or prolonged decomposition at waste dumps. These wastes often have negative values as resources are employed to dispose them onsite or transport them elsewhere for disposal (Sefa-Bonsu, n.d.).

The challenge, therefore, was to convert the large amounts of indigenous waste biomass in Ghana into other useful products like liquid smoke (UNEP, 2009).

1.3. Justification

In Ghana smoking of fish is by the traditional method using wood, waste sugar cane husk, palm nut shells, palm nut husk, or coconut shells and husks as fuel.

However, the efficiency in converting wood biomass to useable smoke in the form of liquid smoke would be four to five times more than that obtained from the traditional smoking process (Red Arrow, 2014).

Liquid smoke production therefore would be a more sustainable and cleaner way to manage waste biomass than the current practices of burning and prolonged decomposition used in Ghana.

However, currently there is no report on the production or use of liquid smoke in food processing in Ghana.

According to Ramakrishnan and Moeller, (2002) the compositions of products of biomass pyrolysis from bench scale experiments and commercial setups are similar. Bench scale experiments are therefore suitable for studying biomass pyrolysis chemistry for liquid smoke manufacture (Ramakrishnan and Moeller, 2002).

In this study an appropriate bench scale setup for the production of liquid smoke was developed and its capacity tested for the yields of liquid smokes from various waste biomasses and for producing liquid smokes with consistent colour characteristics and flavour profiles.

The study was based on the hypothesis that at *($p \leq 0.05$)*:

1. Liquid smokes products from different types of biomass raw materials have significantly different colour characteristics and flavour profiles.
2. Liquid smoke fractions produced from a single batch of biomass raw materials have significantly different colour characteristics and flavour profiles.
3. Separate batches of Liquid smokes produced from separate batches of the same type of biomass raw material have significantly different colour characteristics and flavour profiles.

1.4. Principles of Liquid Smoke Production

Smoke is made up of two phases: a vapour phase and a particulate phase. The vapor contains food preservatives, flavouring and colouring substances in the form of phenols, organic acids, alcohols, and carbonyl compounds, which are soluble in water. The particulate phase contains fine solid particles like tar and char which are insoluble in water.

During liquid smoke manufacture, wood smoke is distilled and condensed and collected as a solution. The solids are allowed to separate out by precipitation and the aqueous phase decanted off (FAO, 2001). The aqueous phase could be used without any further refinement as liquid smoke solution to smoke fish and other foods (Mascheroni, 2012).

The separated solids of tar and ash contain hazardous constituents such as carcinogenic polycyclic aromatic hydrocarbons which could be disposed of. The main compounds responsible for the flavour of liquid smoke are the phenols, carbonyls and carboxylic acids (FAO, 2001).

2. MATERIALS AND METHODS

2.1. Bench Scale Setup for the production of Liquid Smoke

A ½ inch copper pipe (O.D. 0.625; I.D. 0.545; wall thickness 0.040) 70cm long was fitted at one end to the lid of a 12 liter aluminum pressure cooker (Master Chef, MC-PC 9512) (Fig. 1) and joined at the other end through a one hole #2 rubber stopper to a 300mm straight inner tube Liebig glass condenser (Fig. 2). The condenser inlet and outlet were connected with braid reinforced PVC hose to a Refrigerated Water Bath (Grant LTD6G) maintained at 6^{o}C (Fig. 2). Three Pyrex filtering flasks (1000ml, 500ml, 500ml) with side arms were each filled with distilled water (500ml, 400ml, 300ml), and then fitted with one hole rubber stoppers (#8, #7, #7) through which glass tubes were fixed such that the ends of the tubes were below the water levels in the flasks. The flasks were connected in series (1000ml-500ml-500ml) through their side arms by braid reinforced PVC hose (Fig. 3). The mouth of the condenser was connected to the receiving filter flask by braid reinforced PVC hose through the glass tube.


Fig. 1.


Fig 2.


Fig. 3.

Fig. 1. ½ inch Cu pipe fitted to lid of pressure cooker
Fig. 2. Glass condenser
Fig 3. Three filter flasks connected in series

The rubber gasket was removed from the groove in the lid of the pressure cooker and a layer of heat resistant silicone sealant was laid down in its place and allowed to dry to from a gasket (Fig. 4).

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Fig 4. Forming a heat resistant silicone sealant gasket between the lid and container of the pressure cooker

The rubber gasket was then placed on the silicone gasket. Another silicone gasket was layered on the rim of the pan. The three layered silicone-rubber-silicone gasket provided a tight seal when the lid was closed on the pan and prevented the escape of smoke during pyrolysis.

2.2. Production of liquid smoke

2.2.1. Biomass raw materials

The biomass raw materials for the production of liquid smoke were: waste dry Coconut Shells - one batch (C. Shell 1), waste dry Coconut Husks - two batches (C. Husk 1 and C. Husk 2) and dry Mahogany twigs and branches - two batches (Maho 1 and Maho 2) (Fig. 5).

The waste coconut shells and husks were collected from dump sites near the Tema Lorry Station in Accra where vendors of fresh coconuts dump their waste. Dried Mahogany twigs and branches were purchased from a firewood vendor at the Timber Market in Accra.

Fig. 5. Mahogany, Coconut Husks and Shells

The coconut husks were separated from the shells by peeling. The shells, husks and wood were cut into smaller sizes, and then grinded separately with a grinding mill (Integas YLQ90M2-4) into smaller bits.

2.2.2. Pyrolysis of biomass raw materials

Known weights of the various biomasses were pyrolysed separately in the aluminum pressure cooker heated on a gas flame stove (Fig 6). The smoke generated passed through the condenser at 6^{o}C, and then through the first, second and third flasks containing distilled water. The condensable portion of the smoke was absorbed in the water in the flasks (Fig 7).

Fig. 6.

Fig. 7.

Fig. 6. Pyrolysis

Fig. 7. Absorption of smoke in water

The non-condensable gasses were vented off into the atmosphere through the sidearm of the last flask in the series.

The aqueous smoke solution from each flask was kept separate and left undisturbed for seven days for the solids to settle out. The supernatant was first decanted from the solid phase which was tarry, and then filtered through cheese cloth to remove any tar residues and particulate matter. A water insoluble oily phase which separated from the aqueous phase and settled on the surface of the supernatant was removed by filtration through cotton wool to yield a Primary Smoke Condensate. The Primary Smoke Condensate was left undisturbed for 12 weeks for flavor and colour development. Three separate liquid smoke fractions were obtained from Flask 1, Flask 2 and Flask 3 respectively. The byproducts were Biochar, and Primary Tar Fraction.

2.3. Data collection

2.3.1. Yield of liquid smoke

The volume of liquid smoke absorbed in the water in each flask was determined from the initial and final volumes of the contents of the flasks. The yields were calculated from the formula:

$$\text{Percent yield} = \frac{\text{Final volume} - \text{Initial volume}}{\text{Weight of Biomass (g)}} \times 100$$

2.3.2. Yield of Biochar

The yield of Biochar was calculated from the formula:

$$\text{Percent yield} = \frac{\text{Weight of Biochar (g)}}{\text{Weight of Biomass (g)}} \times 100$$

2.3.3. pH

pH measurement was done with a combination electrode, standardized between pH 4.0 and 7.0 and attached to a pH/ion analyser 255 (Corning Scientific Co.,).

2.3.4. Colour (Qualitative)

About 10ml of liquid smoke sample was transferred into a clean glass test tube and matched visually against the same colour in the British Standard Colour Chart, RAL Standard Colour Chart, Australian Standard Colour Chart AS2700, or Federal Standard Range Colour Chart.

2.3.5. Colour (Quantitative)

The colours of the various samples that had been determined subjectively through colour matching with standard colour charts were translated into quantitative values by recording the RGB values listed on the standard colour charts.

2.4. Sensory analysis

2.4.1. Selection of Flavour Attributes

Through pretesting of the liquid smokes, brainstorming and discussion among five panel members, seven flavour attributes were selected for rating. The panel was guided by the descriptors used by Jenkins (2010). There was a clear understanding among the panel of the meaning of the selected attributes (Table 1).

Table 1. Flavour Attributes and their descriptions

Attribute	Description
Fruity	Fruit flavour
Green wood	Associated with green wood/small young branch.
Scorched	Associated with charring or burning
Smoked Food	Characteristic flavour of smoked food
Spicy	Flavour qualities associated with a spice
Phenolic	Associated with tar, bitumen, or solvents
Astringent	Unpleasant rough "sandpapery" or dry sensation in the mouth

(Jenkins, 2010)

Each member of the sensory panel independently rated the intensity of the pre-selected attributes of randomly coded liquid smoke samples on a nine point descriptive rating scale having scores of 0 / none to 9 / extremely.

2.4.2. Star diagrams

The group averages for the flavour scores were calculated and star diagrams having nine point scales plotted with Microsoft Excel.

2.4.3. Flavour profiles

A Microsoft Excel formula (1) was used to convert the group average of each attribute into an Equivalent Descriptive Word (EDW) using the appropriate words for each number on the nine point scale (Table 2).

=IF(C16<1,"absent",IF(C16<2,"veryslightly",IF(C16<4,"slightly",IF(C16<6,"moderately",IF(C16<8,"strongly",IF(C16>=8,"extremely")))))) (1)

Table 2. Example of Microsoft Excel formula worksheet used to convert group averages of flavour attributes into Equivalent Descriptive Words

	Coconut Shell			Equivalent Descriptive Word		
	Flask 1	Flask 2	Flask 3	Flask 1	Flask 2	Flask 3
Astringent	7.5	4.0	3.0	strongly	moderately	slightly
Scorched	4.5	3.2	2.8	moderately	slightly	slightly
Spicy	4.0	2.0	1.8	moderately	slightly	very slightly
Phenolic	3.0	1.5	1.5	slightly	very slightly	very slightly
Smoked Food	2.5	2.0	1.0	slightly	slightly	very slightly
Green wood	2.5	1.5	1.5	slightly	very slightly	very slightly
Fruity	2.0	1.5	1.0	slightly	very slightly	very slightly

The EDW's and star diagrams were then used to compile the flavour profiles of the liquid smoke fractions.

2.4.4. Data analysis

Data were subjected to analysis of variance to test at ($p \leq 0.05$) if:

1. Liquid smokes from different types of biomass have significantly different yields, pH, colour, and flavour profiles.
2. Liquid smoke fractions from the same batch of biomass raw material have significantly different yields, pH, colour, and flavour profiles.
3. Liquid smokes from two different samples of the same biomass raw material have significantly different yields, pH, colour, and flavour profiles.

3. RESULTS AND DISCUSSION

3.1. Bench Scale Setup

According to Hollenbeck (1977) the three general methods of preparing aqueous solutions of smoke are: (1) the controlled pyrolysis of sawdust and absorption of the smoke in water; (2) the controlled pyrolysis of sawdust and continuous condensation of the smoke solution in a condenser and; (3) passing superheated steam over sawdust, or finely divided wood chips followed by condensation of the steam.

The setup used in this study conforms to the first method described by Hollenbeck (1977) and consisted of an airtight pyrolysis unit for smoke generation, a distillation unit for condensing the smoke, and a unit for absorbing the condensed smoke in a liquid. The setup used in this study is more elaborate than the one described by Ibrahim et al (2014) and used in Malaysia.

In the Malaysia setup for producing liquid smoke, smoke from the chimney of a charcoal kiln is condensed by passing it through a 30 meter air cooled stainless steel pipe. The smoke condensate is collected in a polyethylene container and stored at room temperature (Ibrahim et al, 2014).

Another setup in Philippines described by Librero (2012) consisted of a metal drum as the pyrolysis chamber, and a condensation unit in the form of a bamboo pipe connected by a short spout to the top of the drum. When coconut husks are burnt in the drum, the hot smoke rises through the bamboo pipe all the way to the tip of the pipe, and then condenses and flows back down through the pipe into a plastic bottle. The yield of liquid smoke from the husk of twenty pieces of coconut was one liter. The liquid smoke is used as an organic fertiliser and also to neutralise the odor from piggeries.

Wang et al (n.d.) described a setup consisting of a pyrolysis unit of a quartz flask in a microwave oven, a packed bed catalysis reactor containing Zeolite catalyst, and a condenser.

The 4kg capacity pyrolysis furnace used by Yusnaini et al., (2012) to produce Kenari (Canariun indicum L.) shell liquid smoke was 20cm in diameter and 40cm high and with a 1500 watt electric heater encircling the reactor. The reactor cover was connected by a pipeline to cooling tubes used to condense the smoke into liquid smoke.

The setup used in this study could easily be scaled up for community-level liquid smoke production ventures. The scale up should be simple, affordable, easy to maintain and partial to small-scale to encourage the artisanal production of liquid smoke in Ghana (Ameko et al., 2013).

3.1.1. Products from pyrolysis

The products from pyrolysis were smoke vapour and pyrolysed wood (Fig. 8).

The smoke vapour consisted of a condensable portion which was trapped in water and non-condensable gases which was vented off into the atmosphere.

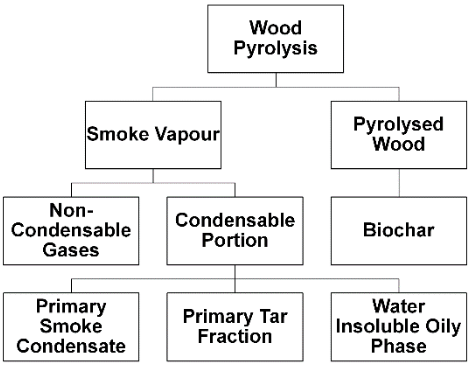

Fig. 8. Products from the pyrolysis of wood during liquid smoke production

The condensable portion of smoke vapour yielded three products: Primary Smoke Condensate, Primary Tar Fraction, and a Water Insoluble Oily Phase. The residue of the pyrolysed wood was in the form of Biochar (Figs. 8 and 9).

Fig. 9.i ii iii iv v vi

i. Fresh aqueous smoke solution
ii. Aqueous smoke solution, with water insoluble oily phase on the surface
iii. Primary smoke condensate
iv. Biochar
v. Primary Tar fraction
vi. Cheesecloth and cotton wool showing filtered ash and tar

In this study, the smoke vapours were condensed in water. However, Nollet and Toldra (2008) indicated that smoke vapours could also be condensed in vegetable oils.

Oil based liquid smokes have different flavors from water based liquid smoke. Water based liquid smokes have acidic smoky notes, while oil based liquid smokes have tarry, creosote flavors (Wheeler, 2013).

Both the primary smoke condensate and primary tar fraction can be refined further through further steps such as extraction, distillation and concentration. Concentration could be done through evaporation, absorption, or membrane filtration (Nollet and Toldra, 2008). However, further refining of the primary smoke condensate and primary tar fraction was not done in this study.

Table 3. Percent yield of liquid smoke from three types of biomass

	Type of Biomass				
	C. Shell 1	C. Husk 1	C. Husk 2	Maho 1	Maho 2
Flask 1	13.8%	38.0%	36.0%	18.9%	23.3%
Flask 2	1.4%	2.0%	2.0%	1.1%	1.7%
Flask 3	0.4%	1.0%	1.0%	0.8%	0.7%
Total	**15.6%**	**41.0%**	**39.0%**	**20.8%**	**25.7%**

The yields of liquid smokes (Table 3) was highest from the coconut husk (39.0% - 41.0%), followed by the mahogany (20.8% - 25.7%), and the least from coconut shell (15.6%). The yields were lower than those obtained by Swastawati et al., (2007) from Lamtoro wood (52.5%) and corn cob (60%). Statistical analysis at ($p \leq 0.05$) showed that:

1. Yields of liquid smokes from different biomass raw materials were not significantly different.
2. Yields of Liquid smokes fractions from the same batch of biomass were significantly different.
3. Yields of liquid smokes from different batches of coconut husk were significantly the same. The same was the case with the liquid smokes from Mahogany.

The highest Biochar yield in this study (Table 4) was from the Mahogany (60.5%), followed by the Coconut shell (50%) and Coconut husk (40%). Swastawati et al., (2007) had Biochar yield of 47.5% from Lamtoro wood and 40.0% from corn cob.

The Biochar could have several uses including improving the crop productivity of soils through carbon sequestration (McLaughlin, 2009), stimulating plants resistance to several foliar pathogens (Kolton et al, 2014), removing nitro explosives and metals from contaminated water (Oh and Seo, 2014), insulating buildings, and filtering sewage (Schmidt, 2012).

The tar could be used as a veterinary antiseptic, a preservative for wood, a caulking agent, and as a substitute for road tar (FAO, 1987).

Table 4. Yield of Biochar residue from production of liquid smoke from three sources of biomass

Type of Biomass				
C. Shell 1	C. Husk 1	C. Husk 2	Maho 1	Maho 2
50.0%	40.0%	40.0%	61.1%	60.0%

All the liquid smoke fractions from this study were acidic with pH of 2.1 – 4.3 (Table 5), and this agreed with the results of Swastawati et al., (2007) for Lamtoro wood liquid smoke (pH 3.0) and corn cob liquid smoke (2.0).

Table 5. pH of liquid smoke from three types of biomass

	Type of Biomass				
	C. Shell 1	C. Husk 1	C. Husk 2	Maho 1	Maho 2
Flask 1	2.1	2.4	2.5	2.5	2.6
Flask 2	2.7	3.1	3.1	2.9	3.3
Flask 3	3.0	3.4	3.6	3.2	4.3

Statistical analysis at ($p \leq 0.05$) showed that:

1. Liquid smokes from different biomass raw materials had significantly different pH.
2. pH of Liquid smokes fractions from the same batch of biomass were significantly different.
3. pH of Liquid smokes from different samples of Mahogany were significantly the same. This was the case also for the liquid smokes from coconut husk.

3.1.2. Colour (Qualitative)

The colours of the fresh liquid smoke fractions depended on the source of the smoke. This was evident from the different colours of primary smoke condensates obtained from the coconut shell, coconut husk and mahogany respectively (Fig. 10).

	Flask 1	Flask 2	Flask 3
Coconut Shell	RAL 2000 YELLOW ORANGE	13591 OSHA SAFETY YELLOW	RAL 1023 TRAFFIC YELLOW
Coconut Husk 1	RAL 1006-MAIZE YELLOW	RAL 1002-SAND YELLOW	RAL 8008-GREEN BROWN
Coconut Husk 2	RAL 1006-MAIZE YELLOW	RAL 1002-SAND YELLOW	RAL 8008-GREEN BROWN
Mahogany 1	OSHA SAFETY ORANGE	AS2700 Y22 CUSTARD	AS2700 X41 BUFF
Mahogany 2	OSHA SAFETY ORANGE	AS2700 Y11 CANARY	AS2700 Y21 PRIMROSE

Fig. 10. Visual appearances and standard descriptions of fractions of primary smoke condensates from different biomass raw materials

The primary smoke condensates had bright yellow-orange-golden hues but these gradually darkened during storage due to the formation of brown coloured polymerisation products. The polymerisation products precipitate under gravity as a tarry mass. The addition of acids, detergents, or organic solvents would prevent the precipitation (Stewart, 1984).

3.1.3. Colour (Quantitative)

There were variations in RGB values of the various primary smoke condensates (Fig. 11).

Statistical analysis showed that:

1. The RGB values of liquid smokes from different biomass raw materials were not significantly different at ($p>0.05$).
2. The RGB values of different fractions of liquid smoke from the same batch of coconut shell were not significantly different at ($p>0.05$). Similar results were obtained for the coconut husk, and Mahogany liquid smokes.
3. The RGB values of liquid smoke from different batches of coconut husk were not significantly different at ($p>0.05$). Similar results were obtained for the coconut husk, and Mahogany liquid smokes.

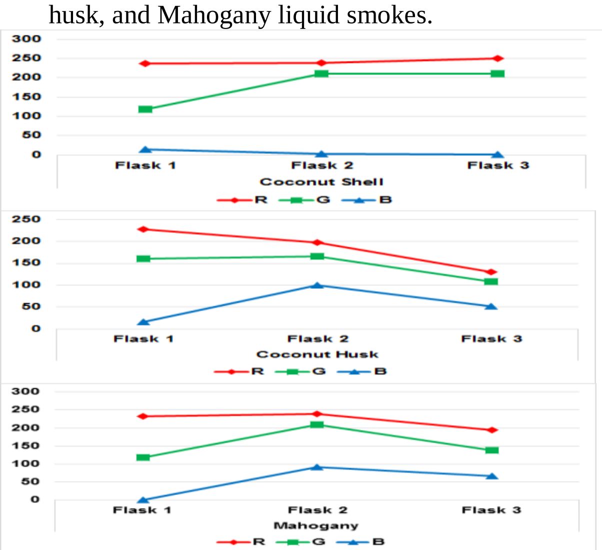

Fig. 11. RGB values of primary smoke condensates from Coconut shell, Coconut husk and Mahogany

3.1.4. Flavour profiles

Coconut shell Liquid Smoke had a flavour which was very slightly fruity, smoked food, and phenolic; slightly scorched to moderately scorched and; slightly spicy (Fig. 12). Its green wood flavour ranged from moderate to very slight. It had a moderate to slightly astringent flavour, but a strongly astringent flavour at higher concentrations.

Statistical analysis of the average group scores from the sensory panel showed that the various flavour attributes of Coconut shell Liquid Smokes had significantly different intensities at ($p\leq0.05$).

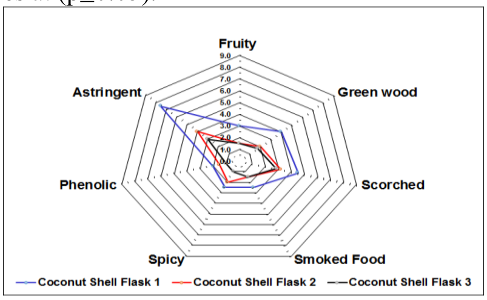

Fig 12. Flavour profile of coconut shell liquid smoke

For the Coconut shell Liquid Smoke, the flavour profiles of the three fractions were significantly different at ($p\leq0.05$).

Coconut Husk Liquid Smoke had a flavour which is very slightly smoked food, spicy and phenolic; very slightly to slightly fruity; slightly green wood; slightly to moderately scorched; the astringent flavour were strong to extreme in the first fraction, moderate in the second fraction and slight in the third fraction (Fig. 13).

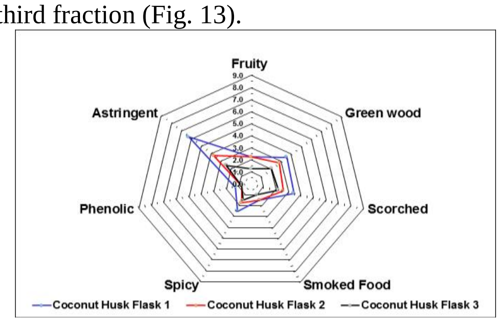

Fig 13. Flavour profile of coconut husk liquid smoke

Statistical analysis of the average group scores from the sensory panel showed that:

1. The various flavour attributes of Coconut Husk Liquid Smokes differed significantly ($p\leq0.05$) in their intensities.
2. There were significant differences ($p\leq0.05$) in flavour profiles among the Coconut Husk Liquid Smoke fractions.
3. The flavour profiles among batches of Coconut Husk Liquid Smokes were not significantly different ($p>0.05$). This showed that the bench scale setup produced Coconut Husk liquid smokes with consistent flavour profiles.

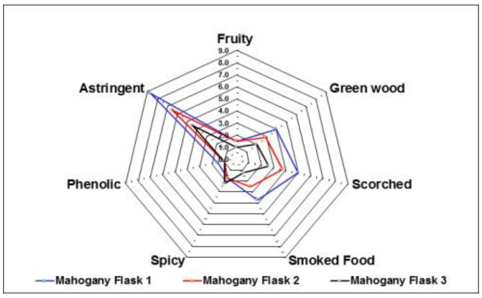

Fig 14. Flavour profile of Mahogany liquid smoke

Mahogany Liquid Smoke had a flavour which is very slightly fruity, spicy and phenolic; slightly green wood and smoked food; slightly to moderately scorched; and moderately to extremely astringent flavour (Fig. 14).

Statistical analysis of the average group scores from the sensory panel showed that:

1. The various flavour attributes of Mahogany Liquid Smokes differed significantly ($p \leq 0.05$) in their intensities.
2. There were significant differences ($p \leq 0.05$) in flavour profiles among the Mahogany Liquid Smoke fractions.
3. The flavour profiles among batches of Mahogany Liquid Smokes were not significantly different ($p > 0.05$). This showed that the bench scale setup produced Mahogany liquid smokes with consistent flavour profiles.

The flavour profiles showed that the flavours of the liquid smokes depended on the type of biomass raw material used to generate the natural smoke, and on the fraction of the final liquid smoke product.

The top flavour notes of the Coconut shell, Coconut husk and Mahogany liquid smokes were in the order: Astringent, Scorched and Green Wood (Table 6).

Table 6. Order of intensities of flavour attributes of liquid smokes

	Coconut Shell	Coconut Husk	Mahogany
1	Astringent	Astringent	Astringent
2	Scorched	Scorched	Scorched
3	Green wood	Green wood	Green wood
4	Fruity	Fruity	Smoked Food
5	Spicy	Smoked Food	Spicy
6	Smoked Food	Phenolic	Fruity
7	Phenolic	Spicy	Phenolic

Liquid smoke can be used in a wide variety of food processing applications including smoking of meat, fish, sauce flavouring, and cheese processing. Foods treated with Liquid smoke can have properties not significantly different from those of traditionally smoked food (Sérot, 2013).

A study by Essumang (2013) showed that the amounts of potentially carcinogenic polycyclic aromatic hydrocarbon (PAH) compounds on four types of fishes (Mackerel, Sardine, Tuna and Cigar minnows) smoked by the traditional natural wood smoking process in Ghana were above the European Commission set limit of 5.0µg/kg. Liquid smoke could be used as a substitute to the natural wood smoke to reduce the levels of PAHs on the smoked fish to make them safer for consumption (Sérot, 2013).

4. CONCLUSION

The bench scale setup used in this study gave yields of liquid smokes that were comparable to those obtained from other bench scale studies.

The hypothesis that:

1. Liquid smoke products from different types of biomass raw materials have significantly different colour characteristics and flavour profiles was shown to be true.
2. Liquid smoke fractions produced from a single batch of biomass raw materials have significantly different colour characteristics and flavour profiles was shown to be true.
3. Separate batches of Liquid smokes produced from separate batches of the same type of biomass raw material have significantly different colour characteristics and flavour profiles was shown not to be true.

The bench scale setup produced Liquid smokes from various waste biomasses with consistent colour characteristics and flavour profiles.

The setup could be scaled up into a simple, affordable, easy to maintain form for community - level liquid smoke production ventures. This would be a more sustainable and cleaner way to manage waste biomass than the current practices of burning and prolonged decomposition.

The liquid smokes produced could be used to improve fish smoking practices in Ghana.

The Biochar byproduct could be used for soil improvement purposes, decontamination of waste water and,as a filter material for sewage treatment.

The tar byproduct could be used as a wood preservative, veterinary antiseptic, a substitute for road tarand, a caulking agent.

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