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Assessment of Avocado and Jack Fruit Seeds Waste in Combustion Characterization for Bioenergy Production

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Abstract*: Hydrocarbon-based fuel and energy systems have become contentious lately owing to the influence they exert on both the economic and environmental rating of societies. The rising rate of consumption and prices of fossil fuels, such as gasoline for transportation and energy pose severe threat to energy security, livelihood and power generation in Uganda and other developing economies. The need to rejig and explore alternative fuel sources such as renewable energy systems that are affordable, cost effective and eco-friendly becomes imperative. Consequently, the potential threat posed by climate change owing to the high emission levels of greenhouse gases, in this case, carbon dioxide, CO_2 as a potential hydrocarbon source is an important factor in the consideration of renewable energy sources. The efficient and cost-effective technology proposed in this study for waste biomass conversion of Avocado and Jack Fruit seeds into a viable fuel source provides clean techniques for transforming them into efficient hydrocarbon fuel energy. This study however explored the Gas Chromatography-Mass Spectrometry (GC-MS), Thermogravimetric analysis (TGA) options, and physical characteristics of the Avocado and Jack Fruit seeds to examine the combustion properties, thereby evaluating the energy efficiency of the waste biomass seeds in predicting the applicability of the seeds in subsequent power generation. Information and communication technology (ICT) have been deployed to show the sustainability of biomass waste in electrical energy generation and its impact on our ecosystem. In this study, the fuels are explored more to generate biodiesel oil and its heavy fraction, like Bio-Asphaltene which could be used in heavy duty engines, transports, boilers and marine engines powering indicated by GC-MS analyses especially the avocado seeds.

***Keywords*: food waste, waste management, energy security, powder generation, jack fruit seed, avocado seed.**

1. Introduction

Gasoline, diesel, kerosene and vacuum residue are some hydrocarbon-based fuel oils frequently used as fuels for industrial boilers, power generation turbines, and as transport fuels for large marine engines (Hsu et al., 2019; Xi et al., 2020; Yusuf et al., 2020; Yusuf and Inambao, 2019a). However, the combustion of these fuels can produce carboniferous particulate emissions and fine soot (commonly referred to as Black Carbon, BC) which, along with associated poly-nuclear aromatic hydrocarbon (PAH) constitute a health problem (Masih et al., 2019; Ravindra et al., 2008). Furthermore, it has been established that black carbon is the second largest contributor to climate change after CO_2 (Cho, 2016). But unlike CO_2, which can stay in the atmosphere for a much longer time, black carbon, because it is a particle, only remains in the atmosphere for a few days before it returns to earth with rain or snow (Cho, 2016).

Soot and char formation emanating from fuel combustion of oils are associated with heavy fuel content such as asphaltenes. In addition, the influence of heavy fraction of bio oil on the combustion of heavy oils was explored by burning oil droplets with different asphaltene content (Atiku et al., 2016). Furthermore, this can be achieved either by suspended singly or passage through a drop tube, and by spray combustion of the gaseous fuels (Bartle et al., 2013). This technique has a great impact on the resource potentials of fuels like Avocado and Jack Fruits biomass. It was observed that the heavy fraction reduced ignition delay because of the volatiles generated by pyrolysis, but did not affect droplet burning time. The stack solids collected during spray combustion depended on a second-order fashion on asphaltene content of fuel oil. Meanwhile, the emitted smoke is composed of incomplete combusted residual fuel, soot particles and cenospheres (Jiang et al., 2019; Vierling et al., 2019).

In this paper, we discussed the experimental examination of volatile organic moieties emanating from avocado and jack fruit particle components and the combustion potential they exhibit during burning, GC-MS, and TGA combustion characteristics. We further examined the physical characteristics and proximate composition of the fuels in perspective, the combustion mechanism, and how the fine particulate soot and cenospheres are produced.

The significance of this study in relation to oil fired boilers with engines such as Internal Combustion (IC) and Turbocharger (Turbo, TC) were discussed. Furthermore, the influence of chemical composition of the fuel (especially in bio-oils and heavy fractions), and the analogous fuels were also discussed.

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A. Impact of ICT on the Sustainability of Biomass Waste

Global warming has become a big challenge to mankind, especially from the adverse effect of fossil fuels on the environment. The restriction induced by fossil fuels is believed to have motivated corporate individuals and government to shift their energy policy from fossil fuels to renewable energy (Ji and Zhang, 2019; Verdolini et al., 2018). Wood, cotton, agricultural residues and bio-energy wastes are some key sources of biomass considered in this study, whereas, energy production in coal - fired power plants by partial substitution of coal with biomass feedstock, also called co-firing is the signature of this study. Recently, biomass co-firing for electrical energy generation has been accepted as a viable use of biomass in existing power station infrastructure. More so, biomass co-firing offers renewable energy generation with minimal capital cost, thereby diminishing the applications of coal and gas as viable sources of fuel for electrical energy generating stations. Recently, however, the fear of carbon emission has induced replacing ~ 20% of the coal fuel with biomass (Ahmad and Tahar, 2014; Nunes et al., 2014). Furthermore, biomass can be used for generating electrical energy, facility heating and, combined heat and power (CHP) system. However, the successful application of biomass as a potential source of energy depends largely on techniques readily available for power generation (Yusuf and Inambao, 2020). In applying the co-firing technology during facility heating and other power generating system, biomass is normally fired directly in the boiler, where the gasification of materials take place.

In general, the energy generating systems associating co-firing biomass with coal are relatively more expensive to sustain than the traditional coal system, however, co-firing is more beneficial to the environment than cost. Therefore, a more sustainable approach is to find an appreciable comparison of the cost of co-firing systems with other renewable energy options, by ensuring co-firing is the cheapest in this situation provided biomass resources and coal-based power plants are available in the same location and region.

The rapid growth in technology and advancement has paved way for the energy crises of the 21st century, which has created adverse effect of climate change as a result of greenhouse gas (GHG) emissions. The adverse effect of global warming has been established beyond doubt and the world has achieved a consensus on it. The global consensus however is to cut down on GHG emissions in order to achieve a green and sustainable future energy (Murugesan, 2009; Ranbhise, 2014). Consequently, researches in energy sustainability and efficiency which has attracted so much interest and funding has continued to develop different other frontiers of knowledge. Furthermore, ICT has played a major role in making infrastructure smarter and energy efficient, and making renewable energy viable for use at macro and micro level. ICT will also support the rollout of renewable energy sources, which increases energy efficiency, promoting investment in energy infrastructure and clean energy technology. More so, that the global government policies envisioned integration of energy and ICT networks as a critical precursor for ensuring access to affordable, reliable, sustainable and green energy sources (Elbatt, T. A., & Andersen, 2004). Digitalization is another concept deployed using renewable energy integration and artificial intelligence (AI) which helps plant operators optimize their renewable energy output. Incidentally, even as the growth in technology is causing global warming owing to harmful greenhouse gas emissions, ICT has become very reliable in re-shaping our ecosystem (Bibri and Krogstie, 2017; Lobaccaro et al., 2016).

B. Ethical Consideration

The need to reduce emission arising from the use of fossil fuel demands ethical consideration. The Intergovernmental Panel on Climate Change (IPCC) in a Special Report on Climate Change and Land (SRCCL), emphasized the effect of fossil fuel on the ecosystem and land use in particular (Odoemene, 2017). In the report, it was further suggested that bioenergy must be used with caution to minimize potential risk to biodiversity, food security and land degradation (Odoemene, 2017).

The Ugandan Government has provided specific legal and policy instruments with clear aim at increasing the use of renewable energy not only as a means of boosting energy security but also for environmental sustainability. Energy Policy 2002, Renewable Energy Policy 2007, Forestry and Tree Planting Act 2003 and the National Environment Management Act 2019 are some of the instruments that have been enforced by the Ugandan Government (Cowie et al., 2007; McDonald et al., 2007). In addition, a Bio Fuel Law was proposed in Uganda, with the requisite legal framework which mandated the use of bio fuel in Uganda. The Bio Fuel Bill 2016 created a conducive environment for the production and management of bio fuels, deployed mainly for power generation and provision of alternative renewable energy, and this was stated clearly in the preamble to the bill (Fehrenbacher, 2016).

A possible ethical concern that may be evident during bio fuel production in Uganda is the effect it may have on food prices and food security. Another concern is the change in indirect land-use and its effects on GHG emissions. To be specific, where forests are cleared to grow crops for bio fuels, the net GHG reduction strategy would have been breached and this is contrary to the relevant provisions in the Bio Fuel Bill 2016. The Bill provides that bio fuels be produced in a system that preserves the natural ecosystem and biodiversity of the food chain, which invariably ensures food security. Similarly, if the provisions of the Forestry and Tree Planting Act 2003 are respected, the fears of deforestation would be allayed. As it is important that crops that are used for the production of fuel are carefully selected, putting in place strategy to ensure food security is not negatively affected. This study, however, provides an opportunity to consider food waste from avocado and jack fruits which is expected to produce heavy biomass hydrocarbon fuels for application in large engines such as, marine and power generating machineries.

2. Experimental Methods

Fine particles of the biomass food waste: avocado and jack fruit seeds, their oil extracts, and their characterized bio-oil with heavy fraction up to 12% were used. Ethanol extracts was separated from both powders using the ASTM method.

A. *Proximate Analysis and Collection of Avocado and Jack Fruit Seeds*

Ripe avocado and jack fruit seeds were obtained and washed with distilled water to remove the remnant of the pulp on the seeds, then 2000 g each of avocado seeds and jack fruit seeds were measured and separately cut into pieces and then oven dried at a temperature of 65 ^{0}C for 48 h. After drying, 692 g and 639 g of both avocado and jack fruit seeds were recovered, respectively. The seeds were ground separately into powers of about 90 microns particle sizes using a milling machine.

1) *Determination of Moisture Content*

The moisture content was determined by drying the samples at 65 ^{0}C in an oven. To determine the moisture content, the weights of the samples (2000 g each of avocado and jack fruit seeds) were taken before drying. After drying, the weights of the samples were also taken which returned as 692 g for avocado and 639 g for jack fruit seeds. The samples were dried in a controlled oven at 65 ^{0}C until a constant weight was achieved. The percentage moisture content was then calculated using Eq. 1:

$$\text{Moisture content (\%)} = (W1 - W2)/W1 \times 100 \quad (1)$$

Where,
W1= Initial weight of sample before drying
W2= Final weight of sample after drying

2) *Determination of Ash Content*

To determine the ash content of avocado in this study, 2 g of avocado seed powder was weighed into a crucible and placed in a temperature-controlled furnace for 6 h for proper ashing. The crucible was then cooled in a desiccator and immediately weighed. The initial and final weights were noted.

$$\text{Ash (\%)} = \text{weight of ash /weight of sample} \times 100$$
$$\text{Ash (\%)} = (W2/W1) \times 100 \quad (2)$$

where weight of empty crucible is not included;
W1= Weight of sample before ashing
W2= Weight of ash

3) *Determination of Volatile Organic Matter of Avocado*

To determine the volatile organic matter of avocado, 1 g of avocado sample was weighed into a crucible, closed with a lid to prevent the sample from being burnt. It was then placed in a furnace at 950 ^{0}C for 7 minutes. The sample was removed thereafter and placed in a desiccator to cool and it was weighed immediately.

The percentage (%) weight loss of avocado sample was calculated as follows:
Initial weight of avocado sample, W1 = 1 g
Final weight of avocado sample, W2 = 0.77 g

$$\text{Volatile organic matter of avocado} = (W2 - W1)/W1 \times 100 \quad (3)$$

4) *Fixed Carbon Content of Avocado Seeds*

Fixed carbon (FC) content of a sample is the quantity of carbon found in the sample after moisture and volatile and ash content materials have been extracted.

$$\text{FC content} = [100(\%) - \{(\%) \text{ moisture} + (\%) \text{ volatile matter}\} - (\%) \text{ ash content}] \quad (4)$$

B. *Extraction of Avocado Seeds Oil*

In extracting avocado seeds oil, 250 g of ground avocado seeds was weighed into a thimble (semi-permeable membrane for filtration) and placed in the Soxhlet extractor with 250 ml of solvent (ethanol). The extractor was thereafter subjected to heating for 2 h, before the extract was transferred into a rotary evaporator for removal of the solvent (ethanol). The total weight of the ground avocado seeds used was 2000 g, but it yielded 60.2 g oil which was processed for further characterization. The percentage (%) oil yield was calculated according to Eq. 5:

$$\text{\% oil yield} = \text{weight of oil extracted (g) / weight of seed (g)} \times 100 \quad (5)$$

1) *Production of Biodiesel from Avocado Seeds Oil*

To produce biodiesel in this study, 50 ml of extracted avocado oil was heated at 65 ^{0}C, 0.6 g of potassium hydroxide (KOH) acting as catalyst was measured and added into 10 ml of methanol and stirred for 5 minutes. The catalyst mixture was then added into the heated oil, covered with a fitted cork, and stirred further for 15 minutes. The mixture was thereafter transferred into a separating funnel for density separation between biodiesel and glycerol, and it was held between 9-11 h. The biodiesel then separated out at the top as supernatant and glycerol at the bottom. The glycerol was carefully drained out while the biodiesel was extracted and washed with distilled water and then dried at 100 ^{0}C (Yusuf and Inambao, 2019b).

To determine the % yield of biodiesel from avocado seeds oil, parameters used in this study are avocado seeds oil, oil produced before purification (ml), biodiesel yield after purification (ml), biodiesel yield (g) and biodiesel % oil yield after purification. The expression presented in Eq. 6 shows the % yield of biodiesel from avocado seeds oil.

$$\text{\% yield of biodiesel from avocado seeds oil} = \text{mass of biodiesel (g)/mass of oil (g)} \times 100 \quad (6)$$

2) *Kinematic Viscosity of Avocado Biodiesel*

Avocado biodiesel was poured through one arm of a viscometer and drawn from the opposite arm to fill the bulb, a stopwatch was used to determine the time the biodiesel gets to the top mark and then flow to the bottom mark as well. The kinematic viscosity of extracted avocado biodiesel was determined using a method and an equation applied in an earlier study (Berlamen and Sunil, 2018).

$$kv = t \times K \quad (7)$$

where
kv = Kinematic viscosity
t = Time in seconds = 512 s
K = Viscometer constant = 0.00768
Therefore, the kinematic viscosity of avocado biodiesel, kv = 3.93 centistokes.

C. Extraction of Oil from Jack Fruit Seeds

Similarly, 250 g of ground jack fruit seeds was weighed into a thimble and placed in the Soxhlet extractor mixed with 250 ml of ethanol. The extractor was then subjected to heating for 2 h before the extract was transferred into a rotary evaporator for removal of the ethanol (Yusuf and Inambao, 2019b). The total weight of the ground jack fruit seed used was 2000 g whereas it yielded 210 g. Meanwhile, 20 g of jack fruit seeds oil sample was set aside for further characterization, and percentage oil yield was calculated using Eq. 8

$$\% \text{ oil yield} = \text{weight of oil extracted (g)}/\text{weight of seed (g)} \times 100 \quad (8)$$

1) Kinematic Viscosity of Jack Fruit Biodiesel

Similarly, jack fruit biodiesel was poured through one arm of a viscometer and drawn from the opposite arm to fill the bulb. A stopwatch was used to determine the time the biodiesel gets to the top mark and then flow to the bottom mark. The method and equation used to determine kinematic viscosity of extracted jack fruit biodiesel is akin to that applied in an earlier study (Berlamen and Sunil, 2018), as presented in Eq. 9.

$$kv = t \times K \quad (9)$$

where
kv = Kinematic viscosity,
t = Time in seconds
K = Viscometer constant

D. GC-Analysis

The GC-technique was used in identifying the molecular weight and corresponding structures in avocado and jack fruit seed powders with particle size greater than 90 microns. In GC, the injector temperature was 250 °C, and the initial oven temperature programmed to 80 °C was held for 2 minutes, small volatile was then observed after an increase in temperature to 120 °C at a rate of 5 °C/min. Thereafter, the temperature was doubled to 240 °C at a rate of 10 °C/min and held for 5 minutes. The temperature was then increased to 550-600 °C which allowed the column to dilute all the oil volatile components at a rate of 15 °C/min after it was held for 60 minutes. The GC peaks were identified and compared against standards derived from literature.

3. Results and Discussion

Table 1 depicts the proximate percentage analysis of moisture contents, volatiles, ash, and fixed carbon content of avocado and jack fruits seed powders. The results show that in jack fruit seeds, a high moisture content of 65% was observed, which indicates that the derived biodiesel fuel contains high oxygenated chemical species. Whereas, the fixed carbon content of 11% presented by jack fruit seeds which is 1.0% less than that displayed by avocado seed simply implies that it possesses a high heavy fraction containing the fuel.

Table 1
Proximate analysis of the raw avocado and jack fruit seeds

Parameters	Avocado seed	Jack fruit seed
Moisture (%)	62.5	65
Volatile (%)	23	22
Ash (%)	2.5	2
Fixed carbon content (%)	12	11

Table 2 shows the composition of biodiesel oil combustion by analytical method. The results show higher carbon content in avocado biodiesel oil than jack fruits biodiesel oil. Therefore, Avocado sample oils can serve as potential source of heavy-fuel Asphaltene and other potential petrochemicals such as large aromatic chemicals.

Table 2
Characterization of the extracted seeds oil

Parameters	Avocado seed oil	Jack fruit seed oil
Moisture content (%)	4	4
Volatile (%)	7.8	9.7
Fixed carbon content (%)	88	86
Ash (%)	0.2	0.2
Flash point (°C)	245	250

Table 3 reveals the requisite fuel characteristics for heavy duty fuel engines. In this study, flash point and density of extracted oil was considered. The flash point of jack fruit seed oil is 250 °C while avocado seed oil is 245 °C, which shows that the jack fruit seed oil contains substantial volatiles, highly flammable liquids and gases unlike the avocado seed oil with low flash point. This fact is also corroborated by the fuel densities.

Table 3
Characterization of the biodiesel oil from avocado and jack fruit seeds

Parameters	Avocado seed oil	Jack fruit seed oil
Flash point (°C)	245	250
Density of extracted oil	0.92 g/ml	0.96 g/ml

A. Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

The indexed chromatogram presented in Fig.1 which represents jack fruits volatile species is consistent with the evolution of a range of volatile aliphatic and monocyclic aromatic hydrocarbons (Gray et al., 2011). It was also observed that the jack fruit volatiles contain prominent peaks which are attributed to the alkane-alkene pairs and are thought to arise from alkyl radicals generated by beta-bond scission of long-chain alkyl aromatics. The chromatograms indexed in Fig. 1 are listed as:

1. *Acetic acid*
2. *Furfural*
3. *2(3H)-Furanone, 5-methyl-*
4. *2(5H)-Furanone*
5. *2,4-Imidazolidinedione, 3-methyl-*
6. *1,2-Cyclopentanedione, 3-methyl-*

7. *Phenol, 2-methoxy-*
8. *Phenol, 2-methoxy-4-methyl-*
9. *Phenol, 4-ethyl-2-methoxy-*
10. *2-Methoxy-4-vinylphenol*
11. *Phenol, 2-methoxy-4-(2-propenyl)-, acetate*
12. *Phenol, 2-methoxy-4-(1-propenyl)-*
13. *Benzaldehyde, 3-hydroxy-4-methoxy-*
14. *Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-*
15. *2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)-*

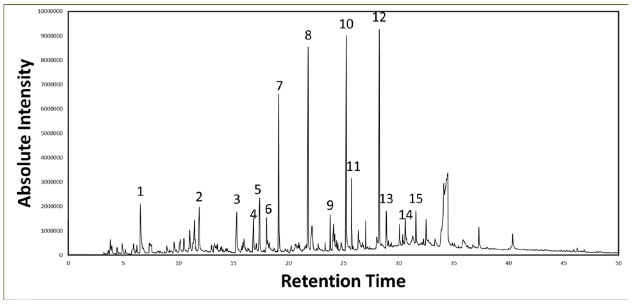

Fig. 1. Jack fruits volatile species

A range of pyrolysis products and oxygenated species including PAH were observed in Fig. 1 and Fig. 2, respectively. Phenolic fragments associated with lignin were also present. It was further discovered that willow bark is also associated with high lignin content as indicated on oxidative pyrolysis which produces benzene, toluene and C-2 benzenes, as eugenol decomposition products which assumes to follow similar route for producing PAH. Pyrolysis temperature has a role to play in terms of volatiles emission during biomass combustion. A temperature range between 500 ^{0}C - 550 ^{0}C was found as the ideal temperature for the volatile release and decomposition products of biomass samples observed in this study. It was further discovered that owing to the high lignin contents of the samples characterized in this study, the pyrolytic products observed in willow bark at 500 ^{0}C are flammable liquid at room temperature, which is an indication of a good source of fast pyrolysis biodiesel oil for power generation.

The series of alkanes/alkenes extended to lower carbon numbers with increasing pyrolysis temperature shown in Fig. 1 were consistent, along with the presence of compounds with ethynyl groups in the side chain, with secondary pyrolysis reactions of the lower temperature products. In addition to the alkanes and alkenes, the primary pyrolysis products of the heavy oil asphaltene detected by GC –MS were aromatic hydrocarbons, especially benzenes, naphthalenes, dihydroindenes and tetrahydronaphthalenes. The presence of these product structures revealed the heavy fraction content of avocado bio-oil, hence can be used to extract alphaltene. Examination of the volatile products by physical investigation and most importantly by Gas Chromatograph, the results shown in Fig. 2 revealed the presence of numerous polycyclic aromatic sulphur compounds (PASH), especially benzothiophens and dibenzothiophens; the latter predominated. Obviously PASH is also heavy fraction fuel and could be a potential source of energy for power generation.

However, similar search revealed the chemical components presented in Fig. 2.

1. *Acetic acid*
2. *Furfural*
3. *Phenol*
4. *Phenol, 2-methoxy-*
5. *Phenol, 2-methoxy-4-methyl-*
6. *Phenol, 4-ethyl-2-methoxy-*
7. *Benzofuran, 2,3-dihydro-*
8. *2-Methoxy-4-vinylphenol*
9. *Phenol, 2,6-dimethoxy-*
10. *Eugenol*
11. *1,2,4-Trimethoxybenzene*
12. *3',5'-Dimethoxyacetophenone*
13. *Phenol, 2,6-dimethoxy-4-(2-propenyl)-*
14. *Phenol, 2,6-dimethoxy-4-(2-propenyl)-*
15. *2,4-Hexadienedioic acid, 3,4-diethyl-, dimethyl ester, (E,Z)-*

In addition, patterns of alkyl group substitution on the benzothiophens and dibenzothiophens shown in Fig. 2 were determined from the avocado biomaterial during GC-Analysis. The prominence of volatile compounds with methyl and phenols is noticeable. However, the same range of compounds identified by MS retention data were shown by GC to be produced during combustion at 500-550^{o}C. The relative proportions of alkyl benzothiophens and dibenzothiophens in the jack fruits oil products was determined from the corresponding GC peaks area using response.

The ashes or fixed carbon content of biomass fuel from combustion scraps were determined by atomic absorption spectrophotometry at 318.5nm on wet acid digestion of these ashes.

Consequently, these volatile compositions were investigated using Py-GC-MS technique on avocado seed powder sample at 400 ^{o}C shown in Fig. 2. More so the resulting chromatogram shows the evolution of a range of volatile n-alkanes and monocyclic aromatic including phenols and light hydrocarbons.

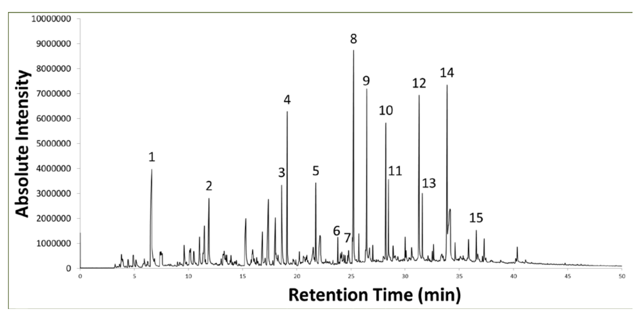

Fig. 2. Structural profile for avocado seed particles

B. Thermogravimetric Analysis (TGA)

The TG-mass loss in Fig. 5 and Fig. 6 shows the start of a major weight loss at 100 ^{o}C, while a temperature of ~ 500 ^{o}C has been employed in analytical pyrolysis experiments (Atiku et al., 2016). The GC-MS chromatograms at 400 ^{o}C and 500 ^{o}C in Fig. 1 and Fig. 2 displays prominent peaks attribute (Atiku, 2015), and large quantities of lower MW alkanes/alkenes were observed, indicating the commencement of dehydration and decarboxylation pyrolysis products, while the series extends to a greater carbon numbers with increase in the pyrolysis temperature of 500ºC. TGA shows significant weight loss arising from the liberation of large volatiles organic components resulting from breaking of the bonds linking the lignin composite as the parent structure in the solid avocado from 400 ºC although the activation energies determined from the TGA curves are considerably smaller, depending on the weight loss region.

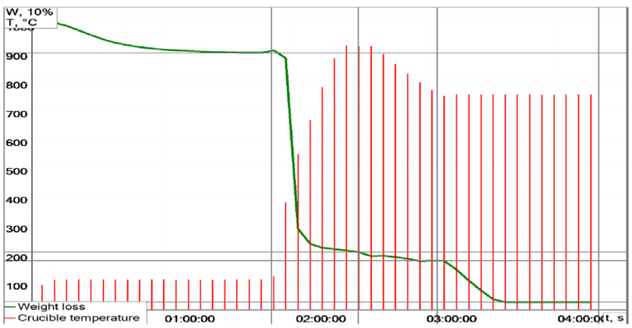

Fig. 3. Thermogravimetric analysis of avocado for volatiles revealing composition during combustion

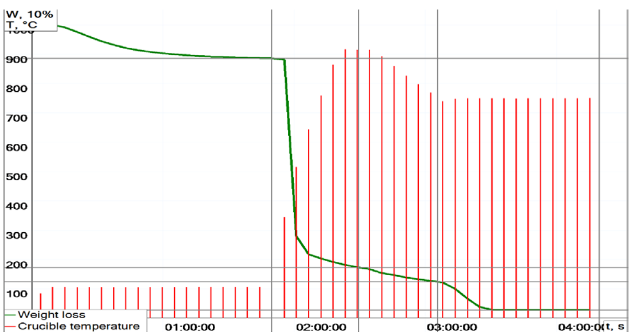

Fig. 4. Thermogravimetric analysis of jack fruit for volatiles revealing composition during combustion

Thermogravimetric analysis (TGA) was applied on the Avocado seed-biomass sample for investigating volatiles. Similarly, kinetic data for processes involving heat losses were derived.

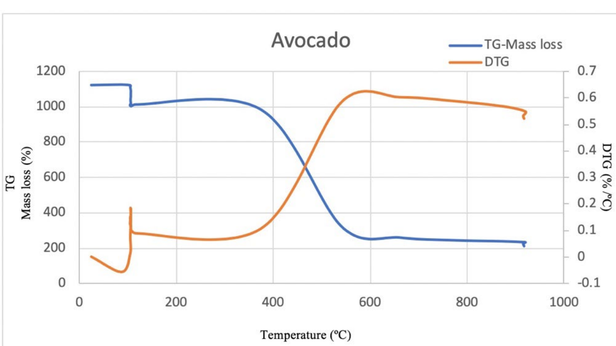

Fig. 5. The TG-mass loss and DTG of avocado

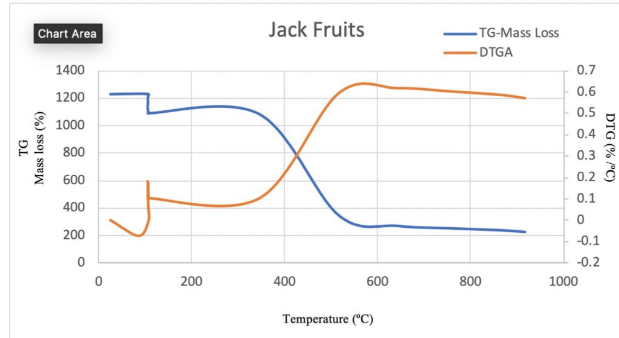

Fig. 6. The TG-mass loss and DTG of jack fruit

4. Conclusion

Gas chromatography-Mass spectrometry (GC-MS) technique enables the characterization and identification of volatile pyrolysis products especially the ignitable ones. Biomass is a mixture of lignin, cellulose, hemicelluloses, and other organic compounds which determine the combustion properties of the biomass, and hence energy content for the fuel-biomass.

GC-MS analysis showed a wide range of oxygenated species such as Phenols, O-PAHs, PAH including acids are key products of the biomass samples under investigation. Temperature and other operating conditions have a significant role for studying the volatile release during combustion of biomass.

Complex organics leading to black carbon formation also detected some of the volatile components observed in this study, evident of good sources of power generation. Hence, power sector fix security issues. This means the fuels can be explored more to generate biodiesel oil and its heavy fraction such as Bio-Asphaltene which could be used in heavy duty engines, transports, boilers and marine engines powering as indicated by GC-MS analyses especially the Avocado seeds.

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