

Comparative Studies on In-situ and Conventional Transesterification of Palm Kernel Biomass for Biodiesel Production

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ABSTRACTS

This study investigated in-situ transesterification of palm kernel biomass at variable reaction time (4h, 5h and 6h), catalyst loading (2wt%, 3wt.% and 5wt.%) and reaction temperatures (30°C, 40°C and 50°C). The biodiesel yields were observed to vary with these parameters. GC/MS analysis showed high fatty acid methyl ester (FAMES) content for all the prepared biodiesel samples (C-18:1, C-14:0, C-16:0, and C-18:0). 2wt.% catalyst loading, 4h reaction time and 50°C reaction temperature were observed to be the best reaction conditions from the experimented parameters that gave the best biodiesel yield at 300rpm mixing intensity. In-situ method records a higher degree of oil extraction and efficient conversion of oil to biodiesel (93.93%) compared to the conventional transesterification method which gave 89.45%. The kinematic viscosity, acid value, and iodine value of 3.96mm²/s, 0.56mgKOHg⁻¹ and 120g100g⁻¹ were found to be within the limits of ASTM D6751-09 and EN14214 standards. These results confirm that an efficient production of biodiesel from palm kernel biomass could be possible through an in-situ acidic transesterification process.

Keywords: biodiesel, fatty acid methyl ester, palm kernel biomass, transesterification H₂SO₄

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1. Introduction

The immense demand of the energy consumption which is of great necessity for human existence and activities in industrialized world today have increased due to increase in population (Ribeiro *et al.*, 2011). Presently, there is depletion in the major sources of non-renewable energy causing climate change and ozone depletion (Atadashi *et al.*, 2011). This has resulted to development of renewable energy sources of limitless duration with a smaller environmental impact than these traditional sources. Examples of renewable energy that have been used include geothermal, biofuels, solar energy, wind, hydrothermal, biomass, biofuels and among others (Marchetti *et al.*, 2007). However, biofuels such as biodiesel is widely used to replace dwindling conventional petroleum diesel without modifying diesel engines since they have similar properties (Simasatitkul *et al.*, 2011, Giwa *et al.*, 2014, 2015a). Its high flash point (150°C), make it less volatile and safer to transport and handle (Kent *et al.*, 2012).

Biodiesel is an important viable alternative transportation fuel which comprises of mono alkyl esters of long chain fatty acids from vegetable oils or animal fats (Mohammed *et al.*, 2008). It is also known as a carbon neutral fuel and a domestic product that reduces the dependence on foreign energy resources and produces jobs for the economy (Fukuda *et al.*, 2001). It enjoys a positive social impact, by enhancing rural revitalization (Anton *et al.*, 2005) and

enhances waste to wealth research. Biodiesel is largely composed of long-chain hydrocarbon groups (with virtually no branching or aromatic structures). It also contains significant amount of oxygen (9%) which makes its combustion efficiency higher than that of petroleum diesel (Kent, 2012).

Previous studies have produced biodiesel from high-oil content agricultural product via transesterification process (Hailegiorgis *et al.*, 2011). This process involves the reaction of an alkyl-alcohol with a long chain ester linkage to yield mono-alkyl esters (biodiesel) and glycerol in the presence or absence of catalyst to chemically break the molecule of triglyceride (Georgogianni *et al.*, 2009c, Gerald *et al.*, 2010). It has been produced from different plant crops such as, coconut, palm oil, soybean oil, jojoba oil, rice bran, sunflower, canola, rapeseed, soybean, sunflower oil; neem oil, pea nut oil and cotton seed oil have been investigation (Sinha *et al.*, 2008, Issariyakul and Dalai 2010, Robles-Medina *et al.*, 2009).

Various alternative fuels such abiogas, producer gas, ethanol, methanol and vegetable oils have been used and still used presently, but biodiesel offers an advantage because of their comparable fuel properties with that of petroleum diesel. Hence, it is renewable and environmentally friendly (Zaher and Gad, 2016). Biodiesel is an oxygenated fuel which is cleaner, and releases less particulate emissions, soot and carbon monoxide than petroleum-based fuel (Aalam and Saravanan, 2015, Selvakumar *et al.*, 2015, Saidat *et al.*, 2016).

These advantages have made the fuel a good environmentally benign one and these have led to its use in many countries, especially in environmentally sensitive areas like Malaysia, Thailand, South Korea, USA, Philippines, Indonesia, China, Australia, Argentina, Malaysia, Brazil, Czech Republic, Germany, France, Italy, Slovakia, Spain etc.

A major challenge to biodiesel commercialization as an alternate fuel to petroleum diesel is the cost of production but can be reduced by increased feedstock supply. This can be achieved by expansion of current agricultural lands or development of new sources of vegetable oils (Demirbas, 2008). To increase the conversion of biodiesel, an alternative method which assists reactions such as in-situ transesterification process was used in this work.

In-situ transesterification therefore facilitates the conversion of the biomass oil to biodiesel directly from the oil bearing biomass by simultaneous extraction and transesterification (Ehimen *et al.*, 2010). In other words, the intact biomass rather than pre-extracted oil directly contact with acidified or alkalinized alcohol that acts as both an extraction solvent and esterification reagent. This process has major advantages of considerable reduced amount of solvent and catalyst and therefore proven to be an efficient and economical method to produce biodiesel compare to conventional route (Johnson and Zhiyou, 2009). It also overcomes the challenges of oil extraction and transesterification process which produce large amount of hazardous solvent waste and are very tedious (Li *et al.*, 2011). However, the overall process of directly producing biodiesel from palm kernel seed by in-situ transesterification via acid catalyst has not been thoroughly investigated.

In this study, biodiesel with good yield was successfully prepared from palm kernel biomass via in-situ transesterification and compared with the yield obtained from the conventional direct transesterification methods. The effect of catalyst loading, reaction temperature and reaction time on the biodiesel yields was also studied

2. Materials and Methods

2.1. Materials

Methanol, hexane, tetraoxosulphate (VI) acid, calcium chloride, sodium thiosulphate, potassium iodide, potassium hydroxide, phenolphthalein solution, starch solution, Wijis solution, distilled water. They were all of analytical grade.

2.2. Biomass and Sample Preparation

Palm kernel seed samples used in this work were obtained from Oluku in Benin City, Edo State, Nigeria. The obtained seeds were screened to remove the seeds with defect, sundried and cracked to obtain the kernel seed. Thereafter, they were washed, sun dried and ground into powder form. It was repeatedly weighed and dried in the oven at 105 °C until a constant weight was achieved.

2.3. In-situ Transesterification Palm Kernel

The in-situ transesterification process was carried out according to (Johnson *et al.*, 2009). In a typical experiment, 120g of palm kernel biomass was placed in a 1L three neck round bottom flask with reflux condenser and mixed with methanolic solution containing sulfuric acid, which was prepared freshly in order to maintain the catalytic activity. N-hexane (95% purity) was added to the methanol and sulfuric acid mixture. The reaction temperature was maintained at 50°C for 4h and a catalyst concentration of 2wt.%.

The reaction mixture was filtered, centrifuged and separated to obtain the biodiesel (fatty acid methyl esters (FAMES)) which was washed with warm distilled water and also dried with calcium chloride. Other biodiesel samples were similarly prepared by varying the reaction parameters at a constant stirring speed of 300 rpm

2.4. Transesterification Reaction of Extracted Oil

The transesterification reaction used to convert the extracted oil into biodiesel was carried out in a 1000mL round bottom flask, as a reactor, fitted with a magnetic stirrer. The experiment was performed at 50°C reaction temperature, 2wt.% catalyst loading and at 4h reaction time. After the reaction, the mixture containing the biodiesel was poured into a separating funnel and allowed to settle for 24h leaving the biodiesel at the top while the unreacted methanol and glycerol were at the bottom of the funnel. The mixture of glycerol and methanol was drained out leaving the biodiesel in the separating funnel to be washed. In order to wash the biodiesel, water of volume twice that of the biodiesel was measured, poured into a separating funnel and allowed to stand for an hour until a clear separation of the two liquids was visible. The water was carefully drained out leaving only the biodiesel in the separating funnel.

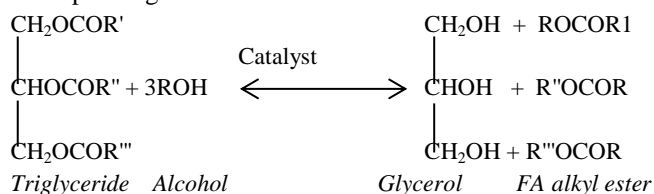


Fig. 1. Transesterification of triglycerides with alcohol

2.5. Characterization Technique

The fatty acid methyl esters (FAMES) in the produced biodiesel were then characterized and identified using GC-MS with a variable split-flow injector (Agilent 7890, Agilent Technologies) coupled with a mass selective detector (mass spectrometer) of 5975 Agilent technologies equipped with a HP5MS Agilent technologies capillary GC column (length 30m, internal diameter 0.320mm, 0.25 mm Agilent HP-5MS column (film thickness 0.25µ). The injector temperature was 250°C and detector temperature was 280°C. The initial column temperature at 80°C, held for 2mins, at 10 °C min⁻¹ to 240°C held for 6 mins before run termination. Helium was used as the carrier gas and column flow was held at 0.5 mL min⁻¹

Table 1: Effect of the reaction process variables on the physiochemical properties of biodiesel produced

Biodiesel characteristics	Catalyst loading (%)			Reaction time (h)			Reaction temperature (°C)		
	2	3	5	4	5	6	30	40	50
Appearance	Light yellow	Light yellow	Light yellow	Light yellow	Light yellow	Light yellow	Light yellow	Light yellow	Light yellow
Acid value mgKOHg ⁻¹	0.56	0.56	0.51	0.56	0.59	0.73	0.51	0.79	0.56
Iodine value g100g ⁻¹	120	119	116	120	122	120	122	118	120
Kinematic Viscosity (at 26°C) mm ² /s	3.96	3.51	2.80	3.96	2.48	2.42	2.55	2.55	3.96

3. Results and Discussion

3.1. Effect of the Reaction Process Variables on the Physiochemical Properties of Biodiesel Produced

Table 2 shows the fuel characteristics of biodiesel synthesized by in-situ transesterification via acid catalyst. The result shows that the acid values of all the prepared biodiesel samples were within the specified limits of ASTM (0.8 max mg KOHg⁻¹) standards. This is an indication that the free fatty acid was completely converted to biodiesel (Anton *et al.*, 2005).

The kinematic viscosity suggests that biodiesel provide sufficient lubrication for the precision fit of fuel injection pumps that will result in decreased wear (Noureddini *et al.*, 1992) while the iodine value measures the degree of unsaturation of the oil (Knothe, 2002). Both values were within the specification by ASTM (1.9-6.0 mm²/s) and Europe's EN 14214 (120 KOHg⁻¹). However, some of the

obtained biodiesel samples gave iodine values that were a bit higher than this standard.

Table 2a-c shows the comparative total-ion chromatogram of all the samples at various catalysts loading. The catalytic performance of hydrogen tetraoxosulphate (vi) (H₂SO₄) at different catalytic loading (2wt.%, 3wt.% and 5wt.%) gave fatty acid methyl ester content with good yield. The FAMES was increased significantly from 96.24% to 97.87% and then to 99.99% as the catalytic loading increased. This may be attributed to high surface area of the catalyst and relatively.

3.2. GC/MS Analysis

GC-MS variation of percentage catalytic loading at 2wt.%, 3wt.% and 5wt.% easy diffusion rate of the reactants in the mesoporous. The influence of catalyst loading on FAME yield was relatively dominant and the acid catalyst (H₂SO₄) used also demonstrated high potential as a catalyst for the production of biodiesel.

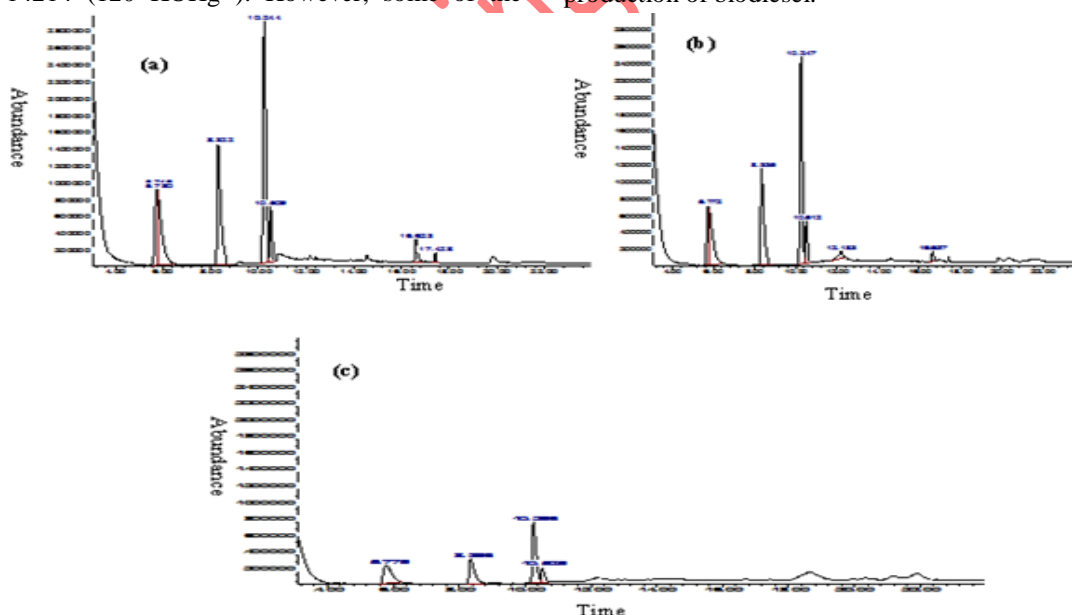


Fig. 2: GC-MS total ion chromatogram at (a) 2wt. % (b) 3wt. % (C) 5wt. %

Table 2a: Detected fatty acid methyl esters at 2wt.% catalyst loading

Name of Fatty acid methyl ester (FAMES)	Retention time (mins)	FAMES yield (%)	Molecular formula	Molecular weight
Methyl tetradecanoate	5.763	28.086	C ₁₅ H ₃₀ O ₂	242
Hexadecanoic acid, methyl ester	8.322	24.534	C ₁₇ H ₃₄ O ₂	270
9-Octadecenoic acid, methyl ester				
(E)-11-Octadecenoic acid, methyl ester	10.244	37.152	C ₁₉ H ₃₆ O ₂	296
Cis-13-Octadecenoic acid, methyl ester				
Methyl Stearate	10.509	6.472	C ₁₉ H ₃₈ O ₂	298

% Total	96.244
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Table 2b: Detected fatty acid methyl esters at 3wt.% catalyst loading

Name of fatty acid methyl ester (FAMES)	Retention time (mins)	FAMES yield (%)	Molecular mass	Molecular formula
Methyl tetradecanoate	5.738	26.386	242	C ₁₅ H ₃₀ O ₂
Hexadecanoic acid, methyl ester	8.335	24.360	270	C ₁₇ H ₃₄ O ₂
9-Octadecenoic acid, methyl ester				
(E)-11-Octadecenoic acid, methyl ester	10.247	39.530	296	C ₁₉ H ₃₆ O ₂
Cis-13-Octadecenoic acid, methyl ester				
Methyl Stearate	10.512	6.596	298	C ₁₉ H ₃₈ O ₂
% Total		97.872		

Table 2c: Detected fatty acid methyl esters at 5wt.% catalyst loading

Name of fatty acid methyl ester (FAMES)	Retention time (mins)	FAMES yield (%)	Molecular weight	Molecular formula
Methyl tetradecanoate	5.775	27.368	242	C ₁₅ H ₃₀ O ₂
Hexadecanoic acid, methyl ester	8.356	23.786	270	C ₁₇ H ₃₄ O ₂
Pentadecanoic acid, 14-methyl ester				
(Z)-9-Octadecenoic acid, methyl ester	10.256	40.034	296	C ₁₉ H ₃₆ O ₂
8-Octadecenoic acid, methyl ester				C ₁₉ H ₃₆ O ₂
(Z)-6-Octadecenoic acid, methyl ester				C ₁₉ H ₃₆ O ₂
Methyl Stearate	10.525	8.811	298	C ₁₉ H ₃₈ O ₂
%Total		99.999		

Therefore, this shows that high FAMES can be achieved using acid catalyzed in-situ transesterification process.

Furthermore, the fatty acid profiling of the biodiesel, obtained at the different variations of catalyst loading (Table 3.2a-c) showed high content of octadecenoic acid methyl ester (C18:1), methyl tetradecanoate (C14:0), hexadecanoic acid methyl ester (C16:0) and methyl stearate (C18:0). The results show that octadecenoic acid methyl ester contain the highest amount of fatty acid methyl ester content of about 37-40% while the lowest content was recorded by methyl stearate (6-8%). The amount of methyl stearate (C-18:0) and octadecenoic acid methyl ester (C-18:1) were found to be highest at 5wt. %

and lowest at 2wt. % respectively. However, 2wt. % shows the highest amounts for methyl tetradecanoate (C-14:0) and hexadecanoic acid methyl ester (C-16:0), whereas 3wt. % has the lowest amount of C-14:0 while 5wt. % recorded the least amount of C-16:0.

The catalytic loading of 2wt. %, 3wt. %, and 5wt. % were all found to contain total saturated fatty acid methyl esters (SAFA) of 59.09%, 57.34% and 55.97% respectively, while the total monounsaturated fatty acids (MUFA) were observed to be 37.15%, 39.53%, and 40.03% respectively. Polyunsaturated fatty acid methyl acid (PUFA) content was not observed.

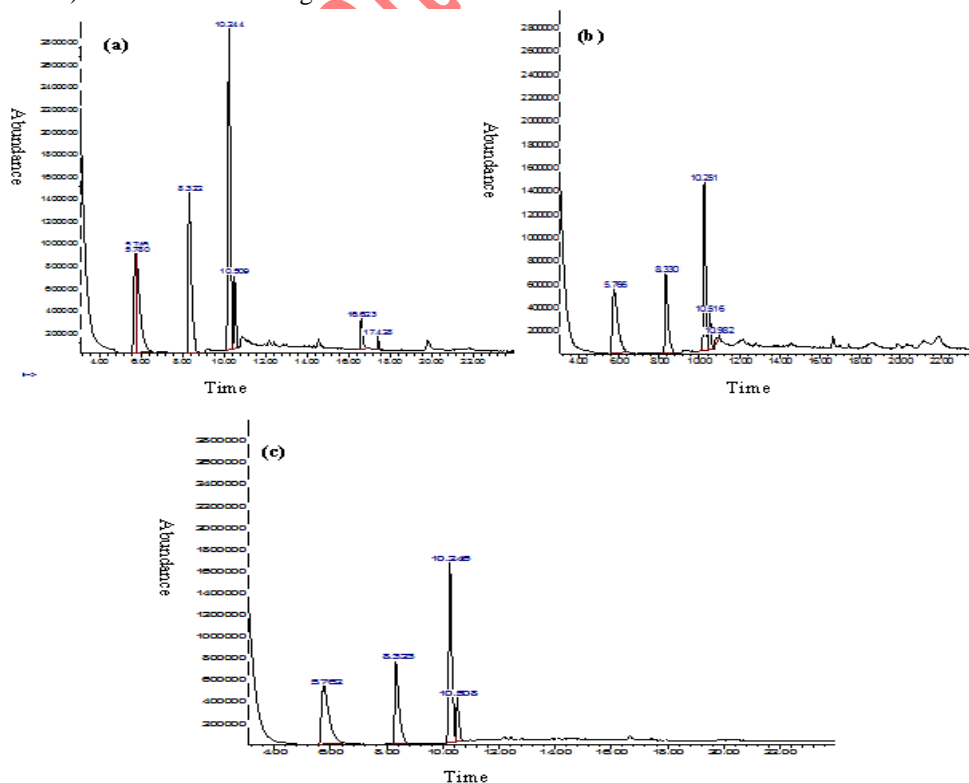


Fig. 3. GC-MS total ion chromatogram at (a) 4h (b) 5h (c) 6h

3.3. GC-MS variation of reaction time at 4h, 5h and 6h

Table 3 (a-c) shows the fatty acid profiling of the comparative total-ion chromatograms at variable reaction times of 4h, 5h, and 6h. The FAME yield increase from 96.88% to 97.85% and then to 99.94% as the reaction time increased. This is an indication that FAME yield increases with increase in reaction time. The results also shows that high content of octadecenoic acid methyl ester (C18:1), methyl tetradecanoate (C14:0), hexadecanoic acid methyl ester

(C16:0) and methyl stearate at the different reaction times. However, low content of 9, 12-octadecadienoic acid methyl ester was recorded at 5h. Octadecenoic acid methyl ester was shown to contain the highest amount of fatty acid methyl ester (34-37.8%) while the lowest amount (1.7%) was found in 9, 12-octadecadienoic acid methyl ester. Although, this observation was seen for the sample prepared using 5hr timing. The highest amount of C-18:0/C-18:1, C-14:0 and C-16:0 were observed at 6hr 5hr and 4hr timing respectively.

Table 3a. Detected fatty acid methyl esters at 4h reaction time

Name of Fatty acid methyl esters (FAMES)	Retention time (mins)	FAMES yield (%)	Molecular weight	Molecular formula
Methyl tetradecanoate	5.746	10.214	242	C ₁₅ H ₃₀ O ₂
Methyl tetradecanoate	5.780	17.872	242	C ₁₅ H ₃₀ O ₂
Hexadecanoic acid, methyl ester	8.322	24.534	270	C ₁₇ H ₃₄ O ₂
9-Octadecenoic acid, methyl ester				
(E)-11-Octadecenoic acid, methyl ester	10.244	37.792	296	C ₁₉ H ₃₆ O ₂
Cis-13-Octadecenoic acid, methyl ester				
Methyl Stearate	10.509	6.472	298	C ₁₉ H ₃₈ O ₂
% Total		96.884		

Table 3b. Detected fatty acid methyl esters at 5h reaction time

Name of fatty acid methyl esters (FAMES)	Retention time (mins)	FAMES yield (%)	Molecular Weight	Molecular formula
Methyl tetradecanoate	5.766	33.012	242	C ₁₅ H ₃₀ O ₂
Hexadecanoic acid, methyl ester	8.330	22.999	270	C ₁₇ H ₃₄ O ₂
(E)-9-Octadecenoic acid, methyl ester				
Cis-13-Octadecenoic acid, methyl ester	10.251	34.406	296	C ₁₉ H ₃₆ O ₂
11-Octadecenoic acid, methyl ester				
Methyl stearate	10.516	6.262	298	C ₁₉ H ₃₈ O ₂
Linoelaidic acid methyl ester	10.904	0.864	294	C ₁₉ H ₃₄ O ₂
9,12-Octadecadienoic acid (Z,Z)- methyl ester	10.982	0.310	294	C ₁₉ H ₃₄ O ₂
% Total		97.853		

Table 3c. Detected fatty acid methyl esters at 6h reaction time

Name of fatty acid of methyl esters (FAMES)	Retention time (mins)	FAMES yield (%)	Molecular weight	Molecular formula
Methyl tetradecanoate	5.762	30.526	242	C ₁₅ H ₃₀ O ₂
Hexadecanoic acid, methyl ester	8.323	23.808	270	C ₁₇ H ₃₄ O ₂
11-Octadecenoic acid, methyl ester				
(E)-9-Octadecenoic acid, methyl ester	10.246	37.870	296	C ₁₉ H ₃₆ O ₂
Cis-13-Octadecenoic acid, methyl ester				
Methyl stearate	10.508	7.797	298	C ₁₉ H ₃₈ O ₂
% Total		99.938		

Table 4a. Detected fatty acid methyl ester at 30^oC

Name of fatty acid of methyl esters (FAMES)	Retention time	FAMES yield (%)	Molecular weight	Molecular formula
Methyl tetradecanoate	5.774	7.451	242	C ₁₅ H ₃₀ O ₂
Methyl tetradecanoate	5.770	15.533	242	C ₁₅ H ₃₀ O ₂
Hexadecanoic acid, methyl ester	8.335	18.708	270	C ₁₇ H ₃₄ O ₂
(E)-9-Octadecenoic acid, methyl ester				
Cis-13-Octadecenoic acid, methyl ester	10.248	27.388	296	C ₁₉ H ₃₆ O ₂
11-Octadecenoic acid, methyl ester				
Methyl stearate	10.525	5.603	298	C ₁₉ H ₃₈ O ₂
Dodecanoic acid, methyl ester	18.436	6.502	214	C ₁₃ H ₂₆ O ₂
Dodecanoic acid, methyl ester	18.682	7.765	214	C ₁₃ H ₂₆ O ₂
Dodecanoic acid, methyl ester	18.707	2.733	214	C ₁₃ H ₂₆ O ₂
Total		91.683		

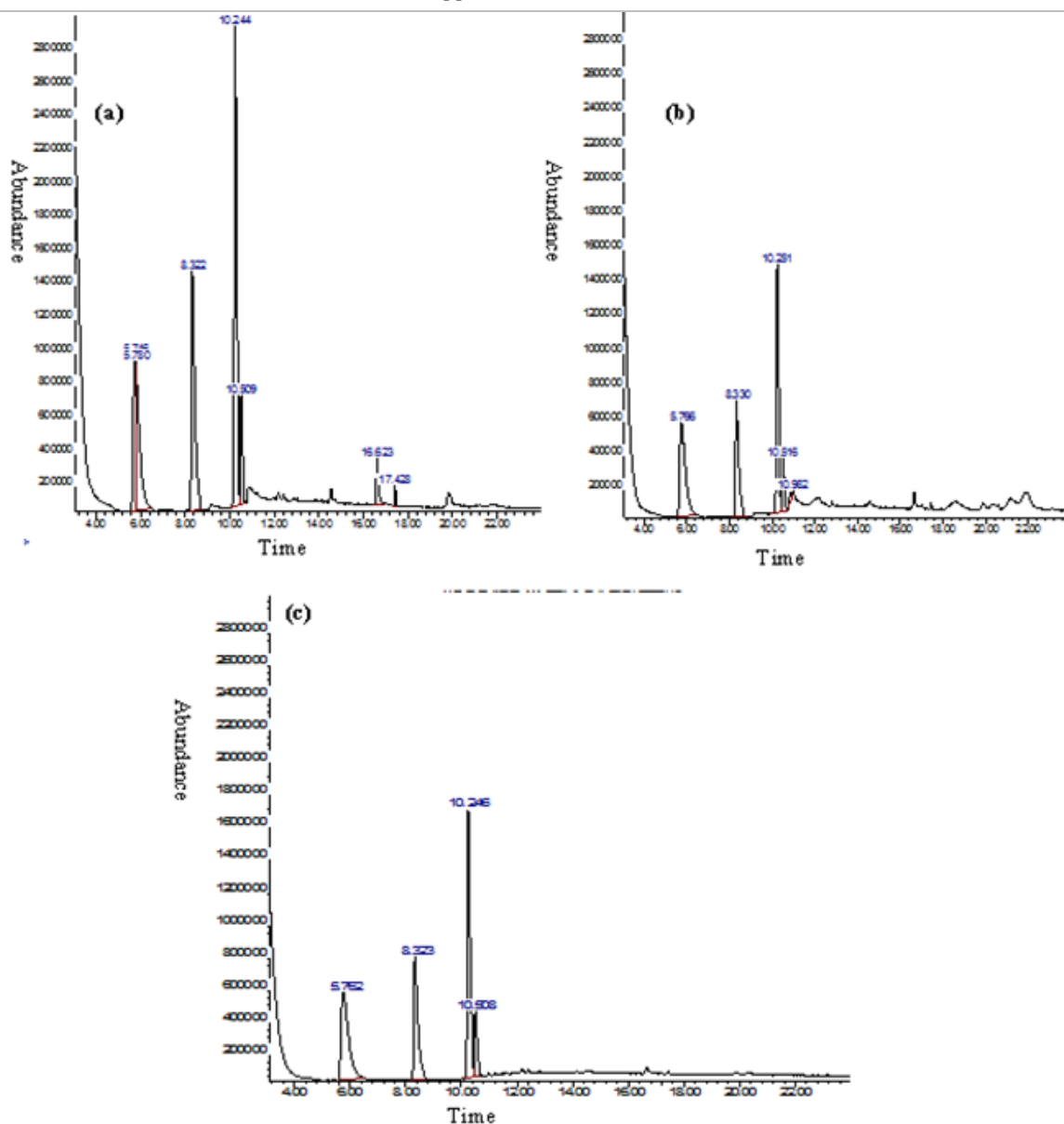


Fig. 4. GC-MS total ion chromatogram at (a) 30 °C, (b) 40°C, (c) 50°C

Table 4b. Detected fatty acid methyl esters at 40°C

Name of fatty acid of methyl esters (FAMES)	Retention time(mins)	FAMES yield (%)	Molecular weight	Molecular formula
Methyl tetradecanoate	5.775	33.369	242	C ₁₅ H ₃₀ O ₂
Hexadecanoic acid, methyl ester	8.335	24.431	270	C ₁₇ H ₃₄ O ₂
(Z)-9-Octadecenoic acid, methyl ester	10.243	35.820	296	C ₁₉ H ₃₆ O ₂
8-Octadecenoic acid, methyl ester	10.506	6.379	298	C ₁₉ H ₃₈ O ₂
Total		99.999		

Table 4. Detected fatty acid methyl ester at 50°C

Name of Fatty acid methyl esters (FAMES)	Retention time (mins)	FAMES yield (%)	Molecular formula	Molecular weight
Methyl tetradecanoate	5.746	10.619	C ₁₅ H ₃₀ O ₂	242
Methyl tetradecanoate	5.780	17.859	C ₁₅ H ₃₀ O ₂	242
Hexadecanoic acid, methyl ester	8.322	24.587	C ₁₇ H ₃₄ O ₂	270
9-Octadecenoic acid, methyl ester	10.244	37.800	C ₁₉ H ₃₆ O ₂	296
(E)-11-Octadecenoic acid, methyl ester	10.244	37.800	C ₁₉ H ₃₆ O ₂	296
Cis-13- Octadecenoic acid, methyl ester	10.244	37.800	C ₁₉ H ₃₆ O ₂	296
Methyl Stearate	10.509	6.674		298
% Total		97.539		

Total saturated fatty acid methyl ester contents (SAFA) of 59.09%, 62.27%, and 62.13% were observed for the varied reaction times (4h, 5h, 6h), the total monounsaturated fatty acid contents (MUFA) were 37.79%, 34.41%, and 37.87% respectively. However, polyunsaturated fatty acid methyl acid (PUFA) content was only observed to be 1.17% for sample prepared using the 5hr reaction time.

3.4. GC-MS variation of reaction time at 30°C, 40°C, 50°C

Table 3.2.3a-c shows the comparative total-ion chromatogram at various reaction temperatures. The GC-MS result shows a slight increase of the FAME yield from 91.68 to 99.99% as the temperature increased from 30 to 40°C. However, a decrease in yield from 99.99% to 97.54% was observed at a temperature of 50°C. This was in agreement with previous study which shown that FAME yield is lower at higher reaction temperatures (Liet *al.*, 2011) than at lower temperature. Moreover, octadecenoic acid methyl ester (C18:1), methyl tetradecanoate (C14:0), hexadecanoic acid methyl ester (C16:0) and methyl stearate (C18:0) were observed at the different reaction temperatures. Fatty acid methyl ester content was higher in Octadecenoic acid methyl ester (27.39-37.80%) and lower in dodecanoic acid methyl ester (16%). At 50°C, C-16:0, C-18 and C-18:1 were also observed to be predominant at 40 °C, at 30°C, C-14:0, C-16:0, C-18:0, and C-18:1 were the lowest. The total saturated fatty

acid methyl esters (SAFA) that were observed at the different reaction temperatures (30°C, 40°C, 50°C) are 63.30%, 64.18%, 59.74%, while the total monounsaturated fatty acid (MUFA) were 27.39%, 35.80%, and 37.80% respectively. Polyunsaturated fatty acid methyl acid (PUFA) content was also not observed.

3.5. GC/MS of conventional direct transesterification method

Table 5 shows the total-ion chromatogram that was obtained using conventional direct transesterification method at 2wt. %, 4h, and 50°C. The Identified peaks of the fatty acid methyl esters and their relative percentages are summarized in the Table. The FAMEs yield obtained was 97.35% High content of dodecanoic acid methyl ester (C10:0), methyl tetradecanoate (C14:0), octadecenoic acid methyl ester (18:1), hexadecanoic acid methyl ester (C16:0) and low content of methyl stearate were also observed using the conventional direct transesterification method. This observation is similar to the results obtained from the in-situ method. Dodecanoic acid methyl ester is shown to contain the highest amount (48.10%), while methyl stearate contains the lowest amount (3.54%). The total saturated fatty acid methyl esters (SAFA) observed was 88.34%, while the total monounsaturated (MUFA) were 27.39%, 35.80%, and 37.80% respectively. Polyunsaturated fatty acid methyl acid (PUFA) content was not observed.

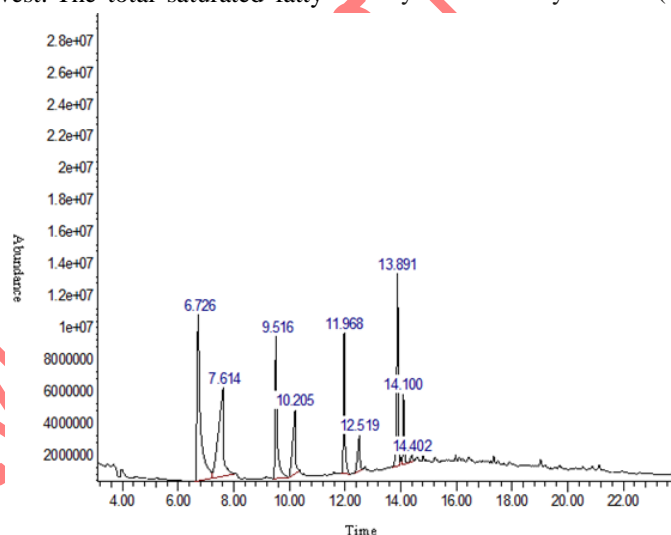


Fig. 5. GC-MS total ion chromatogram of fatty acid methyl ester by conventional method

Table 5. Detected fatty acid methyl esters by conventional method

Name of fatty acid of methyl esters (FAMEs)	Retention time	FAMEs yield (%)	Molecular weight	Molecular formula
Dodecanoic acid, methyl ester	6.726	26.019	214	C ₁₃ H ₂₆ O ₂
Dodecanoic acid, methyl ester	7.614	21.080		
Methyl tetradecanoate	9.516	13.538	242	C ₁₅ H ₃₀ O ₂
Methyl tetradecanoate	10.205	8.297		
Pentadecanoic acid, 14-methyl ester	11.968	9.147		C ₁₇ H ₃₄ O ₂
Hexadecanoic acid methyl ester	12.519	3.707	270	
(Z)-9-Octadecanoic acid, methyl ester				
(Z)-11-Octadecanoic acid, methyl ester	13.891	12.026	296	C ₁₉ H ₃₆ O ₂
7-Octadecanoic acid, methyl ester				
Methyl stearate	14.100	3.537	298	C ₁₉ H ₃₈ O ₂
Total		97.351		

Table 6. Summary of the product analysis at 2wt. %, 50°C and 4h by in-situ and conventional direct transesterification method

Yield%	In-situ method	Conventional method
Volume yield	96.96	91.89
FAME yield	96.88	97.35
Biodiesel yield	93.93	89.45

3.6. Characteristics of the FAMES from palm kernel

It was found that most predominant FAMES in process variables carried out were C-14:0, C-16:0, C-18:0, and C-18:1. The order of the most abundant fatty acids methyl ester are C18:1>C14:0>C16:0>C18:0. These results showed good agreement with the lipid compositions from palm kernel that contained higher amounts of saturated fatty acids and mono-unsaturated fatty acid methyl esters. These results revealed that most of the fatty acids in the biomass were transesterified to make FAME as a biodiesel through process. Moreover, this result implied that FAME from palm kernel biomass had better quality of biodiesel. Generally, the conventional and in-situ transesterification attained the maximum FAMES yield (96%) according to ASTM standard. The volume yield obtained for in-situ and conventional transesterification were 96.96% and 91.89% respectively. Comparison of biodiesel production of palm kernel biomass using in-situ and conventional transesterification as presented in Table 3.4.

The results suggest that in-situ is better than the conventional transesterification method because the volume and FAMES yield of palm kernel biodiesel is higher (93.93%) compared to the conventional method (89.45%). Furthermore, in-situ transesterification is much faster approach as the oil-bearing material contacts acidified alcohol directly instead of reacting with purified oil and alcohol compared to conventional method which requires rigorous extraction of oil before transesterification. In-situ method requires lower methanol requirement, and minimal number of process equipment. Thus, comparison of the cost of the two production processes of biodiesel shows that in-situ transesterification is far better than conventional method as it is more cost effective.

4. Conclusion

This study has successfully showed that biodiesel can be obtained from palm kernel biomass via in-situ transesterification process with fuel properties that are within ASTM standard. Higher yield of biodiesel can be achieved by acid catalyzed in-situ transesterification of palm kernel compared to the conventional transesterification. Variation in catalyst loadings, reaction times and temperature leads to variations in the biodiesel yields that were obtained from the palm kernel biomass. Catalyst loading of 2wt%, reaction time of 4h and 50°C reaction temperature were found to give the better biodiesel yield.

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Conflict of interest: Non declare

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