Physicochemical Characterization of Candlenut (Aleurites moluccana)-derived Biodiesel Purified with Deep Eutectic Solvents

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Abstract: A high-oil candlenut (Aleurites moluccana)-derived biodiesel was purified using new generation solvents called Deep eutectic solvents (DESs) and physicochemical properties of the purified biodiesel were assessed according to the accepted international standards for biodiesel (ASTM D6751; EN 14214). Binary and ternary choline chloride-based DESs containing glycerol and ethylene glycol as hydrogen bond donors were synthesized. The results of the investigation showed that the quality of DESs-purified biodiesel generally improved compared with the unpurified biodiesel and fulfilled the accepted standard limits for biodiesel except carbon residue and oxidation stability properties. Choline chloride/ethylene glycol (ChCl/Eg, 1:2 molar ratio) having a DES/biodiesel ratio of 1:1 (DES2-11) has enhanced the Fatty Acid Methyl Ester (FAME) content of unpurified biodiesel from 81.89% to 98.13%, and the oxidation stability from 2.36 h to 3.06 h. 'H NMR examination showed the successful synthesis of DESs; GC-MS analysis of candlenut oil and its biodiesel revealed oil and fatty acid methyl ester compositions, respectively. The similarity in FAME compositions between DESs-purified and unpurified biodiesel as revealed through GC-MS examination suggests the selective removal of impurities and the efficiency of DESs in improving the quality of candlenut-derived biodiesel.

Key words: candlenut biodiesel, direct acid-base catalysis, fatty acid methyl ester (FAME), deep eutectic solvents (DESs), physicochemical characterization

1 Introduction

The global demand for fossil fuel which is triggered by rapid technological advancement and population upsurge has grown exponentially for the past decades. It is predicted that by the year 2050, with population close to 9 billion or more, the expanding world’s economy will demand for greater energy consumption, with India and China getting a large share not only of the energy cost but also of the bulk of contaminants inherent in the utilization of fossil fuels.

The rising concern on environmental incompatibility of fossil fuels due to excessive CO2 emissions has led to a continuous search for fossil fuel alternatives. Biodiesel is one of the fossil fuel substitutes or additives that has caught attention for the past years because of its close property to petroleum fuel, but with good environmental compatibility such as biodegradability, carbon neutral, low COx, and SOx emissions. Because of the high oxygen and low sulfur contents of biodiesel, it has the advantage of releasing low SOx gases and enhancing lubricity, thus preventing engine damage.

Biodiesel is synthesized via transesterification reaction of oil or fat with a small chain alcohol such as methanol in the presence of an acid, base, or enzyme catalyst. The main reactant can be obtained from edible sources such as coconut, soybean, palm, used vegetable oil, animal fat or from non-edible material such as jatropha, algae, and rubber seeds. Nowadays, extensive researches focused on the use of non-edible oil because of food security issue.

One of the most convenient methods of synthesizing biodiesel is through acid or base catalyzed reaction which is usually followed by wet washing to remove impurities. However, this purification process is not quite attractive as this technique generates large volumes of wastewater and may retain residual water and partially hydrolyzed triglycerides in the biodiesel, thus lowering biodiesel efficiency.

New generation solvents called ionic liquids (ILs) and
deep eutectic solvents (DESs) are gaining much attention in the field of synthesis, electrochemistry, and separation science due to their tunable properties. These are ionic substances which at a certain molar ratio exhibit a very strong ionic or hydrogen bond interaction resulting into a liquid with low boiling point. DESs are gaining popularity over ILs because of their less toxic property and biodegradability. In 2007, Abbott et al. successfully separated glycerol impurity from biodiesel at ambient temperature using DESs composed of quaternary ammonium salt as hydrogen bond acceptor (HBA) and glycerol as hydrogen bond donor (HBD).

The main objective of this investigation is to conduct physicochemical characterization of DESs-purified candle-nut-derived biodiesel. Choline chloride-based DESs with glycerol and ethylene glycol as hydrogen bond donors were used in the study. Fuel suitability of the purified biodiesel was assessed according to the international standards for biodiesel (ASTM D6751; EN 14214).

Candlenut (Aleurites moluccana) commonly known as lumbang in the Philippines is a tropical tree belonging to the genus Aleurites, family Euphorbiaceae. The tree can grow up to a height of 10-15 m. This biofeedstock can produce 30-80 kg of nuts per tree and the seeds can yield 50-60% of nonedible, semi-drying oil. Because of its high oil content, candlenut is a promising biodiesel feedstock.

2 Materials and Methods

2.1 Materials

Candlenut kernels were harvested from the College of Forestry, University of the Philippines at Los Banos, Laguna, Philippines. DESs reagents (choline chloride, glycerol, and ethylene glycol) were purchased from Sigma Aldrich. The reagents were dried for 6 h before being used. Solvents and Catalysts (H2SO4, NaOH, methanol, and hexane (ACS grade) were purchased from Merck. Reagents were utilized without further purification.

2.2 Extraction of candlenut oil

After removing the shells, candlenut kernels were ground and dried at 100°C for 3 h. Soxhlet extraction process was utilized with hexane as the extracting solvent. Ground candlenut (50.00 g) was placed in a thimble before it was introduced into the soxhlet extractor containing 250 mL hexane. Extraction with hexane at 68°C lasted for 3 h. The oil-hexane mixture was filtered before isolating the oil from the extracting solvent by vacuum evaporation.

2.3 Synthesis of candlenut biodiesel

Candlenut biodiesel was synthesized by direct acid-base catalyzed reaction. The acid-catalyzed step was done by mixing candlenut oil and methanol in a 4:1 molar ratio in the presence of 0.700 wt. concentrated H2SO4 relative to the mass of the oil. The mixture was stirred at 400 rpm while being heated at 65°C for 2 h. Without separating the glycerol layer, the base-catalyzed reaction commenced by first neutralizing the acid-catalyzed reaction with NaOH before the mixture was amended with 25 mL methanol containing 0.500 wt. NaOH relative to the weight of the oil. The final solution was heated further under reflux for another 2 h. After allowing the reaction mixture to settle overnight, the biodiesel was separated from the glycerol layer using a separatory funnel.

2.4 Synthesis of binary and ternary DESs

Choline chloride/glycerol DES was prepared in a 1:2 molar ratio. This was prepared by mixing 34.905 g choline chloride with 46.046 g glycerol in a 250-mL Erlenmeyer flask. The resulting mixture was stirred at 300 rpm and heated at 80°C until a clear, homogeneous liquid was formed. For the choline chloride/ethylene glycol DES, a 1:2 molar ratio was prepared by mixing 69.810 g of choline chloride and 46.046 g of ethylene glycol.
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chloride with 62.070 g of ethylene glycol. The same reaction condition was employed until a clear solution was formed. Ternary DES system was prepared in a 1:2:2 choline chloride/glycerol/ethylene glycol molar ratio. With the same reaction condition, a clear solution was formed containing 34.905 g choline chloride, 46.047 g glycerol and 31.035 g ethylene glycol. Formation of DES was confirmed through $^1$H NMR (Bruker AVANCE II spectrometer) which was operating at 300 MHz. With $D_2O$ taken as the internal standard, the chemical shifts were reported in parts per million (ppm).

2.5 Purification of biodiesel with binary and ternary DESs

Crude biodiesel was purified with the different DESs in DES/biodiesel molar ratios of 1:1 and 2:1. For choline chloride/glycerol DESs ($\text{ChCl/Gly,1:2}$), these were labeled as DES1-11 and DES1-21 for DES/biodiesel ratios of 1:1 and 2:1, respectively. Similarly, choline chloride/ethylene glycol DESs ($\text{ChCl/Gly,1:2}$) were labeled as DES2-11 and DES2-21.

For the ternary system, choline chloride/ethylene glycol DESs ($\text{ChCl/Gly/Eg,1:2:2}$) were labeled as DES3-11 and DES3-21 for the DES/biodiesel ratios of 1:1 and 2:1, respectively. Each DES-biodiesel mixture was stirred at 300 rpm at 30°C for 4 h. With a settling time of 2 h, the purified biodiesel was separated from the DES layer.

2.6 GC-MS analysis of candlenut oil and purified candlenut biodiesel

GC-MS analysis (Shimadzu GCMSQP2010 with AOC-20i auto injector) was done on both oil and biodiesel sample. A 0.100 g sample was dissolved in 10 mL hexane and then 0.10 μL was injected under splitless mode condition. A carrier gas (He, 57.5 kPa) with a flow rate of 1.0 mL/min was allowed to pass through a column (Rxi-5MS, 0.25 mm $\times$ 30 m $\times$ 0.25 μm). The oven temperature was initially set at 60°C (0.5 min) and then ramped to 300°C at 5°C/min. The mass spectrometer was operated under electron impact mode (ion source temperature, 230°C; interface temperature, 250°C) and with a scanning speed of 2500 and scanning range of 50-650 m/z.

2.7 Physicochemical characterization of candlenut biodiesel

Physicochemical analysis of purified and unpurified biodiesel was conducted at the Department of Energy, Philippines, utilizing the specified methods of measurements (ASTM D6751; EN 14214): Acid number (ASTM D664, OMNIS Titrator); Density (ASTM D4052, Anton Paar DMA™ 4500 M Density Meter); Flash point (ASTM D93, PAC HFP 339-Automatic Closed Cup Pensky-Martens Flash Point Analyzer); Methanol (EN 14110, Shimadzu GC-2010 Gas Chromatograph); Sulfated Ash (ASTM D 874, Fisher Scientific Muffle Furnace); Water (ASTM D6304, KEM Karl Fischer Moisture Titrator MKA-610-ST); Carbon residue (ASTM D4530, PAC-Herzog OptiDist; Atmospheric Distillation); FAME (DOE TM 01, Shimadzu GC-2014 Gas Chromatograph); Total glycerin (EN 14105, Shimadzu GC-2014 Gas Chromatograph); Kinematic viscosity (ASTM D445, Koehler™ Instrument KV5000 Kinematic Viscosity Bath); Oxidation stability (EN 14112, Metrohm 873 Biodiesel Rancimat®); Sulfur (ASTM D7039, Sindie 2622-10 Sulfur Analyzer®); Water and Sediments (ASTM, D2709, Koehler™ Instrument Oil Test Centrifuge).

3 Results and Discussion

3.1 Biodiesel synthesis and DESs purification

Candlenut generated about 56% of bright-yellow oil upon extraction with hexane for 3 h (Fig. 3). Candlenut oil contains high free fatty acids (6-15%) which can lead to soap formation under base-catalyzed process; thus, a direct acid-base protocol was performed.

Initially, candlenut oil was mixed with methanol in a 4:1 molar ratio in the presence of 0.700% wt. $\text{H}_2\text{SO}_4$ relative to the weight of oil. The solution was stirred (300 rpm) and heated under reflux at 65°C for a period of 2 h. This resulted in the formation of a viscous yellowish solution (Fig. 4A). After cooling the reaction mixture to room temperature, the base-catalyzed step was initiated with the addition of 25 mL alcoholic NaOH (0.250% wt. NaOH relative to the weight of oil) and refluxed at the same reaction condition for another 2 h; a bright-yellow mixture was observed (Fig. 4B).
Ultimately, the crude biodiesel (Fig. 4C, upper layer) was separated from glycerol (Fig. 4C, lower layer) using a separatory funnel.

One of the major problems encountered in the utilization of biodiesel as a petrodiesel substitute or additive is the recurrence of impurities which can lower biodiesel efficiency. This problem arises due to the limitation of the synthetic process such as the reversibility of acid-catalyzed reaction and the formation of soap in base-catalyzed process. This problem if not resolved would lead to combustion engine deterioration.

In the present investigation, we used a new generation solvent called deep eutectic solvent (DES) which has the prospect of improving the purity of biodiesel. Three deep eutectic solvent systems were prepared; 2 binary systems composed of choline chloride/glycerol DES (1:2 molar ratio) and choline chloride/ethylene glycol DES (1:2 molar ratio) and one ternary system composed of choline chloride/glycerol/ethylene glycol DES (1:2:2 molar ratio).

Figure 5 presents the preparation of DES2-11 (ChCl/Eg, 1:2) and the extraction of biodiesel impurities. After 5 min of mixing (300 rpm), a cloudy viscous emulsion was formed (Fig. 5A) but the mixture turned into a clear solution after 15 min of mixing and heating at 80°C (Fig. 5B). DES2 (ChCl/Eg) was used to purify crude biodiesel (Fig. 5C) in a 1:1 DES/biodiesel ratios (DES2-11) which resulted to the formation of a transparent yellow biodiesel liquid (upper layer) and an opaque DES (lower layer) (Fig. 5D). This suggests that some impurities were removed from the biodiesel layer. Similar results were obtained using the other prepared DESs but with varying extraction efficiencies.

3.2 $^1$H NMR analysis of DESs

The $^1$H NMR presented in Fig. 6 depicts the spectra of choline chloride/ethylene glycol (DES2-11), choline chloride, and ethylene glycol. Ethylene glycol exhibited a singlet peak at 3.626 ppm attributed to the equivalent methylene proton resonance. Choline chloride exhibited a singlet peak which appeared at 3.169 ppm, the resonance proton peak of the three equivalent methyl groups attached to nitrogen. The ethanolic moiety of choline chloride showed two methylene resonance peaks; one at 3.487 ppm (triplet) and the other at 4.029 ppm (quartet). In the case of DES2-11 (ChCl/Eg, 1:2) $^1$H NMR resonance peaks were observed at 4.0315 (quartet), 3.6375 ppm (singlet), 3.4920 ppm (triplet), and 3.1740 ppm (singlet). Choline chloride/ethylene glycol DES2-11 produced separate peaks that were slightly displaced downfield with respect to those in their individual spectra, implying hydrogen interactions between choline chloride (ChCl) and ethylene glycol (Eg), the latter being the donor species. The characteristic signals of the hydroxymethylene (4.0295 ppm), the methylene (3.4870 ppm), and the methyl (3.1690 ppm) protons of ChCl shifted downfield to 4.0315, 3.4920 and 3.1740 ppm, respectively while the singlet peak of the methylene protons of Eg was displaced downfield from 3.6260 ppm to...
Fig. 6  $^1$H NMR spectra of choline chloride/ethylene glycol DES (ChCl/Eg, DES2-11), choline chloride (ChCl) and ethylene glycol (Eg).

Fig. 7  GC-MS spectra of candlenut oil (I) and DES2-11 (ChCl/Eg, 1:2) -purified biodiesel (II).
3.3 GC-MS of candlenut oil, unpurified, and DESs-purified biodiesel

GC-MS profiles of candlenut oil and its corresponding biodiesel are presented in Fig. 7. Relative to the GC-MS profile of candlenut oil depicted in Fig. 7-I, the number of peaks for biodiesel (Fig. 7-II), which corresponds to the number of fatty acid methyl esters (FAME), decreased. Other hexane-soluble components in candlenut oil were not detected in the GC-MS spectrum of candlenut biodiesel, implying that those compounds that have not undergone transesterification may have been retained in the glycerol layer. Unsaponifiable lipids such as sterols (peaks 25, 28, and 29), squalene (peak 23) and siloxanes (peaks 4, 10, 20, and 21) were detected in the GC-MS of oil. Similar results were observed in other vegetable oil feedstocks.

Comparison of FAME profiles of unpurified and DES2-11-purified biodiesel revealed small differences in their compositions (Table 1). All FAME compounds in unpurified candlenut biodiesel, except for myristic acid and 2-hexylcyclopropaneoctanoic acid methyl esters, were retained in the DES-purified biodiesel sample. Both samples (unpurified and DES-purified) exhibited similar percentage compositions of fatty acids with the unsaturated fatty acids, linoleic acid (38.23%) and docosatrienoic acid (50.06%) dominating the fatty acid compositions of candlenut; their mass spectra were presented as methyl esters in Fig. 8. Similar fatty acid profiles were obtained with the other DESs-purified biodiesel. The dominance of unsaturated fatty acids in candlenut confirms the high degree of unsaturation exhibited by this biofeedstock as measured analytically by its iodine number. Increase in the number of double bonds enhances fuel efficiency due to lowering of kinematic viscosity; however, it could also lower the oxidation stability of the biodiesel. This problem can be remedied by adding either an antioxidant or blending the biodiesel with petrodiesel. The retention of the FAME profiles in purified biodiesel suggests that DES serves solely as a purifying solvent which removes unwanted impurities in biodiesel such as excess reactants, catalysts, free and bound glycerins.

3.4 Physicochemical analysis of DESs-purified and unpurified candlenut biodiesel

To determine if purified candlenut biodiesel relative to the unpurified biodiesel would yield results more suitable for meeting the standards of biodiesel (ASTM D6751; EN 14214), physicochemical analyses for both samples were done. The results are presented in Table 2 and Figs. 9-16.

Initial analysis of the candlenut oil showed an acid number of 11.97 (mg KOH/g oil) but this value went below the maximum limit (0.50 mg KOH/g oil) set by the international standard (ASTM D6751; EN 14214) upon transesterification of the oil. There was a slight increase in acid number in all DESs-purified samples over that of unpurified biodiesel.

Triglycerides of glycerol which are called oil or fat have high viscosity and if used directly as fuel may cause damage to any combustion engines; but viscosity can be lowered by transesterification of oil or fat with short chain alcohol in the presence of a suitable catalyst to form Fatty Acid Methyl Ester (FAME) called biodiesel.

3.4.1 Fatty Acid Methyl Ester (FAME) of Candleanut-Derived Biodiesel

Results of the analysis (Fig. 9) showed an improvement in FAME from 81.89% (unpurified biodiesel) to a value greater than 90.00% (purified biodiesel) except DES1-21 (89.00%) and DES3-21 (75.22%); however, only DES2-11 (98.13%) passed the standard limit (96.50%).

3.4.2 Total Glycerides Content

Total glycerides, which account for both free and bound

| Table 1 | Fatty acid compositions of unpurified and DESs-purified candlenut biodiesel. |
|---------|--------------------------------------------------------------------------------|
| % Composition Fatty Acid | Unpurified Biodiesel | DES2-11-Purified<sup>‡</sup> Biodiesel |
| Myristic Acid | 0.04 | ND<sup>§</sup> |
| Palmitic Acid | 7.28 | 7.18 |
| Linoleic Acid | 38.23 | 38.03 |
| 8,11,14-docosatrienoic acid | 50.06 | 50.45 |
| Stearic Acid | 3.58 | 3.59 |
| 2-hexyl-cyclopropaneoctanoic acid | 0.55 | ND<sup>§</sup> |
| 14/15-methylhexadecanoic acid | 0.10 | 0.10 |

<sup>‡</sup>DES2-11 = choline chloride/ethylene glycol DES (1:2 molar ratio) with DES/biodiesel ratio of 1:1; <sup>§</sup>ND = not detected.
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Fig. 8  GC-MS spectra of 9,12-octadecadienoic acid (linoleic acid) methyl ester (I) and 8,11,14-docosatrienoic acid methyl ester (II).

Table 2  Physicochemical properties of unpurified and DESs-purified candlenut biodiesel.

| Analysis            | Limit | UP a | DES1 Purified | DES2 Purified | DES3 Purified |
|---------------------|-------|------|---------------|---------------|---------------|
| DES/Biodiesel       |       |      | 1:1 | 2:1 | 1:1 | 2:1 | 1:1 | 2:1 |
| Molar ratio         |       |      |     |     |     |     |     |     |
| Acid No. mg KOH/g oil | 0.500 | 0.031 | 0.140 | 0.121 | 0.122 | 0.140 | 0.110 | 0.072 |
| Viscosity (40°C, mm²/s) | 2.00-4.50 | 4.473 | 3.688 | 3.592 | 3.649 | 3.764 | 3.686 | 4.107 |
| Methanol, % v/v     | 0.200 | UD b | UD | UD | UD | UD | UD | UD |
| Water, % v/v max    | 0.050 | 0.023 | 0.036 | 0.031 | 0.031 | 0.035 | 0.027 | 0.024 |
| Water and sediments (% v/v max) | 0.050 | 0.025 | 0.025 | 0.024 | 0.025 | 0.024 | 0.023 | 0.040 |

a unpurified; b undetected; DES1 = choline chloride/glycerol DES (ChCl/Gly); DES2 = choline chloride/ethylene glycol DES (ChCl/Eg); DES3 = choline chloride/glycerol/ethylene glycol DES (ChCl/Gly/Eg).

Fig. 9  Percent Fatty Acid Methyl Ester (FAME) in unpurified and DESs-purified candlenut biodiesel.

Fig. 10  Percent total glycerins in unpurified and DESs-purified candlenut biodiesel.
glycerins \(^{38}\), were obtained with a value of 0.54% wt. in unpurified biodiesel (Fig. 10). This value is above the maximum standard limit of 0.24% wt. However, for DESs-purified biodiesel the total glycerides were significantly reduced; with DES1-21 and DES2-11 giving the lowest value of 0.06% wt., and DES3-21 showing the highest value of 0.24% wt. Glycerin impurities, if not removed, could generate toxic substances upon combustion such as carbon particulates and acroleins \(^{39}\).

### 3.4.3 Viscosity and Density Properties

Viscosity and density properties, which account for the fluidity of biodiesel, were also assessed to gage biodiesel efficiency (Table 2). The density obtained for both unpurified and DESs-purified biodiesel passed the density standard limit (0.860-0.900 kg/L) (Fig. 11). Similar results were obtained for viscosity; however, a significant drop in viscos-
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ity values was observed in DESs-purified than in unpurified biodiesel. High density of the biodiesel causes stratification especially for mixed fuel and affects cetane number and heating value of the fuel. Biodiesel with high viscosity and density may damage injection pump system due to fuel starvation in some injection pipelines. In addition, biodiesel with high density would result to larger droplet sizes during atomization leading to excessive release of unburned hydrocarbons.

Candlenut biodiesel has lower viscosity compared to other biofeedstock sources because of its high degree of unsaturation. One technical advantage of biodiesel over petrodiesel is its high molecular weight, oxygen content, and unsaturation which can enhance lubricity thus protecting fuel injectors and pumps from damage.

3.4.4 Flash Point of Candlenut-Derived Biodiesel

Flash point is the lowest temperature at which fuel's vapor ignites and it measures the storage stability and safety of the fuel. Biodiesel generally exhibits higher flash point than conventional diesel. All values for both purified and unpurified biodiesel surpassed the minimum standard limit (100°C), deeming the biodiesel products safe for storage and transportation. The values obtained ranged from 166-183°C (Fig. 12). Flash point value may decrease especially if methanol impurity is not removed. In the assessment of methanol (Table 2) the impurity was not detected suggesting that it was completely removed during vacuum distillation.

3.4.5 Sulfur Content

One of the advantages of biodiesel over petrodiesel is its low sulfur content. Sulfur analysis was conducted in biodiesel purified by binary DESs (Fig. 13) and one would notice that both purified and unpurified biodiesel passed the maximum standard limit (10 ppm) with DES1-11 exhibiting the lowest value (2 ppm) same as the unpurified biodiesel. Sulfur can cause corrosion of the combustion engine especially if the fuel has high moisture content. When biodiesel undergoes combustion, sulfur can be oxidized to SOx gases causing various environmental disturbances such as smog formation, acid rain and ozone depletion.

From Table 2, one would notice that water content of both purified and DESs-purified biodiesel is below the maximum limit (0.05% v/v). Under acidic condition, water can initiate hydrolysis of the biodiesel leading to the formation of fatty acids that would cause fouling and engine corrosion.

3.4.6 Carbon Residues

Carbon residues which are mostly composed of carbon ash and soot are pertinent properties measured to assess biodiesel performance. These residues would affect engine operation particularly on the critical component of the engine such as the piston, cylinder head and the injector. The carbon residue values for both DESSs-purified and unpurified biodiesel exceeded the standard limit (0.3% wt.); however, DESs were able to lower except DES2-21 the residual carbon in unpurified biodiesel from 12% (DES1-11) to 74.21% (DES3-11) (Fig. 14). The presence of polyunsaturated esters and polymers may have accounted for an increase in carbon residue, as biodiesel derived from candlenut has a high iodine number.

3.4.7 Oxidation Stability

Low oxidation stability of biodiesel is one of the major technical setbacks that hinders its commercial viability as a fuel. Figure 15 presents the results for oxidation stability of both unpurified and DESs-purified biodiesel. All biodiesel samples fall below the standard minimum limit of 10 h. However, DES2-11 was able to improve the oxidation stability relative to the unpurified biodiesel by about 30%. Oxidation of biodiesel alters its property due to the formation of secondary oxidation products and changes in its molecular weight. Biodiesel exhibits lower oxidation stability than petrodiesel because of its high degree of unsaturation but this can be remedied through the addition of antioxidant or blending it with petrodiesel.

3.4.8 Sulfated Ash

When biodiesel is burned, aside from the ash formed due to unburned hydrocarbons, ash-forming inorganic impurities called sulfated ash are also deposited in the internal engine and can cause damage to the interface between the piston ring and the cylinder wall. Figure 16 depicts the sulfated ash profiles of both purified and unpurified candlenut biodiesel. Except DES1-11 and DES3-11 which surpassed the standard limit of 0.02%, candlenut exhibited a minimal value of sulfated ash in both purified and DESs-purified biodiesel suggesting the economic viability of this biofeedstock as a fossil fuel alternative.

4 Conclusion

In this study, binary and ternary DESs containing choline chloride, glycerol and ethylene glycol were synthesized and utilized to purify candlenut-derived biodiesel. Physicochemical assessment of the purified biodiesel with various DESs showed improvement in biodiesel properties of the candlenut, fulfilling most of the limits set by the international standard for biodiesel. Variation in extraction efficiency has been observed for the different DESs which can be attributed to the nature of impurities, DESs molar ratios, and DESs/biodiesel molar ratios. For candlenut to be economically viable as a biofeedstock source, the inherent property of candlenut biodiesel of having high degree of unsaturation which lowers the oxidation stability of the fuel maybe resolved through the addition of antioxidants or blending the biodiesel with petroleum-based diesel.
Conflict of Interest
The authors declare that there is no conflict of interest.

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