Sustainable Energy Research

RESEARCH

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Production and comprehensive analysis of biodiesel from *Dovyalis caffra* seed oil

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Abstract

Biodiesel is one of the promising biofuels to replace fossil fuels as a primary energy source for machineries and vehicles. It can be produced from various edible and non-edible plants seed oil. *Dovyalis caffra* is one of the indigenous fruits which contains high amount of non-edible oil (43.05%) in its seed parts. However, there is limited research on *Dovyalis caffra* non-edible seed oil for production of biodiesel. This research is aimed to produce biodiesel from *Dovyalis caffra* seed oil. The production process was done by transesterification of oil with methanol using base (NaOH) catalyst and the biodiesel percentage yield result became 96 ± 2.00. Physicochemical characterization (moisture, viscosity, acid value, saponification value, peroxide and free fatty acid) of *Dovyalis caffra* seed oil was conducted and their values became 0.046 ± 0.99, 42.90 ± 0.19, 0.57 ± 0.51, 193 ± 0.21, 2.7 ± 0.73 and 2.25 ± 1.02, respectively. Also, the physicochemical characterization (acid value, saponification value, iodine value, kinematic viscosity, flash point, pour point, ash content and cross caloric value) of produced biodiesel was conducted and the results indicted with values of 0.42 ± 0.01, 226 ± 0.57, 15.64 ± 2.13, 3.2 ± 0.02, 145, 2, 0.32 ± 0.82 and 10,748.0653, respectively. The results from the experiment shows that *Dovyalis caffra* seeds have more oil content with good oil quality for biodiesel production, which is a critical issue in the production process of qualified biodiesel.

Keywords Biodiesel, *Dovyalis caffra* seed, Trans-esterification

Introduction

Energy affects all aspects of development—social, economic, and environmental—including livelihoods, access to water, agricultural productivity, health, education and gender-related issues (Ayodeji & Oyekunle, 2015). Ethiopia imports its entire petroleum fuel requirement and the demand for petroleum fuel is rising rapidly due to a growing economy and expanding infrastructure (Ejigu et al., 2010). Clean energy for today's economic development is crucial to assure a sustainable development in the country. Therefore, it is crucial to search for alternative energy sources. Biochemical conversion methods are currently the most widely used for producing biofuels from biomass, accounting for approximately 80% of all biofuels produced worldwide (Osman et al., 2023).

Biodiesel is non-toxic, biodegradable and a portable fuel produced from biomass of plant and animal products (Khanam et al., 2021) and it is one of the technically and economically feasible options to tackle the fast depletion of fossil fuels and environmental pollution. It is free of lead, contains almost no sulfur or aromatics (toxic compounds such as benzene, toluene and xylene), and substantially reduces emissions of unburned hydrocarbons, carbon monoxide and particulate matter (soot), which have been linked to respiratory disease, cancer and other adverse health conditions (Sarve et al., 2015). The biodiesel production optimization approaches like, computational chemistry and machine learning is very important to applied catalyst design and deactivation, reaction and reactor optimization, stability

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assessment, waste feedstock analysis, process scale-up, reaction mechanisms, and molecular dynamics simulation (Osman et al., 2024). The most important is that biodiesel can be produced from any vegetable oil including waste vegetable oil (Zhang et al., 2003). Among these vegetables grown in the tropics, sub-tropic and desert areas considerable work has been reported using vegetable oils such as soybean oil, palm oil, palm kernel oil, sunflower oil, rape seed oil, etc. (Patel et al., 2013). However, it is not desirable to produce biodiesel from edible oil crops because using food crops as fuel feedstock raises a number of issues and has led to well-known discussions on the relative merits of food and fuel (Khanam et al., 2021). Therefore, the search for additional regional biodiesel feedstocks biomass is an important objective. The recent researchers use biochar from biomass used as catalyst for high-yield biodiesel, ranging from 32.8% to 97.75%, and it plays a vital role in catalytic methane decomposition and dry methane reforming (Osman et al., 2023). Some recent examples, studies of biodiesel from less common or non-edible oils include *Moringa stenopetala* (Ejigu et al., 2010), tobacco (Usta, et al., 2005), Pongamia (Dwivedi et al., 2011), Jatropha (Eboibi et al., 2018), etc.

Increased environmental awareness, depletion of fossil fuel resources, tougher clean air standards, increasing prices and uncertainties concerning petroleum availability necessitate the search for a viable alternative fuel are driving the industry to develop alternative fuels that are environmentally more acceptable (Sinha et al., 2004), in order to lessen the impact of the recent high and unstable oil prices on its economies, the country has had to create creative strategies. (Ejigu et al., 2010). Hence vegetable oil studies have become prominent among various potential alternatives. Since using renewable resources to replace nonrenewable starting materials is one approach to make processes greener, the world will experience an energy crisis as a result of the continued usage of fossil fuels, which are nonrenewable (Patel et al., 2013). Therefore, this study was used *Dovyalis caffra* seed oil for biodiesel production in laboratory scale due to its the amount of oil yield percentage which is relative to the percentage yield of oil from non-edible oil (Jatropha seed) and coking waste oils and also, the quality of oil for biodiesel (fatty acid composition, free fatty acid (FFA) content, viscosity, etc.). *Dovyalis caffra* is an indigenous shrub or small fruit tree that has medicinal values for various ethnic groups in southern Africa (Aremu et al., 2019).

Population growth, urbanization expansion, technological advancement and improve living standards are the factors behind increase in energy demand worldwide (Ejigu et al., 2010). Currently, this energy source in Ethiopia comes from and depends on petroleum product such as crude oil, and natural gases. Over the previous ten years, the amount of petroleum products imported has increased at a rate of 5% annually, reaching 1.37 million tons in 2004–2005 (Ejigu et al., 2010). Due to growing petroleum prices and products, the increase in demand is followed by a considerably faster expansion in the import bill. Though it is non-renewable and has greater impact on global climate and environmental pollutions. As a result of this negative environmental impact of petroleum and its price increment, dwindling reserves has led to researches on technologies and sources of alternative renewable energy that complement petroleum products.

Additionally, petroleum products and contemporary energy sources (gas, electricity) have not yet been able to meet the majority of Ethiopians' domestic energy needs. Only biomass is used for heating, baking, and cooking in rural settings. An estimated 94% of the overall energy usage is attributed to biomass (Ejigu et al., 2010). The utilization of these biomasses results from desertification, erosion, and deforestation. To overcome those problems of petroleum products and non-renewable energy sources, alternative renewable energy production from edible and non-edible plant seed oils have been reported in the literatures. However, there is limitation of research on utilization of *Dovyalis caffra* non-edible seed oil for production of biodiesel. Thus, this study intends to fill this existing research gap on the utilization of *Dovyalis caffra* seed oil for production of biodiesel.

Materials and methods

Sample preparation for oil extraction

Five kg of dried seed sample was collected sample site and cut to smaller parts and was milled into coarse powder using an electrical grinding mill. Then, the milled powder was kept in a tightly closed vessel until extraction.

Oil extraction

The crude *Dovyalis caffra* seed oil was extracted by using Soxhlet extraction with *N*-hexane as a solvent due to its low boiling points (about 68.7 °C) which allows for easy removal of the solvent after the extraction process and relatively inexpensive compared to other solvents (Ahmad, 2020) reports. The oil was degummed with aqueous sulfuric acid to remove gum content of the oil, as the procedure shows in Fig. 1 and the percentage oil content was calculated based on Eq. 1:

$$\text{Seed oil content} = \frac{W_O}{W_S} \times 100, \tag{1}$$

where W_o: weight of oil extracted and W_s: weight of the sample.

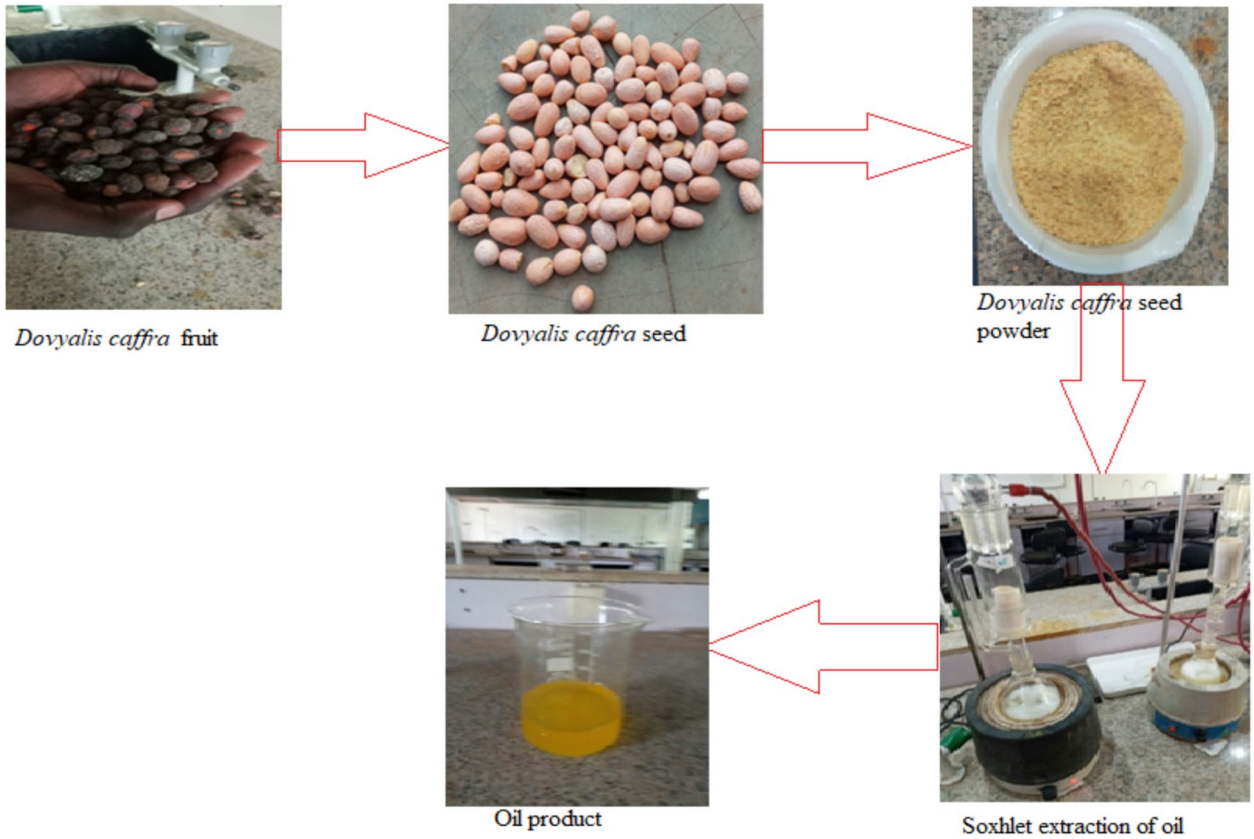


Fig. 1 Oil extraction from *Dovyalis caffra* seed

Physicochemical characterization

Specific gravity of oil

Specific gravity of oil was measured by relative density of oil to water. Distilled water was filled into the pycnometer followed by measuring its weight by using electronic balance. Similarly, oil weight was measured. The specific gravity value was calculated as follows (Hasan et al., 2016):

$$\text{Specific gravity} = \frac{\text{Weight of the oil } (\text{g})}{\text{Weight of distilled water } (\text{g})}. \quad (2)$$

Moisture content of oil

Accurately 10 g of oil sample was put in a crucible and was weighed. After the sample was dried in an oven at 105 °C for 1 h to constant weights, they were allowed to cool in desiccators for 15 min, and the difference was then calculated (Negash et al., 2019):

$$\%\ \text{Moisture} = \frac{W_1}{W_2} \times 100, \quad (3)$$

where W_1: weight loss (g) upon drying and W_2: weight (g) of the oil sample.

Relative viscosity of oil

Oswald U-tube viscometer was used to measure the oil sample's relative viscosity (Maliki et al., 2020).

Saponification value of oil

The saponification value was determined by method described (Hasan et al., 2016):

$$\text{Saponification value} = \frac{(B - T) \times N \times 56.1)}{W}, \quad (4)$$

where B: mL of HCl required by blank, N: normality of HCl, T: mL of HCl required by oil sample, W: weight of oil in gm.

Peroxide value of oil

The concentration of chemicals that change potassium iodide to iodine is showed by the peroxide value. The amount of iodine free from KI by the oxidative action of peroxides present in the oil was measured by titrating with 0.1 N sodium thiosulphate using starch solution as

an indicator after a known measured weight of oil samples was dissolved in acetic acid, followed by the addition of chloroform and saturated KI mixture (Hasan et al., 2016):

$$\text{Peroxide value (meq O2/kg oil)} = (S - B) \times W \times N, \tag{5}$$

where S: volume of sodium thiosulphate consumed by the sample oil, W: weight of oil sample, B: volume of sodium thiosulphate used for blank, and N: the normality of sodium thiosulphate.

Acid values of oil

Acid value was determined based on previous method with the little modification (Ekwu & Nwagu, 2014):

$$\text{Acid value} = \frac{(V \times N \times 56.1)}{W}, \tag{6}$$

where V: volume of standard KOH solution in mL, N: normality of standard KOH solution, W: weight of oil sample in grams, where 1 mL 1 N $Na_2S_2O_3 = 0.127$ g I_2, A: mL of 0.1 N $Na_2S_2O_3$ required by oil sample, B: mL of 0.1 N $Na_2S_2O_3$ required by blank, N: normality of Na_2S_2O, W: weight of oil in g.

Free fatty acid of oil

The breakdown of oil produces free fatty acids. When describing the FFA content of oils, FFA% is typically used. The following formula was used to define free fatty acids:

$$\text{FFA} = \frac{(Sample - blank)TV \times N \times 28.2}{\text{Sample weight}}. \tag{7}$$

Transesterification of Dovyalis caffra seed oil

The method chosen to produce biodiesel is base-catalyzed transesterification. A dry Erlenmeyer flask fitted with a thermometer and magnetic stirrer was filled with exactly 50 mL of *Dovyalis caffra* seed oil, which was heated at 60°C to convince moisture. Methanol (150 mL) and 0.22 g of sodium hydroxide were combined in a different dry Erlenmeyer flask. The optimal methanol-to-oil ratio was obtained based on the preliminary experiments trails. After adding this combination to the oil, it was quickly agitated for 50 min. After pouring the liquid into a separator funnel, it was left to separate overnight. To reduce emulsification, the biodiesel layer was rinsed three times with a 0.1% tannic acid solution (Ejigu et al., 2010).

Biodiesel yield

The biodiesel produced and the vegetable oil used for biodiesel production were weighed and used to calculate the biodiesel yield (%wt) in relation to the amount of oil:

$$\%\ \text{Biodiesel yield} = \frac{\text{Weight of biodiesel produced (g)}}{\text{Weight of oil (g)}} \times 100. \tag{8}$$

Physicochemical characterization of biodiesel produced

Specific gravity of biodiesel

The produced **biodiesel** specific gravity was determined using Eq. (2) as follows.

Flash point of biodiesel

The open cup method, which was described by ASTM D6751 (2009), was used to determine the flash point.

Pour point of biodiesel

The produced biodiesel was put into a cylindrical test tube, which was connected with a thermometer. After that, the sample was placed in an ice bath to cool below 0 °C. After that, it was taken out, tilted on the clamp, and the setup was periodically overserved. The biodiesel pour point was determined by recording the lowest temperature at which it was seen to flow using methods of AOCS (1998).

Acid value of biodiesel

The acid value of biodiesel was calculated using a similar procedure to that described for oil in Eq. (6).

Peroxide value of biodiesel

Exactly 2 g of the biodiesel was dissolved in a solution of glacial acetic acid and chloroform (3:5, v/v), 20% potassium iodide (0.5 mL) and 75 mL of distilled water was added, and the mixture whirled in the dark for a 2 min. After vigorous shaking, the mixture was titrated with 0.1 M sodium thiosulphate until the iodine's yellow color was extinct. After adding 0.5 mL of starch indicator to create a blue color, the titration process was repeated until the entire blue color had disappeared (Aremu et al., 2019):

$$\text{Peroxide value} = \frac{(S - B) \times M \times 100}{\text{Sample weight (g)}}, \tag{9}$$

where S: sample titer value in mL, B: blank titer in mL, M: molarity of sodium thiosulphate.

Calorific value of biodiesel

A bomb calorimeter was used to measure the calorific value of methyl esters using the ASTMD6751 standard technique (Siva Ramakrishnan & Ravi Kumar, 2012).

Viscosity measurements of biodiesel

The viscosity of biodiesel was measured by using Ostwald U-tube viscometer.

FT-IR spectroscopic study of extracted oil and produced biodiesel

FTIR spectrum of extracted oil and biodiesel sample was measured on spectrum FTIR in the frequency range 4500–400 cm^{-1} using KBr pellets (Younis et al., 2009).

Fatty acid compositions of produced biodiesel by GC–MS

The fatty acid compositions of biodiesel were analyzed by gas chromatography–mass spectrometry equipment and determined as fatty acid methyl esters based on method described by Straccia et al. (2012).

Results and discussion

Yield and physicochemical properties of extracted oil

Depending on the type of plant, its oil, storage conditions, etc., more of the bellow tests by them or combined are good indicators of oil quality for biodiesel production. The results of physicochemical characteristics of the study are presented in Table 1. The oil yield was found to be 43.05%. According to the Food and Agricultural Organization (FAO), any seed containing more than 17% oil is considered an oil seed and can be used as a feedstock for biodiesel synthesis (Akinoso et al., 2010) Consequently, *Dovyalis caffra* seed can be used in industrial vegetable oil processing. The current experiment oil content was slightly lower than oil content of (48.2%) obtained from *Jatropha curcas* L. seeds reported by other researchers (Ntalikwa, 2021), but in range with the amount of oil extracted from Jatropha seed 30- 46 w/w reported by other researchers (Jonas et al., 2020).

Refractive index of extracted oil

The results of the refractive index of this study are presented in Table 1. Refractive index, also called index of refraction, is a measure of the bending of a ray of light when passing from one medium into another. It can also be defined as a dimensionless number that describes how light or any other radiation propagates through the medium. The recorded refractive index of *Dovyalis caffra* seed oil is 1.41 ± 0.13 which agrees with the refractive index of oil obtained from *B. aegyptiaca* fruit seed with result of 1.4734 and from *Jatropha curcas* L. seeds with result of 1.46 reported by Ali et al. (2021) and Folaranmi (2013), respectively. The high refractive index of oil showed that the fatty acids in the oil will contain a high number of carbon atoms.

Moisture content of extracted oil

One of the main determinants of the feedstock's storage life is its moisture content. While a high moisture content in the feedstock lowers the heat of combustion, a low moisture content implies a favorable shelf life characteristic (Cheah et al., 2016). Additionally, high moisture content in the oil will act as a medium for the growth of microbial colonies and encourage serious corrosion and plugging of the storage tank system. The oil extracted from *Dovyalis caffra* seeds in this study had a moisture content of 0.046 ± 0.99, which was less than the maximum moisture limit specified in the standard diesel fuel oil standards (0.05). From Table 1, it can be observed that oil has the lower moisture content.

Density of extracted oil

According to the analysis data, the density of the oil before it was converted to biodiesel was 0.836 ± 0.34 g/cm^3, which was less than the SNI value (0.85–0.89 g/cm^3)

Table 1 Physical and chemical properties of *Dovyalis caffra* seed oil

Properties	Study result	Literature results	References	ASTM D-975 diesel fuel
Refractive index	1.41 ± 0.13	1.46	Folaranmi (2013)	–
Moisture content %	0.046 ± 0.99	0.04–0.159		0.05
Viscosity (cp)	42.90 ± 0.19	42.71	Ali et al. (2021)	1.5–5.8 mm^2/s
Density (g/cm^3)	0.836 ± 0.34	0.874	Ahmed et al. (2016)	0.81–0.87
Specie gravity (g/mL)	2.21 ± 0.82	4.77	Ahmed et al. (2016)	–
Acid value (mg/KOH/g)	0.57 ± 0.51	0.568	Deka and Basumatary (2011)	0.02
Saponification value (mg KOH/g)	193 ± 0.21	195	Ntalikwa (2021)	–
Peroxide value (meqkg−[1])	2.7 ± 0.73	2.9	Ahmad (2020)	–
Free fatty acid (mg KOH/g))	2.25 ± 1.02	2.3	Ahmed et al. (2016)	–

Data are expressed as means ± standard deviations ($n = 3$)

and the Pertamina value for the diesel oil (0.82–0.87). The fatty acid content and raw material purity have an impact on the oil density value (Suwari et al., 2018). Many unsaturated fatty acids were present in *Dovyalis caffra* seed oil, according to a high density value. Increasing the quantity of unsaturated oil components in the product may be the reason for the increased density of the extracted oil.

Viscosity of extracted oil

The viscosity of oil from *Dovyalis caffra* seeds met the SNI standard, as measured by oil resistance to fluid, which was 42.90 ± 0.19 cP (Ntalikwa, 2021). These outcomes support the conclusion (Ali et al., 2021) that the oil's unsaturated fatty acid makeup would mostly contribute to the viscosity value. As to Suwari et al. (2018), the viscosity decreases as the number of double bonds with the same length of the carbon chain increases.

Specific gravity of extracted oil

The specific gravity value of the presently extracted oil is found as 2.21 ± 0.82. This specific gravity value for *Dovyalis caffra* seed oil is lower than the privies reported data investigated oil from jatropha seed with a result of 4.77 reported by Ahmed et al. (2016) however, greater than specific gravity values of 0.9 documented by Aigba et al. (2021). The highest specific gravity obtained for *Dovyalis caffra* seed oil compared to some of non-edible oils could be attributed to the presence of high content of linoleic acid. Previous studies have associated high specific gravity levels to presence of linoleic acid (Mengistie et al., 2018).

Acid value of extracted oil

Because of oxidation activity, the acid value may be a sign of oil damage (Suwari et al., 2018). The acid value of *Dovyalis caffra* seed oil obtained in this study was 0.57 ± 0.51 mg KOH/g, which was greater than the maximum of 0.02 mg KOH/g oil reported in the ASTM D-975 diesel fuel specification for biodiesel products (Zhang et al., 2018). The hydrolysis of oil produced a high fatty acid, as indicated by a high acid value. Because high acidity in oil products can corrode internal combustion components and key fuel delivery systems, they are generally undesired (Cheah et al., 2016).

Saponification value of extracted oil

The saponification value obtained in this work is 193 ± 0.21 mg KOH/g of oil. The current result of saponification value for oil extracted from *Dovyalis caffra* seed is in range of 190–195 oil from jatropha seed reported by privies researcher (Folaranmi et al., 2013; Ntalikwa, 2021; Ahmed et al., 2016). A high molecular weight will have a low saponification value, according to the oil made of long-chain fatty acids. Conversely, oils with a lower molecular weight will have a higher saponification value (Kotta & Buang, 2018).

Peroxide value of extracted oil

The peroxide value, is a measurement of the main lipid oxidation products, is a helpful predictor of the early phases of rancidity that occur under mild conditions (Yihunlamlak &Tanje, 2020; Asuquo, 2008). The oil extracted from *Dovyalis caffra* seeds has a peroxide value of 2.7 ± 0.73 mEq/g. These results are significant when considering the stability of gasoline during storage. According to current study, a low peroxide value makes the oil more suitable for long-term storage since it exhibits fewer oxidative and lipolytic activities (Zang et al., 2018).

Free fatty acid of extracted oil

Free fatty acid and acid value are the most significant characteristics of the oil that were examined since they are typically taken into account both before and after the manufacturing of biodiesel (Ahmed et al., 2016). It is determined that the percentage of free fatty acid in *Dovyalis caffra s*eed oil (2.25 ± 1.02) satisfies the necessary requirements. Low free fatty acid content of *Dovyalis caffra* oil is crucial for efficient transesterification and chemical process used to covert oils in to biodiesel. High FFA level can leads to soap formation during transesterification process, reducing yield and complicating the purification method (Ahmed et al., 2016). The oil's propensity to conduct hydrolytic activities is decreased by the low percentage of FFA (Manji et al., 2013).

Transesterification of Dovyalis caffra seed oil to fatty methyl ester

The most common process used in converting oil to biodiesel is transesterification in which the former is converted to normally methyl esters and glycerin by alcohol and strong alkaline catalyst (NaOH) under heat. Oil transesterification lowers triglyceride viscosity and enhances the end product's physical characteristics (Madras et al., 2004):

$$\underset{\textit{Dovyalis}\ \text{Oil}}{\text{Triglyceride}} + \text{Methanol} \xrightarrow{\text{NaOH}} \underset{\text{Biodiesel}}{\text{Methyl ester}} + \text{Glycerin} \qquad \text{(Ejigu et al., 2010).}$$

Table 2 Physical and chemical properties of biodiesel

Properties	Unit	Current result	Limit (ASTMD6751)	EN 14214 standards
Yield	%	96 ± 2.00	–	–
Acid value	mgKOH/g	0.42 ± 0.01	< 0.8	0.5 max
Saponification value	mgKOH/g	226 ± 0.57	–	–
Iodine value	(gI_2/100g)	15.64 ± 2.13	120 max	–
Density	g/cm^3	0.88 ± 0.01	–	
Kinematic viscosity 40 °C	(mm^2/s)	3.2 ± 0.02	1.9–6.0	3.5–5.0
Flash point	°F	145	130 min	101 min
Pour point	°F	2	− 15 to 10	–
Water by distillation	% vol	0.062 ± 1.32	0.5 max	–
Ash content	% wt	0.32 ± 0.82	0.1 max	0.20 max
Cross caloric value	cal/gm	10,748.0653	10,600 min	–

Data are expressed as means ± standard deviations ($n = 3$)

The alkali catalyst is the most often used catalyst for transesterification reactions because it breaks down triglycerides, allowing methanol to form a bond with the fatty acids and create biodiesel (Demirbas, 2005; Lotero et al., 2005). Using methanol has the benefit of separating glycerin, which can be accomplished by straightforward decantation (Nagi et al., 2008).

Yield and physicochemical properties of prepared biodiesel

Based on the experiment, the biodiesel yield obtained from transesterification of *Dovyalis* caffra seed oil is 96 ± 2.00% at 60 °C for s60 minutes and ratio of methanol: oil of 6:1 shown in Table 2. The current result lines up with previous research investigation of biodiesel produced from jatropha curcas seed (Aranisola et al., 2010; Wang et al., 2011).

Acid value of biodiesel

The result of acid value of biodiesel analyzed in this study is presented in Table 2. Based on results obtained, the acid number from biodiesel produced from *Dovyalis* caffra seed oil (0.42 ± 0.01) falls within the range of the ASTMD-6751 standard. Acids can be formed when traces of water is presence in the biodiesel which result into hydrolysis of the esters to form alcohol and acids (Ouaid et al., 2009). The acid number increases with an increase in peroxides because the esters first oxidize to form peroxides which then undergo further reactions, including a split into more reactive aldehydes which further oxidize into acids (Aworanti et al., 2019). Acid number indicates the level of free fatty acids present in biodiesel. Acid value lower than 0.5 mg KOH/g is ideal as fuel for vehicle (Aworanti et al., 2019). A high acid value can has a strong solvency effect on rubber seals and hoses in the engine, thereby causing premature failure. It may also leave deposits, which can clog the fuel filter or drop fuel pressure.

Saponification value of biodiesel

Saponification value represents the number of milligrams of potassium hydroxide required to saponify 1g of fat. It is a measure of the average molecular weight of all the fatty acids present (Ibeto et al., 2011). *Dovyalis caffra* seed biodiesel have saponification values of 226 ± 0.57 mg KOH/g witch is closely related with the previous research reported by Ahmad, (2020) with the result of 225 mg KOH/g of saponification values, thereby indicating the presence of high fatty acids in the biodiesel. This the high fatty acids in the biodiesel shows, high amount of soap can result in irregular combustion and thick exhaust smoke but would also increase the cleanliness of the fuel internal components and reduce friction between rubbing parts.

Iodine value of biodiesel

The iodine value of the biodiesel sample of this study is less than 110 (15.64 ± 2.13 gI_2/100 g). These values are significantly lower than the maximum value of 120 g I_2/100 g approved by ASTM D6751. According to Drapcho et al. (2008), Onyezeka et al. (2020), the lower the IV, the better the fuel will be as a biodiesel and IVs greater than 50 may result in decreased engine life but give better viscosity characteristics in cooler conditions.

Cloud point and pour point of biodiesel

The corresponding limit specified for the biodiesel standard's ASTMD6751 is applied to the result with a temperature of 10 °C, the biodiesel's cloud point and pour point are higher than those of gasoline diesel (Peterson & Reece, 1996; Folaranmi, 2013). The produced biodiesel pour point (2°F) met the necessary standard range.

Flash point of biodiesel

Flash point is defined as the lowest temperature at which it can vaporize to form an ignitable mixture in air (Folaranmi, 2013). The current produced biodiesel has a higher flash point of (145°F) as compared to that of the petrol diesel flash point of (50°F). This makes the biodiesel sample safe for use and storage. Also, fuels with lower flash point tend to ignite at lower temperature making it highly dangerous if it is not stored and used properly.

Viscosity of biodiesel

One of the crucial factors is the fuel's viscosity, which has a significant impact on engine performance. The fuel will flow more slowly and the degree of atomization will be more challenging if the viscosity is high (Rao, 2011; Suwari et al., 2018). Generally idea, worse fuel atomization results from higher viscosity. According to the literature, biodiesel has a higher viscosity than petroleum diesel because of its high fatty acid composition (Ayetor et al., 2015). The viscosity of *Dovyalis caffra* seed oil biodiesel (3.2 ± 0.21 cp) is still marginally higher than that of petroleum diesel (2.4 cp).

Density of biodiesel

The density of produced biodiesel founds in the range of 0.86 and 0.90 g/cm^3 which was studied by previous researcher (Alptekin & Canakci, 2008). In this study, the density of produced biodiesels is between these values with the results of 0.88 ± 0.01 g/cm$^{3.}$ Since the densities of methanol and oil are similar to the density of the produced biodiesel, it has been noted in numerous investigations that the density of biodiesel has not changed significantly (European Biodiesel Board, 2008).

Water by distillation of biodiesel

Water determinations in biodiesel are first performed setting standard parameters. Water content in biodiesel is water that is dissolved and not dissolved in fuel (Aworanti et al., 2019). Water will result in corrosion, foaming, and a decreased heating value (ASTMD6304). Water can be used to quantify volatile chemicals that have dissolved in it. Water can solidify in frigid temperatures, blocking gasoline lines (Aworanti et al., 2019). Because it determines distinct purposes in analysis, it is crucial to include the water content criterion based on ASTMD6304 in the biodiesel specification.

Ash content of biodiesel

The ash content of *Dovyalis caffra* seed oil biodiesel is 0.32 ± 0.02 which lines up with the earlier result of ash content of biodiesel produced from neem plant oil reported by Bhandare et al. (2015).

Calorific value

Calorific value represents the amount of heat transferred into the chamber during the combustion and indicates the available energy in fuel. Based on the analysis results, calorific value of produced biodiesel in this study is 10,748.0653 cal/gm. The result shows that the produced biodiesel has a higher calorific value as compared to that biodiesel from coconut oil (10,031.5277 cal/gm) and palm kernel oil (10,509.2195 (Ayetor et al., 2015), but lower than the value of petroleum diesel (10,986.9112 cal/gm) reported by Ayetor et al. (2015).

FTIR analysis of extracted oil and biodiesel produced

The FTIR spectra for a sample of the extracted *Dovyalis* caffra seed oil and prepared biodiesel are presented in Fig. 2A, B. Since the result of the transesterification process is chemically similar to its precursor (extracted oil), there are some rather straight forward variances between the spectra. Both biodiesel and oil spectra frequently show peaks in the 1800–1700 cm^{-1} range that are qualified to the stretching of C=O, which is characteristic of esters (Soares et al., 2008). The "fingerprint" region of the spectrum, which spans 1500–900 cm^{-1}, is the primary area that permits chemical comparisons between oil and its corresponding biodiesel. The asymmetric stretching of $-CH_3$, which is absent in the oil spectrum and present in the biodiesel spectrum, is represented by the peak at 1468 cm^{-1} (Rabelo et al., 2015). The corresponding peaks for $-CH_2-C-CH_2-OH$ are only found in the oil spectrum. The stretching of $O-CH_3$, represented by the absorbance at 1196 cm^{-1}, is typical of biodiesel. Another region that allows for discrimination of biodiesel and oil is 1075–1100 cm^{-1}, covering the asymmetric axial stretching of $O-CH_2-C-CH_2-OH$, with respective peaks present only in the oil spectrum. The peak at 1739.7 cm^{-1} was found to be different, and the C=O stretching band in biodiesel was found to have shifted to the lower wave numbers, such as 1750 cm^{-1} in oil, thus indicating the increasing deterioration of the oils during production of biodiesel (Hasnain et al., 2023). The most common use of FTIR in feedstock and final products analysis is free fatty acid (FFA) determination, since FFA content is a critical parameter in the conversion of oils to methyl esters (Aryee et al., 2009). The first research related to this subject is reported by Ozg ul-Yucel and Proctor (2004). The author proved that high-FFA rice bran, which cannot be used for producing good quality food oil, would be a fine feedstock for biodiesel production. Instead of using extraction and the subsequent titration method, the Fourier transform infrared (FTIR) spectroscopic method was used to rapidly measure rice bran FFA. FTIR can be used to assess the quality of biodiesel by detecting impurities.

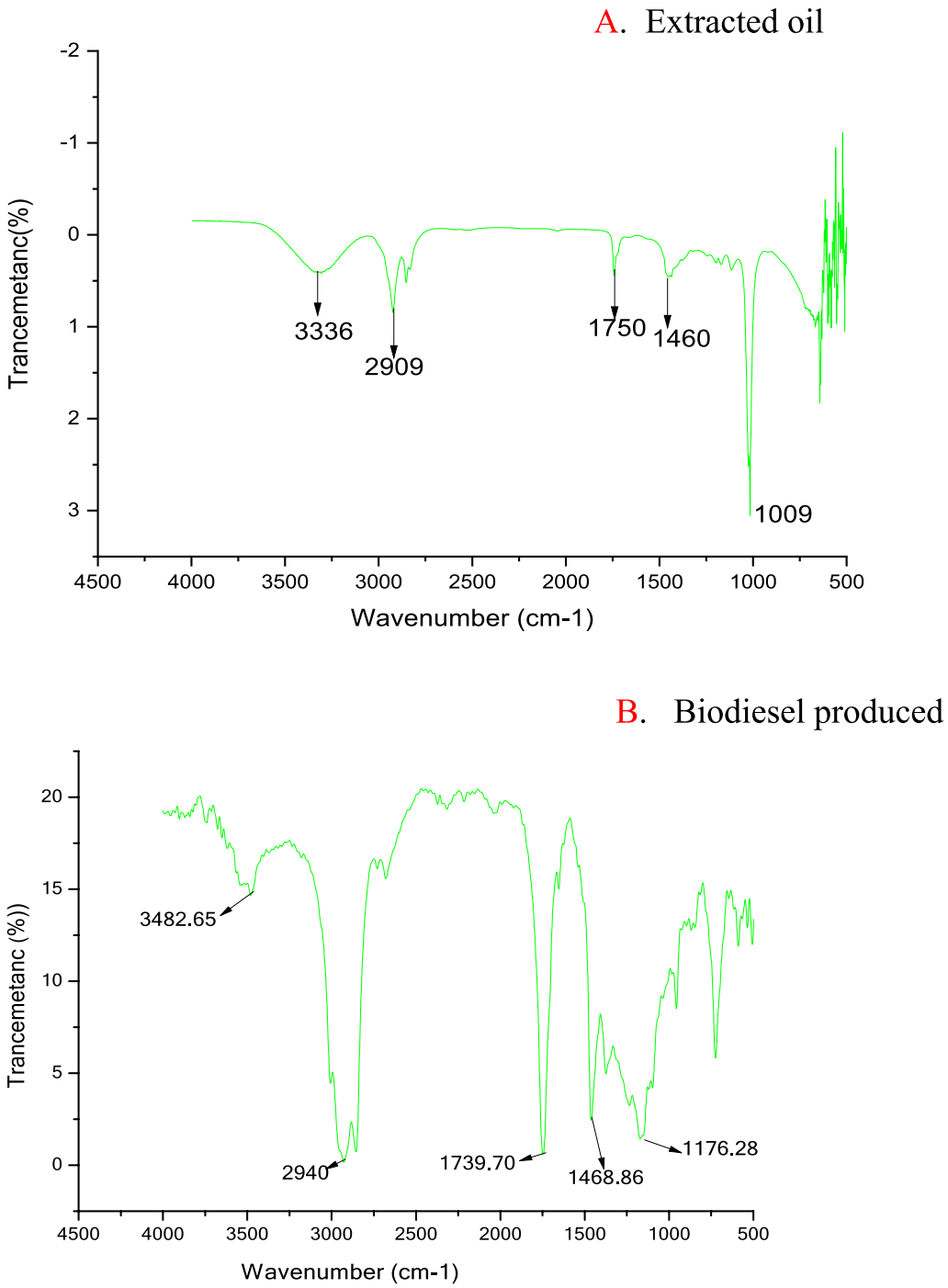


Fig. 2 FTIR spectrum of *Dovyalis caffra* seed oil (**A**), and *Dovyalis caffra* seed oil biodiesel (**B**)

The presence of these impurities can affect the fuels performance, including its cetane number, viscosity and cold flow properties (Rosset & Perez-Lopez, 2019).

Gas chromatography–mass spectroscopy analysis of biodiesel

The FACs chromatogram on a gas chromatograph revealed that *Dovyalis caffra* seed biodiesel is made up of 13 distinct fatty acid esters. The esters are identified as

Table 3 Compositions fatty acids in prepared biodiesel

No	Identified ester	Chemical formula	Retention time	Area peak (%)	Area
1	Octanoic acid, methyl ester	$C_9H_{18}O_2$	8.361	6.97	317,311,902
2	Decanoic acid, methyl ester	$C_{11}H_{22}O_2$	14.110	0.63	28,728,560
3	Tetradecanoic acid, methyl ester	$C_{15}H_{30}O_2$	16.558	1.35	61,342,530
4	Pentadecanoic acid,methyl ester	$C_{16}H_{32}O_2$	17.716	0.08	3,656,773
5	9-Hexadecenoic acid, methyl ester (Z)-	$C_{17}H_{32}O$	18.584	0.41	18,458,643
6	Heptadecanoic acid, methyl ester	$C_{18}H_{36}O_2$	19.812	0.11	5,216,846
7	Methyl stearate	$C_{19}H_{38}O_2$	20.829	3.14	143,092,603
8	Methyl octadeca-9-yn-11-trans-enoate	$C_{19}H_{32}O_2$	21.729	0.30	13,720,259
9	Hexadecanoicacid,1(hydroxymethyl)-1,2- ethanediyl ester	$C_{35}H_{68}O_5$	22.412	0.53	24,093,392
10	Eicosanoic acid,methyl ester	$C_{21}H_{42}O_2$	22.634	0.24	11,007,384
11	Hexadecanoic acid, BIS(2-ethylhexyl) ester	$C_{22}H_{42}O_4$	23.270	0.28	12,679,132
12	9-Octadecenoic acid,1,2,3- propanetriyl ester (E,E,E)	$C_{57}H_{10}O_6$	23.962	0.47	21,575,973
13	Hexadecanoicacid,2-hydroxyl-1 (hydroxymethyl)ethyl ester	$C_{19}H_{38}O_4$	24.293	1.43	65,027,854

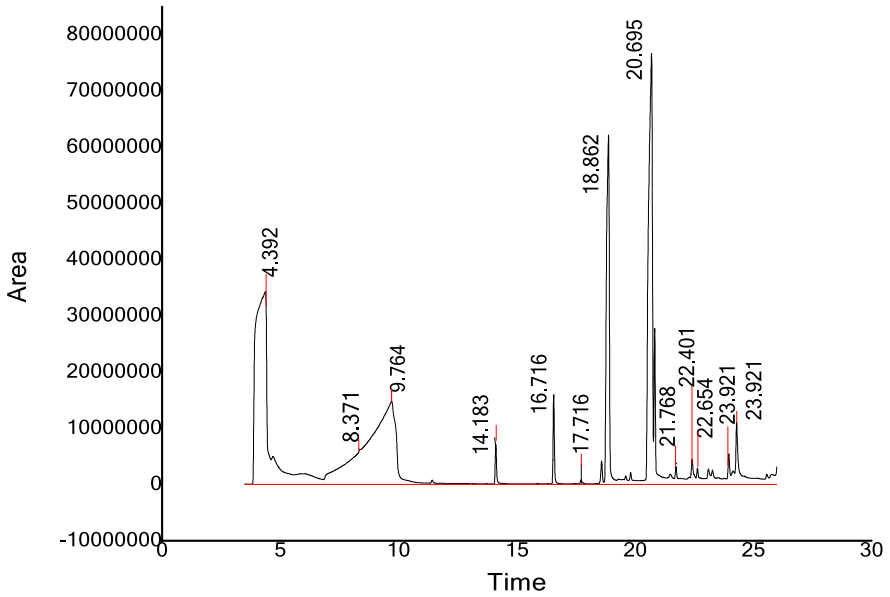


Fig. 3 The gas chromatograph chromatogram of fatty acid of prepared biodiesel

methyl esters of octanoic acid, decanoic acid, tetradecanoic acid, pentadecanoic acid, 9-hexadecenoic acid, heptadecanoic acid and others. The analysis reported that octanoic acid, methyl ester (6.97%) as the predominant component of *Dovyalis* caffra seed biodiesel followed by methyl stearate (3.14%), tetradecanoic acid, methyl ester (1.35%), and decanoic acid, methyl ester (0.63) shown in Table 3. Fatty acid composition direct affects the physical and chemical properties of biodiesel, cetane numbers and viscosity. Different fatty acid composition influences the combustion characteristics of biodiesel. Understanding the compositions allows producers to predict and optimize performance in engines. Also, fatty acid composition affects oxidative stability; certain fatty acids are more prone to oxidation, which can lead to degradation of fuel over time.

Components with different retention time were eluted from the gas chromatography (GC) column as indicated in the chromatogram. Identification of constituents was done on the basis of their retention time and mass spectra library search. The mass spectrographs of the identified constituents are given in Fig. 3. The relative amount

of individual components was calculated based on GC peak areas. The comparison of the GC-MS spectrograph obtained with the instruments data bank together with NIST-MS data demo version revealed that the compostion of the oil.

Conclusion

The complete analysis of the biodiesel produced from *Dovyalis caffra* seed oil highlights its promising qualities as a feasible alternative fuel source. The high oil yield from *Dovyalis caffra* seeds cites them as an attractive feedstock for biodiesel production. The experiments conducted have shown that the seeds keep more oil content, which is a critical factor in biodiesel production. Additionally, key fuel properties such as viscosity, flash point, and ash content were evaluated and found to be within acceptable ranges, aligning closely with the ASTMD 6751 standards for biodiesel. This indicates that the biodiesel produced from *Dovyalis caffra* seed oil not only meets standards, but can also potentially exceed the performance characteristics of conventional diesel fuels.

The study emphasizes the potential of *Dovyalis caffra* seed oil biodiesel as a sustainable and renewable energy source, contributing to energy security and environmental sustainability. Continued research and development could further unlock the full potential of this biofuel, promoting its adoption in the renewable energy sector and supporting efforts to mitigate climate change through the use of cleaner fuel alternatives.

Acknowledgements
The Renewable Energy Research Center of Arba Minch University provided materials and assistance for which the authors would like to thank.

Author contributions
T. M. H: Data curation; Investigation; Writing review & Writing original draft. A. W. K: Conceptualization; Formal analysis; Software; Supervision; Methodology; E. G. B.: Project administration; Resources; Software; Supervision; Validation. M. M. S: Software, Investigation; Resources.

Funding
For this research, no specific grant from a public, corporate, or nonprofit entity was provided.

Availability of data and materials
The manuscript has all the information that is required.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
The published version of the article was reviewed and approved by all authors.

Competing interests
The authors declare no competing interests.

Received: 19 February 2025 Accepted: 31 March 2025
Published online: 18 April 2025

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