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Biodiesel Production from Coriander (Arslan Variety) Seeds and Evaluation of Its Properties According to the EN 14214 Standard

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HIGHLIGHTS

- Biodiesel was produced from Arslan variety coriander seeds via transesterification.
- Biodiesel meets EN 14214 in density, flash point, and water content.
- Cold flow properties show suitability for use in cold climates.
- Viscosity exceeds EN 14214, blending with diesel is recommended.

Abstract

The energy sector plays a critical role in various domains such as production, transportation, and agriculture. The environmental impacts and limited reserves of fossil fuels have accelerated the search for sustainable energy sources. In this context, biodiesel production from coriander (Coriandrum sativum L., Arslan variety) seeds has emerged as a promising, eco-friendly, and renewable energy alternative. In this study, coriander seed oil was converted into biodiesel using a single-step transesterification process, and its physicochemical properties were evaluated for compliance with the EN 14214 standard. The analyses revealed that the biodiesel's density (0.8748 g cm-^{3}), flash point (145°C), water content (54 mg kg-1), and copper strip corrosion test results (1a grade) were in accordance with the standards. Additionally, the cold filter plugging point (-14°C) demonstrated suitability for usage in cold climates. However, the kinematic viscosity (5.43 mm^2 s^{-1}) exceeded the EN 14214 standard range (3.5–5.0 mm^2 s^{-1}), suggesting that blending with diesel fuel is necessary to optimize engine efficiency and reduce emissions. As there is limited literature on the use of Arslan variety coriander seeds for biodiesel production, this study is expected to provide a novel perspective to the energy sector. The findings highlight the potential of coriander biodiesel as a sustainable and economically viable alternative. Biodiesel's low emission values, biodegradability, and ability to reduce dependence on fossil fuels further underscore its importance as an eco-friendly energy source. Additionally, the bioactive properties of coriander, such as antibacterial and antifungal

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effects, offer ecological advantages. This study emphasizes the need for further exploration of diesel-biodiesel blends and their emission profiles to enhance the practical applications of coriander biodiesel in the energy sector.

Keywords: Sustainability; Bio-Energy; Eco-Friendly; Arslan Variety

1. Introduction

Energy is a fundamental component critical to the sustainability of modern life. Energy resources directly influence the operation of various sectors such as industry, transportation, and agriculture. The rapid growth of the global population has driven an increasing demand for energy, which, coupled with the limited availability of fossil fuel resources and their environmental impacts, presents significant challenges both economically and ecologically. The effects of fossil fuel-dependent energy systems on greenhouse gas emissions and climate change necessitate the adoption of sustainable and environmentally friendly energy sources (Kaplan, Aydin, & Fidan, 2009; Özer, 2014; Şahin & Mengeş, 2022) . In this context, renewable and low-carbon footprint fuel alternatives, such as biodiesel, are gaining increasing importance.

Biodiesel is a renewable fuel produced through the transesterification of vegetable or animal oils in the presence of alcohol and a catalyst. Due to its low emission values and biodegradability, biodiesel not only promotes environmental sustainability but also reduces dependency on fossil fuels. With these characteristics, biodiesel can be used either directly in diesel engines or blended with fossil fuels, making it a preferred option across various applications, particularly in road transportation (Babu, Kumar, & Sathiyaraj, 2020). Currently, traditional vegetable oils such as soybean, rapeseed, and sunflower oils are commonly used as raw materials for biodiesel production. However, limitations related to food production and agricultural land use associated with these sources have driven interest in alternative vegetable oil sources for energy production.

In recent years, the coriander plant (Coriandrum sativum L.), known for its distinctive botanical and chemical properties, has emerged as a potential alternative feedstock for biodiesel production. A member of the Apiaceae family, coriander is an annual herb native to the Mediterranean and Middle East regions, notable for its seeds' high fatty acid content (Bhat, Kaushal, Kaur, & Sharma, 2014; Bhuiyan, Begum, & Sultana, 2009; Laribi, Kouki, M'Hamdi, & Bettaieb, 2015; Pandey, Tripathi, & Tewari, 2023). Coriander seeds contain 9–27% oil, with a composition suitable for biodiesel production, making them an attractive raw material for the biodiesel industry. Moreover, research on coriander oil indicates that it possesses antibacterial, antifungal, and antioxidant properties, further enhancing the ecological benefits of coriander biodiesel (El-Din & Youssef, 2023; Kori, Mahesar, Sherazi, Laghari, & Otho, 2023; Nguyen, Talou, Evon, Cerny, & Merah, 2020; Prachayasittikul, Prachayasittikul, Ruchirawat, & Prachayasittikul, 2018; Ustun-Argon, Gumus, & Yengin, 2023). There are seven registered coriander varieties in our country (Arslan, Gürbüz, Pel-Mus, Kudret-K, Gamze, Erbaa and Sancar Bey). Studies have shown that parameters such as location, fertilisation, weeds, variety and sowing date affect the fatty acid composition and chemical profile of coriander (Erdoğdu & Esendal, 2018; Mert & Bahadırlı, 2024; Tunçtürk, 2011).

Although several studies have been conducted on biodiesel production from different coriander varieties, there is limited research focusing specifically on the Arslan registered variety, which is one of the seven official coriander cultivars in Türkiye. The distinct fatty acid profile and agronomic adaptability of this variety provide a novel perspective for biodiesel research. To the best of our knowledge, this is the first comprehensive study to evaluate the fuel properties of biodiesel derived from the Arslan variety in accordance with the EN 14214 standard. By addressing this gap, the study contributes original findings on the feasibility, fuel quality, and cold flow properties of coriander biodiesel, while also proposing its potential use in cold climate conditions. This originality highlights the significance of our research in expanding alternative feedstock options for sustainable biodiesel production.

2. Materials and Methods

In this study, coriander seeds (Arslan registered variety) grown in Yozgat Bozok University Application and Research Centre were used (altitude: 1105 m). The study area has an arid climate, with annual rainfall of

554.2 mm, average temperature of 11.7 °C, and relative humidity of 64.5%. The soil in the study area is loamy, poor in organic matter, low in lime, and slightly alkaline. Phosphorus is low and potassium is high. Sowing was done by hand in April, with 40 cm row spacing, 3 m row length, and 1.5 kg of seed per decare. No fertilization or irrigation was performed. Hoeing was used for weed control. The yellowish-brown fruits were harvested in August.

Methanol (CH_3OH) was used for methoxide production, and sodium hydroxide (NaOH) served as the catalyst during biodiesel production. All chemicals used in the study are listed in Table 1. Deionized water (DIW) was used throughout the experiments.

Table 1. Chemicals used in coriander (Arslan registered variety) seed crude oil based biodiesel production

Polymer emulsion	Chemical Formula	Functions
Methanol	CH_3OH	Transesterification
Sodium hydroxide	NaOH	Catalyst

2.1. Biodiesel Production

Biodiesel production from the crude oil of coriander (Arslan registered variety, Coriandrum sativum L.) was performed in accordance with the literature (Ozdemir & Mutlubas, 2016; Şahin, Şenkal, Eryılmaz, & Uskutoğlu, 2023) using a single-step transesterification method. The process was conducted with a temperature-controlled magnetic stirrer.

In this study, the transesterification reaction was carried out using a methanol–sodium hydroxide (CH_3OH–NaOH) solution prepared with 100 mL of methanol (20% v/v with respect to the crude oil) and 0.35% NaOH (approximately 1.75 g for 500 mL of oil). The prepared solution was added to 500 mL of coriander oil, and the mixture was stirred at 1000 rpm for 60 minutes at 55–60 °C. After completion of the reaction, the mixture was allowed to settle for approximately 12 hours to separate the biodiesel and glycerin phases. At the end of this period, a two-phase mixture of biodiesel and glycerin was obtained. The biodiesel-glycerin mixture was separated using a separatory funnel based on density differences, with glycerin (higher density) settling at the bottom phase and fatty acid methyl ester (biodiesel) forming the upper phase.

Once the phases were separated, the excess alcohol was removed through evaporation at 70°C. After separating the biodiesel-glycerin mixture, trace amounts of soap and catalyst in the biodiesel were removed through washing with distilled water. The reaction mixture was neutralized to ensure stability. Ultimately, biodiesel with a yellow color and a viscosity similar to that of petro-diesel was obtained from the crude coriander oil of the Arslan variety.

2.2. Fuel Analyses

The study focused on examining the fuel characteristics of biodiesel derived from the oil of coriander seeds (Coriandrum sativum L., Arslan variety). The evaluated properties encompassed density, water content,flash point, kinematic viscosity, copper strip corrosion, cloud point, calorific value, color, cold filter plugging point, and pour point. The methodologies and instruments used for these tests are summarized in Table 2. A portion of the fuel analyses was carried out at the Fuel Analysis Laboratory within Selçuk University's Department of Agricultural Machinery and Technologies Engineering.

Table 2. Fuel analyses performed in the study, instruments used and standard methods

Fuel Property	Device	Measurement Range	Unit	Measurement Accuracy	Manufacturer	Standard Method
Density	Kem Kyoto DA-130N	0.0000 - 2.0000	g cm^{-3}	±0.0001	Kem Kyoto Elektronik, Japan	EN ISO 3675 EN ISO 12185
Kinematic Viscosity	Koehler K23377	Ambient temperature – 150	°C	±0.01	Koehler Instrument Company, US	EN ISO 3104
Flash Point	Koehler K16270	Ambient temperature - 370	°C	±0.01	Koehler Instrument Company, USA	EN ISO 2719 EN ISO 3679
Water Content	Kem Kyoto MKC-501	10µg-100mg	µg	±0.01	Kem Kyoto Electronic, Japan	EN ISO 12937
Calorific Value	IKA C 200	0-40.000	J	±0.0001	IKA, UK	DIN 51900
Cold Filter Plugging Point	Tanaka AFP-102	With a coolant down to -600C	°C	±0.01	Tanaka Scientific Limited, Japan	ASTMD6379
Cloud Point and Pour Point	Koehler	-	°C	-	-	ASTM D97
Copper Strip Corrosion	Koehler K 25330	0-190	°C	±0.01	Koehler Instrument Company, USA	EN ISO 2160

3. Results and Discussion

The tests conducted on crude coriander oil (CCO) and biodiesel produced from coriander oil (CBD) of the Arslan registered variety were carried out in accordance with the EN 14214 standard. The results of these analyses are presented in Table 3.

Table 3. Analysis results of coriander (Arslan registered variety) crude oil (CCO) and coriander (Arslan registered variety) crude oil biodiesel (CBD)

Features	CCO	CBD	EN 14214
Density (15°C) (kg m^{-3})	907.6	874.8	860-900
Kinematic Viscosity (40°C)	35.48	5.43	3.5-5.0
Flash Point (°C)	-	145	>120
Water Content (mg kg^{-1})	352.42	54	<500
Calorific Value (Mj kg^{-1})	39.416	39.284	-
Color (ASTM D1500)	3.2	1.9	-
Copper strip corrosion (3h/50°C)	1a	1a	1
CFPP (°C)	0	-14	-
Cloud Point (°C)	6.0	-13.3	-
Pour point (°C)	-6	-15	-

Table 3 also presents the properties of crude coriander oil (CCO) prior to transesterification. The inclusion of these data allows for a direct comparison with coriander biodiesel (CBD), thereby illustrating the effect of the conversion process. As shown, the viscosity and density of CCO are much higher than the acceptable limits for direct fuel application, while its cold flow properties are inadequate for engine use. After transesterification, these parameters improved significantly, bringing CBD within or closer to EN 14214 standards. This comparison highlights the necessity of the transesterification process in transforming raw coriander oil into a usable biofuel and demonstrates the added value of biodiesel production from the Arslan variety.

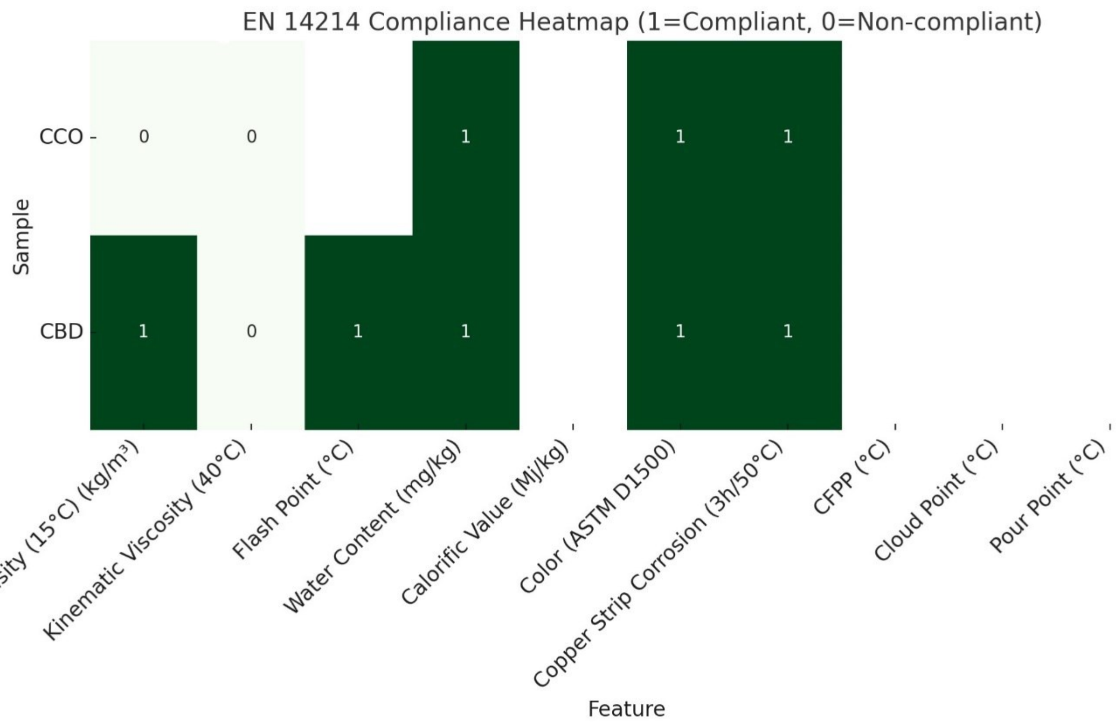

Figure 1. EN 14214 compliance heat map of crude coriander oil (CCO) and coriander biodiesel (CBD). Green cells (value = 1) indicate compliance with the EN 14214 standard, while white cells (value = 0) indicate non-compliance.

As shown in Figure 1, most of the biodiesel properties (CBD) complied with the EN 14214 standard, except for kinematic viscosity, which exceeded the upper limit. In contrast, the crude oil (CCO) exhibited limited compliance due to its high viscosity and density, further confirming the necessity of the transesterification process.

3.1. Density

Density is a fundamental property influencing spray and atomization characteristics in diesel engines. The density of coriander biodiesel (CBD) was measured as 874.8 kg m^{-3} at 15°C, aligning with the EN 14214 standard range of 860–900 kg m^{-3}. This value indicates that the hydrocarbon density of CBD is comparable to that of conventional diesel fuel. High density in biodiesel fuels is considered advantageous for compensating energy losses during engine startup (Karikalan, Chandrasekaran, Venugopal, Jacob, & Baskar, 2021; Shameer, Ramesh, Sakthivel, & Purnachandran, 2016). Similar results were reported by Şahin et al. (2023), who found a density of 869,9 kg m^{-3} for biodiesel from the Gürbüz coriander variety.These close values suggest that coriander-based biodiesel from different cultivars, including the Arslan variety, shows consistent density characteristics suitable for blending with diesel fuels.

In conclusion, CBD can be blended with diesel fuel, and the resulting mixture can be seamlessly integrated into existing distribution systems and combustion engines.

3.2. Kinematic Viscosity

Fuel viscosity is closely related to its chemical composition and significantly impacts fuel atomization and injector lubrication, similar to density. Low-viscosity fuels may fail to adequately lubricate the injection system, leading to wear and leakage over time. Conversely, high-viscosity fuels tend to form larger droplets during injection, resulting in poor combustion and increased exhaust emissions.

The kinematic viscosity of CBD at 40°C was measured as 5.43 mm^2 s^{-1}, exceeding the EN 14214 standard range of 3.5–5.0 mm^2 s^{-1}. Elevated viscosity can reduce combustion efficiency and potentially increase emissions due to the formation of larger droplets during fuel injection (Babu et al., 2020; Kotaiah, Periyasamy,

& Prabhahar, 2020; Miraculas, Bose, & Raj, 2016; Shameer et al., 2016; Tamilselvan, Nallusamy, & Rajkumar, 2017).

The kinematic viscosity of crude coriander oil (CCO) was 35.48 mm^2 s^{-1}, which is much higher than the acceptable limit for direct fuel use. After transesterification, this value decreased sharply to 5.43 mm^2 s^{-1}, demonstrating the effectiveness of the process in converting triglycerides into fatty acid methyl esters.

3.3. Flash Point

The flash point of CBD was determined to be 145°C, which is well above the EN 14214 standard requirement of >120°C. The flash point serves as an important reference parameter for risk classification and provides insight into the volatility of the fuel. The higher the volatile components in a fuel, the lower its flash point.

This property is critical for ensuring safe handling, transportation, and storage of the fuel. A high flash point indicates that biodiesel can be stored and transported safely while reducing the risk of ignition (Foroutan, Esmaeili, Mousavi, Hashemi, & Yeganeh, 2019; Ozdemir & Mutlubas, 2016).

3.4. Water Content

The water content of CBD was measured at 54 mg kg^{-1}, significantly below the EN 14214 standard limit of 500 mg kg^{-1}. Low water content is crucial for protecting biodiesel from adverse effects such as microbial growth and corrosion (Fregolente, Fregolente, & Wolf Maciel, 2012; Şahin et al., 2023). This characteristic contributes to extending the storage and service life of biodiesel.

3.5. Calorific Value

The calorific value of a fuel refers to the amount of heat released during the complete combustion of a specific quantity under standard conditions, representing its energy content. This parameter is closely linked to fuel viscosity and is one of the most critical indicators of biodiesel's impact on engine performance.

The calorific value of CBD was determined to be 39.284 MJ kg^{-1}. This high calorific value demonstrates that CBD provides high energy efficiency during combustion and possesses an energy potential comparable to that of conventional diesel fuels (Karikalan et al., 2021).

3.6. Color

The color value of CBD was determined to be 1.9, indicating a low level of coloration, which corresponds to a clear or pale appearance. This typically signifies a cleaner and more refined product with fewer contaminants or impurities, a desirable characteristic in biodiesel (Şahin et al., 2023).

3.7. Copper Strip Corrosion

The copper strip corrosion test evaluates the corrosive impact of a fuel on materials. For CBD, the test yielded a result of 1a, signifying a low risk of corrosion as per the EN 14214 standard. Corrosion can compromise metallic components, adversely affecting the functionality of engines and related infrastructure. Consequently, this outcome is crucial for preserving the durability and reliability of both engine and fuel system components (Şahin et al., 2023).

3.8. Cold Flow Properties

Insufficient cold flow properties in a fuel can damage fuel supply components in engines and cause starting issues, especially in cold climates or during winter. The cold flow properties of CBD were evaluated through tests for cloud point, cold filter plugging point, and pour point.

The pour point of CBD was recorded at -15°C, the cloud point at -13.3°C, and the cold filter plugging point at -14°C. These values comply with the EN 14214 standard requirement of < -10°C. The ability of CBD to maintain fluidity at such low temperatures ensures its usability during winter and in regions with cold climates (Foroutan et al., 2019; Şahin et al., 2023).

4. Conclusions

In this study, the physicochemical properties of biodiesel derived from coriander seeds were evaluated based on the EN 14214 biodiesel standard, and its potential for use in diesel engines was assessed. The analysis results indicate that coriander biodiesel meets the standards for critical fuel properties such as density, flash point, water content, and corrosion resistance. However, the elevated kinematic viscosity suggests the need for blending the biodiesel with diesel fuel for optimal use.

The density of coriander biodiesel aligns with the EN 14214 standard, signifying its compatibility with diesel engines and its advantage in blending with conventional diesel fuel. The kinematic viscosity of the biodiesel, however, exceeds the standard range, which could lower engine efficiency and increase exhaust emissions. Therefore, it is recommended to use coriander biodiesel in low proportions blended with diesel fuel.

The flash point of 145°C ensures safe storage and transportation of the biodiesel, reducing the risk of ignition. The calorific value of 39.284 MJ kg^{-1} demonstrates its comparable energy potential to conventional diesel, while the low water content minimizes risks of corrosion and microbial growth in fuel systems. The cold flow properties, including the cold filter plugging point and cloud point, comply with the EN 14214 standard, ensuring the usability of coriander biodiesel in cold climates and during winter.

Given the high kinematic viscosity, optimizing blending ratios of coriander biodiesel with diesel fuel is recommended to improve engine performance and reduce emissions. Further experiments on various biodiesel-diesel blends would help determine the most effective blending ratios.

To fully assess the environmental impacts of coriander biodiesel, comprehensive analyses of CO, HC, NOx, and particulate matter emissions are required. Studying changes in emission values when blended with diesel fuel can provide a broader understanding of its eco-friendly characteristics.

These findings and recommendations underscore the potential of coriander biodiesel as a biofuel that offers both environmental sustainability and economic advantages. Evaluating and optimizing its application could contribute to the broader and more effective use of biodiesel in the energy sector.

A limitation of this study is that no specific cultivation data (soil characteristics, irrigation, or fertilization) were included, since the primary aim was to evaluate the biodiesel properties of coriander seeds rather than agronomic practices. Future studies combining cultivation strategies with biodiesel quality analyses will be important to better understand how agricultural factors influence oil composition and biodiesel performance.

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Conflicts of Interest: The authors declare no conflict of interest.

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