Tikrit Journal of Engineering Sciences (2025); 32(Sp1): 2647
DOI: http://doi.org/10.25130/tjes.sp1.2025.43

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Characteristics of Biofuels Produced Using Soya Oil

N.A. Shtyrkhunova *[a], Z.Sh. Sharipov [b], A.V. Zatsarinny [c], A.S. Apatenko [d]
a Admiral F.F. Ushakov State Maritime University, Novorossiysk, Russian Federation.
b Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan.
c Kuban State Agrarian University named after I.T. Trubilin, Krasnodar, Russian Federation.
d State Agrarian University – Moscow Timiryazev Agricultural Academy, Moscow, Russian Federation.

Keywords:
Biofuel; Soybean oil; Methyl ester; Fatty acid composition; Heat of combustion; IR spectroscopy; Gas chromatography; Alternative fuel.

Highlights:

- *Fourier-transform infrared spectroscopy confirmed successful transesterification by identifying distinct ester-related absorption bands in the methyl ester of soybean oil.*
- *Gas chromatography revealed that linoleic acid was the dominant fatty acid in both raw soybean oil and its methyl ester, accounting for over 50% of the total fatty acid composition.*
- *The measured viscosity of the methyl ester (4.5 mm^2/s at 20°C) meets the requirements of EN 14214, indicating suitability for diesel engine applications.*

ARTICLE INFO
Article history:

Received	10 Jul. 2025
Received in revised form	18 Sep. 2025
Accepted	30 Dec. 2025
Final Proofreading	30 Dec. 2025
Available online	31 Dec. 2025

Citation: Shtyrkhunova NA, Sharipov ZS, Zatsarinny AV, Apatenko AS. **Characteristics of Biofuels Produced Using Soya Oil**. *Tikrit Journal of Engineering Sciences* 2025; **32**(Sp1): 2647.
http://doi.org/10.25130/tjes.sp1.2025.43

Corresponding author:
N.A. Shtyrkhunova
Admiral F.F. Ushakov State Maritime University, Novorossiysk, Russian Federation.

Abstract: Amid the energy crisis and environmental concerns, this study evaluates the characteristics of soya oil-based biofuels. Soybeans are considered a promising renewable resource for biodiesel production. The work aims to characterize the spectral properties, fatty acid composition, and physicochemical parameters of biofuels obtained by transesterification of soybean oil. The study analyzed samples of the original soybean oil and soybean oil methyl ester (SOME) using spectroscopy, gas chromatography, and physicochemical methods. The analysis confirmed the success of the transesterification reaction and revealed changes in molecular structure. Key properties of the resulting biodiesel were a density of 880 $kg\ m^{-3}$ and a kinematic viscosity of 4.5 $mm^2\ s^{-1}$ (both at 20 °C), an acid number of 0.2 mg KOH g^{-1}, and a higher heating value of 39.0 MJ kg^{-1}. These values align with EN 14214 requirements for biodiesel. Gas chromatography showed that the main components were linoleic, oleic, palmitic, linolenic, and stearic acids. Measurements of physicochemical parameters revealed that the density and viscosity of SOME met the biodiesel standards. The calculated calorific value of SOME is slightly lower than that of diesel fuel. The results confirm the possibility of using SOME in diesel engines, but further research is needed to optimize the production process.

1.INTRODUCTION

In the context of the growing global energy crisis, exacerbated by the depletion of fossil fuel reserves and worsening environmental problems, the search for alternative energy sources is becoming a priority. The desire for energy independence and to mitigate environmental harm is driving the scientific community and industry to develop renewable energy sources, with biofuels occupying a special place. Biofuels derived from biomass can reduce dependence on fossil fuels and greenhouse gas emissions, thereby facilitating the transition to a more sustainable energy system. However, biofuel production is not without drawbacks, and identifying the most efficient and environmentally acceptable path is challenging. Therefore, the production of ethanol from corn, which has become widespread in the United States, is criticised for competing with food markets and for its intensive use of fertilisers and pesticides, thereby contributing to environmental pollution. Rapeseed biodiesel, widely produced in Europe, also raises concerns about land use and potential negative impacts on biodiversity. Other alternative energy sources, such as solar, wind, and hydropower, have limitations related to variability, the need for large areas, and potential environmental impacts. The development and analysis of various energy supply systems, including those employing neutral buoyancy, are also important areas of research [12]. In this challenging situation, producing biofuels from vegetable oils, particularly soybean oil, is a promising approach that warrants detailed study and optimisation. Soybeans are among the most widespread and economically significant crops worldwide, and their production volumes continue to grow. Worldwide soybean production exceeds 350 million tons annually, with Brazil, the USA, Argentina, and China as the leading producers. Soybean oil, obtained from soybean processing, is a valuable food product and a promising feedstock for biodiesel production. Soybean oil contains a wide range of fatty acids, including oleic (about 20–30%), linoleic (about 50–55%), linolenic (about 5–10%), palmitic (about 10–12%), and stearic (about 3–5%). The ratio of these fatty acids significantly affects the properties of the resulting biodiesel, including the cetane number, pour point, oxidation stability, and emission characteristics. Biodiesel is produced from soybean oil via transesterification, which converts the oil's triglycerides into fatty acid methyl or ethyl esters. This process reduces the oil's viscosity and improves its fuel properties, making it suitable for use in diesel engines [4, 5]. The relevance of using soybean oil for biofuel production stems from several factors. First, soybeans are a renewable resource that provides a sustainable supply of raw materials. Second, soybean oil has a relatively high energy density and can be used in existing diesel engines with minimal modifications. Third, biodiesel production from soybean oil can contribute to rural development and job creation. However, potential problems associated with soybean biodiesel production should also be considered. The use of arable land for soybean production can compete with food production and lead to deforestation. In addition, intensive soybean farming is associated with increased use of pesticides and fertilisers. Therefore, an important area of research is the development of sustainable soybean production methods that ensure high yields with minimal environmental impact. Research is also needed to improve the quality of soybean oil and optimise the transesterification process to produce biodiesel with improved characteristics. In particular, a promising direction is the genetic modification of soybeans to increase oleic acid content in the oil and reduce linolenic acid content, thereby improving biodiesel stability to oxidation. In addition, it is necessary to develop new technologies for soybean oil processing to minimise biodiesel production costs and enhance its competitiveness relative to fossil diesel fuel [3]. In connection with the above, the purpose of this work is to study the characteristics of biofuel based on soybean oil. This work adds value beyond prior biodiesel characterisations by reporting a single, internally consistent dataset that links FTIR/GC-FID fingerprints with fuel-relevant properties measured on the same SOME batch. This provides a side-by-side compliance check against EN 14214 (FAME, B100) and EN 590 (diesel) in the Results section, and documents instrument settings and reference temperatures to enable reproducibility and a transparent comparison to the standards.

2.METHODS AND MATERIALS

A comprehensive assessment of biofuel characteristics was conducted. Biofuel was produced from soybean oil. The original soybean oil was studied experimentally. The analysis of soybean oil methyl ester (SOME) was carried out. SOME was obtained via transesterification. The research program was quite extensive. Spectral properties of samples were determined. The fatty acid composition of oils was assessed. The density and viscosity of the studied substances were measured. The acid number of biofuel samples was determined. The higher calorific value of the samples was calculated. Modern laboratory equipment was used for analysis. The use of contemporary equipment ensured the accuracy of the results. A Shimadzu IRTracer-100 Fourier transform infrared spectrometer

(FTIR) was used to study the functional groups and molecular structure of the samples. Measurements were carried out over the wavelength range 4000-600 cm^{-1} with a resolution of 4 cm^{-1}. The samples were analysed using transmission analysis, in which a thin film of oil or biodiesel was placed between two potassium bromide (KBr) windows. To improve accuracy, each spectrum was averaged from 64 scans. The resulting spectra were processed using LabSolutions IR software to identify characteristic absorption bands corresponding to different functional groups. In addition, attenuated total reflection (ATR) measurements were performed using a Pike Technologies GladiATR attachment with a diamond crystal. The fatty acid composition was determined by gas chromatography. The chromatograph used was a Chromatec-Crystal 5000 with FID. Gas chromatography with FID (GC-FID) is an accurate method. Separation of the components was achieved using a capillary column. An Agilent J&W DB-WAX column, 30 meters long, was used. The internal diameter of the column was 0.25 mm. The stationary-phase film thickness was 0.25 µm. Nitrogen was used as the carrier gas in the process. The carrier gas flow rate was 1.5 mL/min. The injector temperature was maintained at 260 °C. The detector temperature was 280 °C. The column temperature was programmed for the separation. The initial temperature was 100 °C (hold for 1 minute). Heating to 240 °C was performed at 5 °C/min. The hold at 240 °C lasted for 10 minutes. Fatty acid methyl ester standards were used for peak identification [7]. A representative GC-FID chromatographic profile exhibited well-resolved peaks corresponding to the identified FAMEs (C14:0–C20:0). Peak identities were confirmed by co-injection with certified FAME standards and by the expected elution order on a polar DB-WAX phase. It is important to note that, alongside laboratory studies, data analysis methods also play a key role, including the use of Kohonen self-organising maps and decision trees to identify patterns [17], as well as data mining methods [9]. In addition, the following measurements were carried out to evaluate the physicochemical properties of biodiesel: density was determined using an Anton Paar DMA 4500 M digital density meter at 20°C. Viscosity was measured using a Brookfield DV2T viscometer at the same temperature, and the acid number was determined by titration in accordance with ASTM D664. The higher calorific value was calculated from fatty acid composition data.

3.RESULTS AND DISCUSSION

In this study, a comprehensive assessment of the characteristics of soybean oil-based biofuel was conducted, including analyses of spectral properties, fatty acid composition, and physicochemical parameters. The experimental work began with the analysis of the original soybean oil and the soybean oil methyl ester (SOME) obtained by transesterification with methanol and potassium hydroxide as a catalyst. The reaction was carried out at 60 °C for 2 hours with stirring. The resulting SOME was washed with water to remove residual catalyst and glycerol, and then dried. The first stage of the analysis involved examining the spectral characteristics of the samples using Fourier transform infrared spectroscopy (FTIR). This enabled the identification of functional groups and the evaluation of molecular structure changes during transesterification. The fatty acid composition was determined using GC-FID. Soybean oil and SOME (methyl ester) were studied. Gas chromatography with FID is an accurate analysis method. The quality assessment of raw materials and products became possible. This allowed the quality of the final product to be assessed. The physicochemical parameters were determined at the final stage. The density, viscosity, and acid number were measured. The higher calorific value was calculated based on the data. The fatty acid composition data were used for the calculations. The analysis of the IR spectra revealed the key absorption bands. Figure 1 shows the IR spectrum of soybean oil; the pronounced ester carbonyl band at 1743 cm^{-1} observed in SOME confirms successful transesterification. The bands correspond to esters and hydrocarbons. An intense band in the region of 1743 cm^{-1} was detected. It corresponds to the vibrations of the carbonyl group (C=O). This band is more pronounced in the SOME spectrum. This indicates successful transesterification. The band characterising the stretching vibrations of the simple ether bond (C-O) was observed at 1160 cm^{-1}. In addition, the spectra exhibited bands associated with methylene (CH2) vibrations at 2925 cm-1 and deformation vibrations at 1465 cm-1, characteristic of hydrocarbon chains in fatty acids. The obtained data are consistent with the results of other studies. Other scientific groups also noted an increase in the intensity of the C=O band. This was observed after transesterification of vegetable oils [1]. The study of the SOME spectra showed similar values. SOME was obtained from different soybean varieties. The results obtained are consistent with those reported by other authors [6, 15]. The experiments are correct. The consistency of the data increases the reliability of the results. The research results are highly correlated. This indicates the reliability of the conclusions obtained.

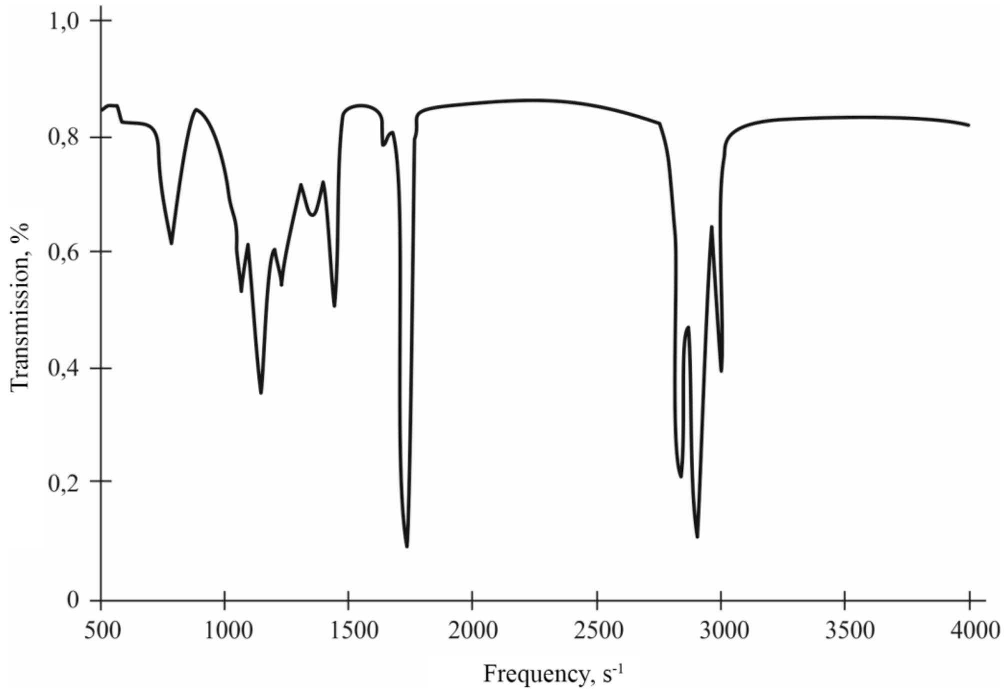

Fig. 1 The IR Spectrum of Soybean Oil.

Table 1 The Fatty Acid Composition of Biofuel from Soybean Oil.

Fatty acid	Formula	Content (%)
Linoleic (C18:2)	C18H32O2	51.2
Oleic (C18:1)	C18H34O2	23.4
Palmitic (C16:0)	C16H32O2	11.0
Linolenic (C18:3)	C18H30O2	7.8
Stearic (C18:0)	C18H36O2	4.0
Myristic (C14:0)	C14H28O2	< 0.5
Arachidic (C20:0)	C20H40O2	< 0.5

The fatty acid composition analysis by GC-FID (Table 1) revealed that the dominant components of soybean oil and SOME were linoleic (C18:2), oleic (C18:1), palmitic (C16:0), linolenic (C18:3), and stearic (C18:0) acids. The contents of these acids in soybean oil were 51.2, 23.4, 11.0, 7.8, and 4.0%, respectively. After transesterification, the fatty acid composition in SOME remained almost unchanged, indicating that the process did not significantly alter the fatty acid ratio. However, a slight increase in the fatty acid methyl ester content was observed, confirming the successful reaction. It is worth noting that the fatty acid composition of soybean oil may vary with soybean variety, growing conditions, and geographic region. In particular, soybean samples grown in Brazil generally have higher linoleic acid content than those grown in the USA. The data obtained on the fatty acid composition of soybean oil are within the range reported in the literature [5]. In addition, we detected trace amounts of myristic (C14:0) and arachidic (C20:0) acids, with concentrations below 0.5% in both samples. The influence of biofuel composition on engine performance and emissions should also be considered [7].

Measurements of physicochemical parameters were carried out. The density of soybean oil was 918 kg/m³ at 20°C. The density of SOME (methyl ester) was 880 kg/m³ at 20°C. The viscosity of soybean oil was 55 mm²/s. The viscosity of SOME was 4.5 mm²/s at the same temperature. The acid number of soybean oil was 0.5 mg KOH/g. The acid number of SOME was 0.2 mg KOH/g. The higher calorific value was calculated for the samples. The calorific value of soybean oil was 39.5 MJ/kg. The calorific value of SOME was 39.0 MJ/kg. The density and viscosity values of SOME comply with EN 14214. This suggests it could be used in engines. Reducing viscosity after transesterification is essential. This determines the suitability of oils as fuel. The high viscosity of oils impedes fuel atomization. Deposits may form on engine injectors. The low acid number of SOME indicates stability. SOME is resistant to oxidation. The calorific value of SOME is slightly lower than that of diesel. Diesel fuel has a calorific value of 42–44 MJ/kg. To contextualise the practical relevance, key fuel properties of SOME measured in this work are juxtaposed with typical EN 590 diesel specifications (Table 2).

Table 2 The Compliance-Oriented Comparison of some (this work) with EN 14214 (FAME) and EN 590 Diesel Specifications.

Property	SOME	EN 14214 (limits/ test basis)	EN 590 diesel (limits/typical)
Density, kg·m⁻³	880 (20 °C)	860–900 (15 °C)	820–845 (15 °C)
Kinematic viscosity, mm²·s⁻¹	4.5 (20 °C)	3.5–5.0 (40 °C)	2.0–4.5 (40 °C)
Acid value, mg KOH·g⁻¹	0.2	≤ 0.5	—
Cetane number	not measured (literature for SOME ≈ 49–51)	≥ 51	≥ 51
Flash point, °C	not measured	> 120	≥ 55
Higher heating value, MJ·kg⁻¹	39.0	—	42–44 (typical)

Note: Reference temperatures differ between measurements and standards (the density at 15 °C and viscosity at 40 °C for standards vs. 20 °C reported for SOME). EN 14214 values are shown for neat FAME (B100); EN 590 applies to petroleum diesel (and low-FAME blends). Sources summarising EN 14214/EN 590 parameters include Crown Oil specification summaries, DieselNet technical overviews, and IPU/Intertek testing pages.

Within these constraints, the measured density and viscosity of SOME fall within the FAME ranges specified in EN 14214, accounting for differences in reference temperature. The heating value is, as expected, lower than that of EN 590 diesel. This is due to the oxygen content in fatty acids. Some can be used successfully in diesel engines. It can be used in pure form and in mixtures. Comparable power and efficiency are provided. It is essential to consider the engines' operating characteristics [8, 10, 13]. This is especially important for marine engine applications. Comparison of the results obtained with those from other studies showed that the characteristics of the soybean biodiesel produced in this work are within the values reported in the literature. In particular, a study conducted at the University of Iowa showed that the density of SOME is 875-885 kg/m³, viscosity is 4-5 mm²/s, and the higher calorific value is 39-40 MJ/kg. Other studies also confirm the feasibility of using soybean biodiesel in diesel engines. Therefore, field tests conducted in Brazil showed that using SOME as a fuel for agricultural machinery did not reduce power or fuel efficiency. However, it did help reduce greenhouse gas emissions. Our results, along with those of other studies, confirm the potential of soybean oil as a feedstock for biodiesel production. At the same time, ensuring the smooth operation of diesel engines on biofuel remains relevant [14, 16]. Automated monitoring and control systems can play an essential role in improving the efficiency and safety of diesel engines operating on biofuels [11].

4.CONCLUSION

The article evaluates the characteristics of biofuel produced from soybean oil. The study is relevant given the search for alternative energy sources amid the energy crisis and escalating environmental problems. Soybean oil, a renewable resource with high energy density, is considered a promising feedstock for biodiesel production. The work aimed to investigate the spectral properties, fatty acid composition, and physicochemical parameters of biofuel produced from soybean oil via transesterification. During the study, samples of the original soybean oil and soybean oil methyl ester (SOME) were analysed using Fourier transform infrared spectroscopy, gas chromatography with a flame ionisation detector, and methods for density, viscosity, and acid number determination. Analysis of the IR spectra confirmed the success of the transesterification reaction, as evidenced by an increase in the intensity of the carbonyl ester band in SOME. Gas chromatography revealed that the main components of soybean oil and SOME are linoleic, oleic, palmitic, linolenic, and stearic acids. Measurements of physicochemical parameters showed that the density and viscosity of SOME are significantly lower than those of soybean oil and that SOME meets the requirements of the EN 14214 standard for biodiesel fuel. The calculated higher calorific value of SOME is slightly lower than that of diesel fuel but comparable to that of biodiesel. The study's results confirm the feasibility of using SOME in diesel engines, both in pure form and in diesel fuel mixtures. In particular, the measured density and viscosity of SOME, together with its heating value, fall within the ranges commonly accepted for biodiesel and remain sufficiently close to those of conventional diesel to enable practical blending without engine hardware modifications. The data obtained are consistent with results from other studies and support the feasibility of using soybean oil as a feedstock for biodiesel production. Further research is needed to optimise the production process and enhance its competitiveness. As a next step, we plan to validate engine-relevant performance using a single-cylinder compression-ignition test bench on B10–B100 blends. The campaign will quantify brake thermal efficiency, brake-specific fuel consumption, smoke opacity, and NO_x/CO/HC at steady-state points representative of ISO 8178 cycles, enabling a direct comparison of SOME–diesel blends versus the EN 590 baseline fuel.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

N.A. Shtyrkhunova: Conceptualisation, Writing – original draft, Methodology, Investigation, Data curation, Formal analysis. **Z.Sh. Sharipov:** Methodology, Software, Validation, Formal analysis, Writing – review & editing. **A.V. Zatsarinny:** Resources, Supervision, Project administration, Writing – review & editing. **A.S. Apatenko:** Visualisation, Funding acquisition, Writing – review & editing, Data curation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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