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PRODUÇÃO DE BIODIESEL EMPREGANDO ROTAS ALTERNATIVAS E ÓLEO DE FRITURA COMO MATÉRIA-PRIMA

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RESUMO

O presente trabalho abordou a produção de biodiesel empregando óleo residual de fritura (WFO) como matéria-prima em rotas alternativas à catálise química, sendo os ensaios realizados pelos alunos do ensino médio da escola estadual Judith Vianna, no município de Alfenas, Minas Gerais. Os estudantes realizaram a coleta do WFO na forma de uma gincana dentro da escola com a participação da comunidade. Na sequência, foram realizadas as análises para determinação das propriedades físico-químicas do WFO recolhido, tais como o teor de ácido graxos livres (0,98 ± 0,01 % m/m), acidez total (3,52 ± 0,04 mg KOH/ g óleo), índice de peróxido (9,50 ± 0,07 meq/kg óleo), índice de saponificação (197,95 ± 0,12 mg KOH/g óleo), teor de água (0,29 ± 0,02 %) e densidade (0,94 ± 0,03 g/mL). O biodiesel foi produzido por duas rotas distintas empregando-se o WFO: pela rota alternativa de hidroesterificação, na qual ocorreu primeiramente uma reação de hidrólise seguida de uma reação de esterificação, sendo ambas as reações catalisadas por enzimas; e também pela rota tradicional de transesterificação, utilizando um catalisador básico (NaOH). O óleo de soja refinado também foi utilizado para a produção de biodiesel, nas duas rotas como padrão para comparação com os resultados obtidos com o WFO. Os estudantes também realizaram as análises para o biodiesel obtido utilizando-se o WFO pela rota de hidroesterificação: teor de ésteres (25,00 ± 0,12 %), acidez total (0,20 ± 0,02 mg KOH/ g), densidade (0,84 ± 0,04 g/mL) e teor de água (0,09 ± 0,00 %). O presente trabalho possibilitou que os estudantes compreendessem a importância de se conhecer as propriedades físico-químicas da matéria-prima a ser utilizada para a produção de biodiesel, para que uma melhor rota de produção possa ser adotada, permitindo assim, que o WFO possa ser utilizado na produção do biodiesel. Além disso, o trabalho também promoveu uma maior conscientização ambiental quanto à destinação destes resíduos oleaginosos, e da importância em se substituir os combustíveis fósseis como o diesel pelo biodiesel, visando contribuir para a redução das alterações climáticas observadas nos últimos anos.

PALAVRAS-CHAVE: Biodiesel. Óleo residual de fritura. Alterações climáticas.

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ALTERNATIVE ROUTES TO BIODIESEL PRODUCTION USING WASTE FRYING OIL AS RAW ATERIAL

ABSTRACT
This work reports the production of biodiesel using waste frying oil (WFO) as feedstock in alternative routes to chemical catalysis, carried out by high school students at the Judith Vianna State School, in the municipality of Alfenas, Minas Gerais. The students collected WFO through a competition held within the school, with the participation of the community. Subsequently, analyses were performed to determine the physicochemical properties of the collected WFO, such as free fatty acid content (0.98 ± 0.01 % w/w), total acidity (3.52 ± 0.04 mg KOH/g oil), peroxide value (9.50 ± 0.07 meq/kg oil), saponification value (197.95 ± 0.12 mg KOH/g oil), water content (0.29 ± 0.02 %), and density (0.94 ± 0.03 g/mL). Biodiesel was produced using two distinct routes employing WFO: the alternative hydroesterification route, in which a hydrolysis reaction occurs first, followed by an esterification reaction, both catalyzed by enzymes; and the traditional transesterification route, using a basic catalyst (NaOH). Refined soybean oil was also used for biodiesel production in both routes as a standard for comparison with the results obtained using WFO. The students also analyzed the biodiesel obtained from WFO via the hydroesterification route: ester content (25.00 ± 0.12 %), total acidity (0.20 ± 0.02 mg KOH/g), density (0.84 ± 0.04 g/mL), and water content (0.09 ± 0.00 %). This work allowed students to understand the importance of knowing the physicochemical properties of the raw material used for biodiesel production, so that a more suitable production route can be adopted, thus enabling the use of WFO in biodiesel production. Furthermore, the work also promoted greater environmental awareness regarding the disposal of these oily residues and the importance of replacing fossil fuels, such as diesel, with biodiesel, thereby contributing to mitigating climate change observed in recent years.

KEYWORDS: Biodiesel. Waste frying oil. Climate change.

RUTAS ALTERNATIVAS PARA LA PRODUCCIÓN DE BIODIÉSEL UTILIZANDO ACEITE DE FRITURA USADO COMO MATERIA PRIMA

RESUMEN
Este trabajo aborda la producción de biodiésel utilizando aceite de fritura usado (WFO) como materia prima en rutas alternativas a la catálisis química, llevadas a cabo por estudiantes de secundaria de la Escuela Estatal Judith Vianna, en el municipio de Alfenas, Minas Gerais. Los estudiantes recolectaron el WFO dentro de la escuela, con la participación de la comunidad. Posteriormente, se realizaron análisis para determinar las propiedades fisicoquímicas del WFO recolectado, tales como el contenido de ácidos grasos libres (0,98 ± 0,01 % m/m), la acidez total (3,52 ± 0,04 mg KOH/g de aceite), el índice de peróxido (9,50 ± 0,07 meq/kg de aceite), el índice de saponificación (197,95 ± 0,12 mg KOH/g de aceite), el contenido de agua (0,29 ± 0,02 %) y la densidad (0,94 ± 0,03 g/mL). El biodiésel se produjo utilizando dos rutas distintas empleando WFO: la ruta alternativa de hidroesterificación, en la que primero ocurre una reacción de hidrólisis, seguida de una reacción de esterificación, ambas catalizadas por enzimas; y la ruta tradicional de transesterificación, utilizando un catalizador básico (NaOH). También se utilizó aceite de soja refinado para la producción de biodiésel en ambas rutas, como estándar

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de comparación con los resultados obtenidos con WFO. Los estudiantes también realizaron análisis del biodiésel obtenido a partir de WFO mediante la ruta de hidroesterificación: contenido de ésteres (25,00 ± 0,12 %), acidez total (0,20 ± 0,02 mg KOH/g), densidad (0,84 ± 0,04 g/mL) y contenido de agua (0,09 ± 0,00 %). Este trabajo permitió a los estudiantes comprender la importancia de conocer las propiedades fisicoquímicas de la materia prima que se utilizará para la producción de biodiésel, de modo que se pueda adoptar una ruta de producción más adecuada, permitiendo así el uso de WFO en la producción de biodiésel. Además, el trabajo promovió una mayor conciencia ambiental con respecto a la eliminación de estos residuos oleosos y la importancia de reemplazar los combustibles fósiles, como el diésel, por biodiésel, con el objetivo de contribuir a la reducción del cambio climático observado en los últimos años.

PALABRAS CLAVE: Biodiesel. Aceite de fritura usado. Cambio climático.

1 INTRODUCTION

Unbridled industrialization driven by disorderly societal growth based solely on economic interests has proven to be detrimental to the preservation of our planet. In recent years, promoting industrialization as a means of improving humanity's standard of living has been a primary concern, often with little regard for the potential adverse environmental impacts arising from such unrestrained activities. However, human survival depends on environmental balance; therefore, one of the key challenges faced by current generations is how to promote economic growth and development without causing further environmental degradation (Cavalcante *et al.*, 2021; Santos *et al.*, 2020). In this context, biodiesel has emerged as a renewable alternative to conventional petroleum-derived diesel.

Biodiesel is a biofuel produced from renewable and biodegradable biomass sources, and it can be used in internal combustion engines as a substitute for conventional diesel without requiring any engine modifications (Vega *et al.*, 2026; Vasudevan and Briggs, 2008).

According to the National Program for the Production and Use of Biodiesel, in January 2008, the mandatory biodiesel blend established by law was 2% (B2) across the national territory. This percentage has undergone successive increases over the years. More recently, Resolution No. 16, issued by the National Energy Policy Council (CNPE) on April 1, 2023, established that the biodiesel content in conventional diesel must increase from 10% to 12%,

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with a projected rise to 13% in 2024 (Brasil, S1).

Waste frying oil (WFO) is an economically and environmentally attractive feedstock for biodiesel production, as it reduces costs and avoids competition with edible oils. Its use also helps prevent environmental pollution caused by improper disposal. However, WFO contains high levels of free fatty acids and water, making it unsuitable for direct use in conventional base-catalyzed transesterification, as these components lead to soap formation, catalyst deactivation, and reduced biodiesel yield (Pourzolfaghar *et al.*, 2016; Christopher *et al.*, 2014). Despite these limitations, the replacement of refined oils with WFO represents a promising and cost-effective alternative, as refined oils can account for up to 80% of production costs (Preto *et al.*, 2025; Cavalcanti-Oliveira *et al.*, 2011).

Alternative route for biodiesel production

Although pretreatment of WFO can improve transesterification performance, it increases production costs, motivating the search for alternative approaches. Hydroesterification has emerged as a promising route, enabling the production of high-quality biodiesel without prior feedstock treatment and yielding high-purity glycerol (Lima Neto *et al.*, 2025; Wancura *et al.*, 2019). This process involves hydrolysis of triglycerides followed by esterification of free fatty acids (FFA) and is not negatively affected by high water or FFA content (Gebremariam and Marchetti, 2018; Pourzolfaghar *et al.*, 2016).

Furthermore, hydroesterification can be made more environmentally friendly by using lipases as catalysts in one or both steps. Lipases offer several advantages over chemical catalysts, including high selectivity, specificity, operation under mild conditions, and the production of high-purity products (Oladepo *et al.*, 2026; Hama *et al.*, 2018). In addition, enzymatic processes are more sustainable and present another important advantage: the absence of by-product formation, eliminating the need for additional purification steps (Vega *et al.*, 2026).

Therefore, the present work proposed an approach to biodiesel production using WFO as a feedstock through an alternative route to chemical catalysis. It also aimed to promote environmental awareness regarding the disposal of oily residues and the importance of replacing fossil fuels to halt climate change. This project was carried out involving high school students from the state school Judith Vianna in the municipality of Alfenas, Minas Gerais, and undergraduate students from UNIFAL-MG.

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2 METHODOLOGY

This work is an extension project that has an interface with research and it was carried out with 162 young high school students from 6 classes, i.e., three 1st year classes, two 2nd year classes and a senior year class at State School Judith Vianna (EE Judith Vianna), located in Alfenas, Minas Gerais, throughout the year 2023. The activities were developed both in the classrooms of EE Judith Vianna and in the Multidisciplinary Laboratory I at the campus of UNIFAL-MG, also located in Alfenas. Monthly meetings were conducted between the EE Judith Vianna pedagogical coordinator and the UNIFAL-MG project coordinator to monitor and evaluate the project and adjust the previously established schedule when necessary, due to unforeseen events. All meetings were held in person at EE Judith Vianna.

The practical or theoretical classes were taught by two scholarship students from the undergraduate Biotechnology course at UNIFAL-MG under the supervision of the project coordinator or sub-coordinator. No undergraduate students were left unsupervised. Theoretical activities were carried out in EE Judith Vianna classrooms and practical activities in Multidisciplinary Lab. I at UNIFAL-MG, and they were divided as follows:

2.1- Investigative experimental activities in teaching chemistry applied to biodiesel production:

The activities were developed in cycles by undergraduate students from UNIFAL-MG on the Biotechnology course, teachers, and school students from EE Judith Vianna. The experimental activities were planned in three cycles: a) Preparation and characterization of WFO; b) Different routes for biodiesel production, (hydroesterification, transesterification with chemical catalysis and transesterification with enzymatic catalysis); c) Characterization analyzes for biodiesel produced through different routes. Thus, for each cycle the planning described below was performed: a)- Bibliographic search about the content; b)- Selection or development of the episode; c) Studying and deepening the content to be taught; d) Planning and carrying out experiments that should incorporate the episode under laboratory conditions; e) Implementation and evaluation of the teaching episode in terms of possibilities from the perspective of students and teachers (Pérez and Castro, 1996).

2.2- Collection and characterization of waste frying oil:

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Collection of waste oil: WFO was collected by the students themselves from their homes and local communities during a competition held at the beginning of the school year.

Analysis of WFO: The WFO collected was analyzed to determine its physicochemical properties: free fatty acid content, total acidity, peroxide value, saponification value, water content and density. All analyses were carried out in duplicate for each group of students and in accordance with the official methodology published by the Instituto Adolfo Lutz (IAL), originating from the international legislation "American Oil Chemists' Society" – AOCS. For all assays, blanks (controls) were used, along with refined soybean oil as a standard and control.

The student groups consisted of 2 to 4 members, with the number of groups varying according to the total number of students in each class (1st year, 2nd year, and senior year classes). The results presented here correspond to the average of the best assays obtained among the student groups.

2.3- Biodiesel production through different routes and its characterization:

Three routes were used to produce biodiesel using WFO previously collected by the students themselves as feedstock. These routes were: a) hydroesterification catalyzed by enzymes according to Costa *et al*. (2020); b) transesterification route through enzymatic catalysis (Freitas *et al.*, 2009) and c) transesterification route through chemical catalysis (NaOH) also using refined soybean oil to make a comparison with the result obtained using WFO.

The biodiesel produced via the hydroesterification route was characterized in terms of ester content, total acidity, density, and water content (Costa *et al.*, 2020). For all assays, blanks (controls) were used, along with refined soybean oil as a standard control. All analyses were carried out in duplicate for each student group. The results presented here correspond to the average of the best assays obtained among the student groups.

2.4- Presentation of biodiesel production at the EE Judith Vianna Science Fair:

The fair was organized by students with the support of teachers from EE Judith Vianna and scholarship holders from the UNIFAL-MG project. Senior high school students presented the biodiesel production routes observed during experimental laboratory activities. All glassware and reagents required for the activities were provided by UNIFAL-MG.

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3 RESULTS AND DISCUSSION

This work presented an educational intervention aimed at addressing limitations inherent in traditional teaching methodologies by fostering the integration of academic content with the daily routine of the students. They were actively engaged in the development of solutions to solve the proposed problem-based activities, as well as in the discussion and choice of experimental activities focused on biofuels and waste oil reuse. Thus, three cycles of classroom and laboratory activities were developed throughout the school year. Therefore, theoretical instruction and laboratory practice were combined, fostering critical thinking, student autonomy, and a deeper understanding of sustainable energy concepts.

3.1 First circle:

Activities developed with high school students in the classroom:

The initial theoretical classes addressed key topics, including biofuels, their advantages and challenges, and the environmental impacts of fossil fuels, highlighting the importance of cleaner energy sources. Students were also introduced to catalysts, their role in chemical reactions, and the differences between chemical and biological catalysts. Subsequently, concepts such as density and viscosity were explored through group activities, including experiments with floating objects, liquid layering, and fluid flow comparisons. Finally, the concepts of acids, bases, and pH were discussed, along with the importance of analyzing physicochemical properties of the feedstocks used in biodiesel production.

Activities developed with high school students in the laboratory:

The laboratory activities involved laboratory safety procedures and the mandatory use of appropriate protective clothing. Waste frying oil (WFO), previously collected by high school students, was filtered, and its density and viscosity were analyzed after filtration, along with those of refined soybean oil used as a control. Subsequently, the total acidity (Fig. 1a) and free fatty acid content (Fig. 1b) were determined by NaOH titration for WFO and refined soybean oil. Then, peroxide value, saponification value, and moisture content were analyzed for both WFO and refined soybean oil. Finally, a transesterification reaction was performed using NaOH (chemical catalysis) and WFO as feedstock.

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(a) (b)

Figure 1 – (a) Practice of determining total acidity in WFO; (b) Practice of determining free fatty acid content in WFO.

3.2 Second circle:

Activities developed with high school students in the classroom:

High school students discussed why waste frying oil (WFO) has higher levels of free fatty acids, acidity, moisture, and density compared to refined soybean oil. The results of a transesterification reaction using WFO and NaOH served to introduce saponification and its relevance to biodiesel production. In a subsequent class, key concepts were reviewed, focusing on alternative strategies to ensure process efficiency, including different biodiesel production routes. Chemical equations for the reactions studied were presented and analyzed to highlight similarities and differences between the processes. Additionally, students constructed molecular models of triglycerides, glycerol, alcohols, water, and free fatty acids using Styrofoam balls and toothpicks

Activities developed with high school students in the laboratory:

The first activity of this cycle involved an enzymatic transesterification reaction using waste frying oil (WFO) and immobilized *Candida rugosa* lipase. The biodiesel produced was washed and separated from glycerol by decantation. Subsequently, students performed the enzymatic hydrolysis stage of a hydroesterification process using free lipase from *Geotrichum candidum* (Fig. 2a), also followed by washing and phase separation to obtain free fatty acids (Fig. 2b). Then, the previously produced biodiesel was filtered with anhydrous sodium sulfate to remove residual water and stored under refrigeration for further analysis. After that, the free fatty acid-rich phase obtained from hydrolysis was dried and then subjected to esterification with ethanol using immo-

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bilized *Pseudomonas fluorescens* lipase. The produced biodiesel was stored for subsequent characterization. To finish this cycle, the different biodiesel production routes were compared with a conventional base-catalyzed transesterification using refined soybean oil and NaOH as a catalyst.



(a) (b)

Figure 2 – (a) Hydrolysis step of the hydroesterification route via enzymatic catalysis using WFO as feedstock; (b) Separation of biodiesel obtained in the esterification reaction, which is the second reaction of the hydroesterification route.

3.3 Third circle:

Activities developed with high school students in the classroom:

The students held a debate to select the most suitable biodiesel production route for waste frying oil (WFO), discussing the advantages and disadvantages of each method, including the possible substitution of chemical catalysts with enzymatic ones and their implications for production costs and feedstock selection. The main differences between chemical and biological catalysts were then addressed, including their operating conditions, optimal pH and temperature ranges, and enzyme substrate specificity, along with basic biochemical classification.

A game-based activity was used to reinforce enzyme/substrate relationships, such as lipases with lipids and cellulases with cellulose. It was also discussed whether biodiesel quality might vary depending on the production route and feedstock used, and students were informed about the analytical methods applied to evaluate this. In the final theoretical class, held after the completion of laboratory activities, results obtained from enzymatic biodiesel production

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using WFO demonstrated that biodiesel obtained through alternative enzymatic routes showed comparable quality to that produced from refined vegetable oil.

Activities developed with high school students in the laboratory:

Ester content, total acidity, and density analyses were performed to characterize biodiesel produced by students through different routes using waste frying oil (WFO) as feedstock (Fig 3a) The same analyses were also performed on biodiesel produced from refined soybean oil. (Fig. 3b). A final laboratory activity was conducted to compare the glycerol obtained from the different biodiesel production processes.



(a) (b)

Figure 3 – Practice of characterizing the biodiesel produced: (a) Total acidity analysis using refined oil as feedstock; (b) Total acidity analysis using WFO as feedstock.

*Discussion of results*Table 1 shows the values obtained for analyses carried out on waste frying oil (WFO) and refined soybean oil. The values displayed correspond to the average of the best results obtained among student groups.

Table 1 - Physicochemical properties of WFO and refined soybean oil.

Properties	**WFO**	**Refined soybean oil**
Free fatty acid content (% w/w)	0.98 ± 0.01	0.36 ± 0.03
Total acidity (mg KOH/g oil)	3.52 ± 0.04	0.33 ± 0.05
Peroxide value (meq/kg oil)	9.50 ± 0.07	7.93 ± 0.11
Saponification value (mg KOH/g oil)	197.95 ± 0.12	190.68 ± 0.19
Water content (%)	0.29 ± 0.02	0.03 ± 0.00

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Density (g/mL)	0.94 ± 0.03	0.81 ± 0.01

During its application in food frying, soybean oil undergoes thermal and oxidative degradation, resulting in the formation of polymers, dimers, and oxidized triglycerides, including diglycerides and free fatty acids (Araújo *et al.*, 2013). Consequently, the differences observed between WFO and refined soybean oil can be attributed to these degradation processes (see Table 1).

Although feedstocks with high acidity and water content are not suitable for biodiesel production via alkaline transesterification, such limitations do not apply when the hydroesterification route is employed. In this approach, hydrolysis occurs as the initial step in the presence of water, leading to the formation of free fatty acids. Consequently, feedstocks such as WFO or other acidic oils can be effectively utilized (Lima Neto *et al.*, 2025).

When WFO was used as feedstock in the transesterification route with NaOH, no biodiesel formation was observed due to soap formation (Cavalcante *et al.*, 2021). Therefore, WFO was used in hydroesterification, which consists of a two-reaction sequence (hydrolysis followed by esterification). The analyses for biodiesel obtained in this route were shown in Table 2.

The esterification step in the hydroesterification route achieved a conversion of 25% after 2 h. The result obtained is considered promising, since the reaction lasted only 2 hours and no optimization assays were performed, and a similar value was also obtained for refined soybean oil (see Table 2).

Table 2 - Properties of biodiesel obtained via hydroesterification of WFO and refined soybean oil.

Properties	**WFO**	**Refined soybean oil**
Ester content (% w/w)	25.00 ± 0.12	27.36 ± 2.38
Total acidity (mg KOH/g oil)	0.20 ± 0.02	0.23 ± 0.01
Water content (%)	0.09 ± 0.00	0.08 ± 0.02
Density (g/mL)	0.84 ± 0.04	0.85 ± 0.03

Due to its high substrate specificity, enzymatic catalysis provides significant advantages for biodiesel production, including operation under milder temperature, pH, and pressure conditions (Vega *et al.*, 2026). Therefore, the hydroesterification route with enzymatic catalysis

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is a promising alternative for biodiesel production from feedstocks having higher free fatty acid and water contents in their composition (Preto *et al.*, 2025).

Science Fair at EE Judith Vianna

At the time when the activities of this project were completed, the senior-year students chose biodiesel production via the hydroesterification route using WFO in order to demonstrate that the quality of the obtained biodiesel was equivalent to that obtained via the transesterification route (industrial process) using refined vegetable oil and a chemical catalyst (NaOH). The students prepared posters (Fig .4) explaining the routes using appropriate chemical equations and produced all the biodiesel required for the Science Fair presentation in collaboration with undergraduate scholarship students from UNIFAL-MG.



Figure 4 –High school students explaining the activities carried out at the Science Fair on the theme of biodiesel production.

4. CONCLUSION

This work contributed to the training of 162 high school students by encouraging the search for alternative solutions to climate change, particularly the replacement of conventional diesel with biodiesel. Students gained experience in understanding biofuels, the use of WFO in biodiesel production through alternative route, and the characterization of WFO and biodiesel according to Brazilian standards adapted from international protocols.

The biodiesel produced via hydroesterification using WFO as feedstock and enzymatic catalysis for both hydrolysis and esterification steps exhibited good properties, despite WFO

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initially elevated acidity and water content. Hydroesterification constitutes a promising route in which waste or unrefined oils can be used as feedstock without the need for any pretreatment.

The learning process was conducted collaboratively between undergraduate students of UNIFAL-MG and high school students, promoting active participation and critical thinking. Two undergraduate students from UNIFAL-MG were also trained in extension activities and scientific research related to enzymatic technologies for alternative biodiesel production. Furthermore, the activities developed encouraged high school students to continue their education by enrolling in university undergraduate courses.

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