Journal of Laboratory Chemical Education 2023, 11(2): 20-26
DOI: 10.5923/j.jlce.20231102.02

Education for Sustainable Development for High School Students: Synthesis of Biodiesel from an Amazon Region Oil (Babassu)

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Abstract We introduced education for sustainable development to sixty high school (HS) third-year students, via a three-stage collaboration project between HSs and the Institute of Chemistry, University of São Paulo (ChemUSP). The general theme of the project is biofuels, with emphasis on biodiesel (BD). In the first stage, the students answered a questionnaire on important aspects of biofuels, including synthesis, and environmental impact. After discussing the results of this questionnaire, the students were informed (in the HSs) about the activities they will do at ChemUSP. During their visit to the latter, they synthesized BD from bioethanol and an Amazon region vegetable oil, babassu oil (BO), using a base catalyst (sodium ethoxide, C_2H_5ONa). The experimental variables were reaction time (45 to 105 minutes) and the molar ratio of bioethanol/babassu oil ($\chi_{EtOH/BO}$; 6-12). We used design of experiment to generate a table, where the fourteen experiments of the three HSs were carried out in a random order. While doing the experiments, the students determined acid numbers of fresh-, and recycled vegetable oils, and visited the Central Analytical Laboratory of ChemUSP. We subjected the combined results of all students to statistical analysis using a commercial software. The Pareto chart, the 3D response surface and the corresponding correlation (BD yield versus experimental variables) showed that the BD yield depends on $\chi_{EtOH/BO}$ much more than on reaction time, within the ranges of the studied variables. These results were discussed with the students at the HSs, after their visit to ChemUSP. A second questionnaire was then given, now focusing on BD. The result showed greater awareness of relevant aspects of the subject, including the oils employed in the industrial process to obtain BD; transesterification of oils with bioethanol; environmental, and economic impact of using BD. The students evaluated this project positively because of its green chemistry approach (use of renewable feedstocks; use of chemometrics), because of their active participation in the chemistry laboratory (development of experimental skills), and their contact with ChemUSP.

Keywords Education for sustainable development, Biofuels, Biodiesel, Green chemistry principals, Transesterification, Viscosity, Statistics

1. Introduction

The United Nations Educational, Scientific and Cultural Organization (UNESCO) has been the leading agency for implementation of the Decade of Education for Sustainable Development (ESD; 2005-2014); the Global Action Program on ESD (2015-2019), and is now responsible for the implementation of ESD for 2030. Among other goals, these programs give "learners of all ages the knowledge, skills, values and agency to address interconnected global challenges including climate change, loss of biodiversity, unsustainable use of resources, and inequality" [1]. Regarding climate change, the (adverse) contribution of burning fossil fuels to the emission of greenhouse gases [2], in particular CO_2, is established beyond doubt [3]. The key role of education in combating this global problem has been recognized; actions are being implemented, especially by United Nations agencies [4].

Recently, we have started a program between High Schools (HSs) and the Institute of Chemistry of the University of São Paulo (ChemUSP) to promote the connection between these educational institutions. These apparently separate organizations perform the same function, and are, in fact, *not only interrelated, but overlap* [5,6]. The strategy of our program is to implement activities that start by discussing a

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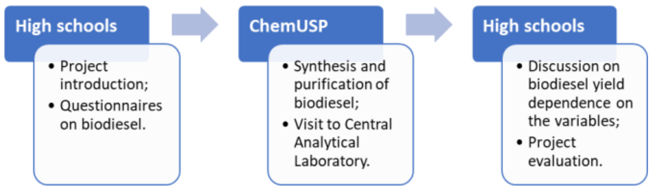
Received: Jul. 20, 2023; Accepted: Aug. 4, 2023; Published: Sep. 12, 2023
Published online at http://journal.sapub.org/jlce

project in the HS (in the present case, biodiesel, BD); doing the experiment in the undergraduate laboratory of ChemUSP (base-catalyzed synthesis of BD), and then analyze the data obtained in the HS, see **Scheme 1** below. Our approach uses "learning by doing", an active learning methodology, based on experience to assimilate concepts through actions. It also encourages the student to take decisions (where appropriate) and draw conclusions from their own results. In the present ESD project, we emphasize the significance of biofuels, particularly BD, in the context of green chemistry. Additionally, the students were introduced to chemometrics to show the relative importance of the two experimental variables studied, namely, the molar ratio of bioethanol/babassu oil ($\chi_{EtOH/BO}$) and reaction time.



Scheme 1. A flow diagram of the activities carried out in this project, both at high schools and at the Institute of Chemistry of the University of São Paulo (ChemUSP)

Figure 1. Photographs of the high school students at the ungraduated laboratory of ChemUSP

A challenging aspect of the present project is that the participating students come from three schools from São Paulo Metropolitan area, namely, Humboldt College; São Paulo State HS Luiz G. Righini, and Waldorf Micael College. The collective results of these students will be used to generate the statistical model to optimize the process, *vide infra*. We were pleased that despite their different backgrounds, and the fact that they are doing this experiment for the first time, the data of all 60 students generated a robust statistical model to show the dependence of the yield of babassu oil-based BD on the bioethanol (hereafter designated as ethanol)/babassu oil molar ratio (χEtOH/BO), and transesterification reaction time (t). The students evaluated the project positively because of the economic and environmental relevance of BD, their participation in decision making about the vegetable oil employed, and their contact with ChemUSP. This contact included demonstration of advanced analytical techniques at the Central Analytical Laboratory (CAL). **Figure 1** shows the students of the three HSs in the undergraduate laboratory of ChemUSP.

2. Experimental

2.1. Materials

Commercial absolute ethanol (EtOH) 99.8% was from LabSynth, SP, and babassu oil (BO) was from COPPALJ oil extraction company, Maranhão, Brazil. The sodium ethoxide catalyst was freshly prepared before the experiment of each school, by dissolving clean sodium metal in absolute EtOH. The metal dissolution was carried out in an Erlenmeyer flask, protected with a Drierite-containing drying tube. The concentration of the base was determined *before each HS visit* by titration with standardized HCl solution; the final base concentration was adjusted to 0.152 mol L^{-1}. Recycled frying oil was obtained from EcoABC, São Paulo. The material necessary for the experiments includes: 10 mL burettes, pipettes, Erlenmeyer flasks, semi-analytical balance, hotplates with magnetic stirring, borosilicate glass cylindrical oil baths containing ethylene glycol (EG); red spirit-filled immersion thermometers, Luer lock glass syringes, and separation funnels.

2.2. Procedures

2.2.1. Determination of the Acid Number (AN) of Babassu Oil and of Recycled Frying Oil

Weigh ca. 5 g of fresh BO, and/or 1g of the recycled oil into separate 125 mL Erlenmeyer flasks. To each flask, add 50 mL of ethanol and 3-5 drops of phenolphthalein indicator solution. Using magnetic stirring and 10 mL burette, titrate each oil solution with alcoholic KOH solution (0.050 mol L^{-1}) until the solution changes its color from colorless to (persistent) light pink.

Calculate the oil acid number using Equation 1.

$$\mathrm{AN\ (mg\ KOH/g\,oil)} = \frac{\mathrm{V(KOH)} \times \mathrm{C(KOH)} \times 56.1}{\mathrm{m(oil)}} \qquad (1)$$

where V(KOH) is the volume of KOH solution used, C(KOH) is its concentration, 56.1 is the molar mass of KOH, and m(oil) is the mass of the oil sample in grams.

2.2.2. Synthesis of Babassu Oil-Based Biodiesel

Place the provided EG heating bath (containing a magnetic bar) on a hotplate with magnetic stirring. Place the (hotplate + EG bath) on a laboratory scissor jack. Insert a thermometer into the EG and begin the (stirring + heating) of the EG until 95 ± 5°C. Concurrently, introduce a magnetic stirring bar into a 3-necked, 125 mL round-bottom flask; mark the flask with the groups´ name (G1, G2, etc). Using the indicated burette and a glass syringe, introduce the volumes of BO, and then the EtOH as indicated in Table 1 below. Once the reagents were added, close the three "necks" of the flask with the provided polypropylene stoppers.

Assemble the transesterification reactor above (not in contact with) the EG bath, by inserting a reflux condenser provided with a $CaCl_2$ (drying agent) tube in the central neck of the flask containing (BO + EtOH). When the temperature of the EG bath reaches the indicated range (95 ± 5°C), circulate water into the reflux condenser; use the 5 mL syringe to introduce the catalyst solution (C_2H_5ONa/C_2H_5OH; 0.152 mol L^{-1}), then use the laboratory jack to slowly raise the hot plate/EG bath (*caution!*) until the liquid in the 3-necked flask is slightly below the level of the EG. When the ethanol begins to reflux, start recording the reaction time.

At the end of the specified time (see Table 1), turn off the heating, carefully lower the hot plate/EG bath, place the reaction flask in a cold-water bath, wait for the solution to cool down, and then *carefully* disassemble the equipment.

Using an addition funnel, transfer the reaction mixture to a 125 mL separatory funnel (note: the funnel's tap should be closed), add 40 mL of 18% (w/v) NaCl solution to which the indicated volume of 0.15 mol L^{-1} HCl solution was added, see Table 1. *Gently shake* the mixture, and wait for the two phases (BD and mixture (ethanol + glycerol + saline solution) to separate, discard the aqueous phase. Repeat the washing of the oily phase 3 more times, each with 40 mL of the NaCl solution (*without adding* HCl), wait 5-10 minutes for phase separation; slowly remove the aqueous (bottom) layer.

On the fourth wash, use a strip of pH paper (pH range 0-14) to measure the pH of the aqueous phase. Repeat the wash with the NaCl solution if the pH is not equal to that of distilled water. Separate the phases, and remove any remaining water from the organic (cloudy) phase as follows: cover the surface of a Büchner funnel with a filter paper (rapid filtration), cover the latter with a thin layer of anhydrous $MgSO_4$ (a drying agent). Slowly filter the oil phase through the $MgSO_4$ layer into a small Büchner flask using a water pump (be careful to moisten the entire surface of the drying agent with the oil). Transfer the product (a clear, or slightly turbid oil) to a small Falcon tube, marked with the groups´ number, give this tube to the instructor.

2.2.3. Calculation of the Biodiesel Yield from Viscosity Measurement

In our previous article [6], we conducted a study on biodiesel yield determination by viscosity. The preparation of mixtures of BO and authentic BD from babassu oil was carried out using 5 mL burettes. Mixtures were prepared by varying mass percentages of authentic BD (15%, 30%, 45%, 60%, 75%, and 90%). The viscosities of the (BO + authentic BD) mixtures, were determined using the Brookfield rheometer. We obtained Equation 2 through regression analysis, using a linear fit ($R^2 = 0.997$). Based on these data, the students were able to calculate the biodiesel yields from viscosity measurements data.

$$\ln(\eta/mPa\ s) = -0.02445 \times BD\ mass\% + 3.6288 \quad (2)$$

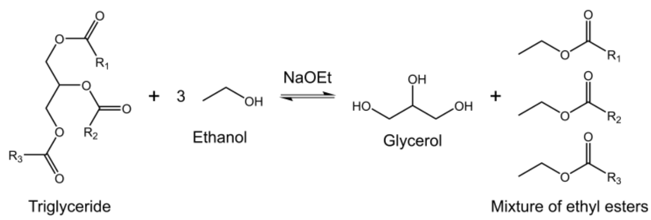
2.3. Hazards

Ethanol poses hazards of flammability and toxicity. BO is combustible; sodium ethoxide-, and HCl solutions are corrosive. There are no significant hazards in this project that require precautions other than wearing personal protective equipment. All liquid wastes were collected and sent to the safety division of ChemUSP.

3. Results and Discussion

3.1. Relevance of the Project

As stated in Introduction, the project is on base-catalyzed synthesis of BD, see **Scheme 2**.



Scheme 2. General scheme for transesterification of a triglyceride with ethanol in the presence of base catalyst, sodium ethoxide (NaOEt)

The production/economics/environmental impact of BD are issues of great relevance, both locally and worldwide. For example, most cargo in Brazil is transported by trucks, resulting in the consumption, during 2022, of 63.23 billion liters of diesel fuel, containing 6.62 billion liters of BD [7]. Depending on the source of BD, its greenhouse gas emissions are 40 to 86% less than those generated by burning petroleum-based diesel oil [8]. There is a continuous debate regarding the use of edible oils for BD production [9], and the need to increase the use of nonedible-, and waste oils/fats for this purpose [10], both locally [11], and worldwide [12]. In this regard, the Amazon region is an important source of oils/fats, produced from wild and cultivated plants, that are not used for food because they are highly saturated, as is the case of BO [13].

3.2. Preparation in High School for ChemUSP Visit

After we informed the students about the HS-ChemUSP project, see Scheme 1, we gave a pre-visit questionnaire on aspects of biofuels, including:

Q1-pre: Give examples of commercial biofuels;

Q2-pre: What are the starting materials for the biofuels that you mentioned?;

Q3-pre: Give two environmentally important effects resulting from using biofuels;

Q4-pre: Do you know how biodiesel is commercially produced?

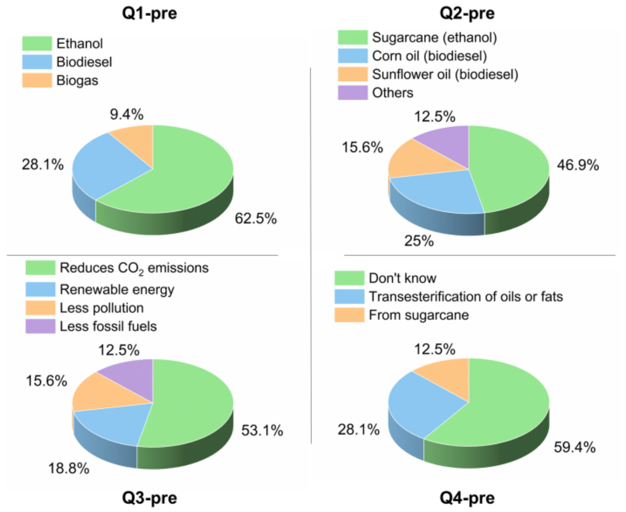


Figure 2. Summary of the students' answer to the first questionnaire, Q-pre. The questions were: give examples of commercial biofuels (Q1-pre); what are the starting materials for the biofuels that you mentioned (Q2-pre)?; give two environmentally important effects resulting from the use of biofuels (Q3-pre); do you know how biodiesel is commercially produced (Q4-pre)?

A summary of the students´ answers to these questions is shown in **Figure 2**. The answers to Q1-pre were expected because ethanol alone was introduced in Brazil as a biofuel for passenger cars in 1975, and flex-fuel cars that run on gasoline, ethanol, and any mixture of these two fuels were introduced locally in 2003 [14]. Regarding Q2-pre, we were surprised by the percentage of answers that indicated the use of corn-, and sunflower oils for making BD because soybean oil is, by far, the main vegetable oil employed to make BD in Brazil, 71.2% in 2021 [15]. The answer to Q3-pre shows the awareness of the students about the (positive) environmental impact of using biofuels instead of petroleum-based fuels. The answers to Q4-pre reflect the fact that oils and fats are discussed only scantly during their chemistry course. This project, therefore, also fills an information gap about oils/fats and practical aspects of biofuels.

After discussing the results of the above-mentioned questionnaire, we explained the following, in each school:

(i) The results from the students of the three schools will be employed together;

(ii) The students will use ethanol for BD production because it is much less toxic than (frequently employed) methanol [16], and because Brazil is the world 2nd largest producer of ethanol [17];

(iii) Sodium ethoxide, not alcoholic KOH, will be used as catalyst to avoid eventual hydrolysis of the triglycerides, leading to soap formation and difficulty in oil/aqueous solution phase separation.

After a discussion of a supplied list of Amazon region oils/fats [13], the students decided to use BO, based on its availability at a low price. We then explained details of the visit to ChemUSP, including safety precautions (using a laboratory coat; safety goggles, and gloves); duration of the visit (8 hours, including lunch time); the setup of the experiment, the workup of the produced BD, and demonstration of advanced analytical equipment at CAL (Shimadzu model msQP2010 GC equipment, and Shimadzu LC20AD liquid chromatography equipment).

Table 1. Synthesis of biodiesel by the high school students from babassu oil (BO) and ethanol (EtOH), using a sodium ethoxide/EtOH solution as a catalyst

Synthesis No.	BO volume, mL	EtOH volume, mL[a]	Cat. volume, mL[b]	Reflux time, min	HCl volume, mL[c]	Biodiesel yield[d]
1	12	7.8 (12)	3.3	45	3.3	83.0%
2	12	7.8 (12)	3.3	105	3.3	92.3%
3	12	3.1 (6)	2.5	75	2.5	40.8%
4	12	5.4 (9)	2.9	45	2.9	60.3%
5	12	5.4 (9)	2.9	75	2.9	62.6%
6	12	5.4 (9)	2.9	75	2.9	61.3%
7	12	3.1 (6)	2.5	45	2.5	38.4%
8	12	3.1 (6)	2.5	105	2.5	44.1%
9	12	5.4 (9)	2.9	105	2.9	64.4%
10	12	7.8 (12)	3.3	75	3.3	91.0%
11	12	5.4 (9)	2.9	75	2.9	63.8%
12	12	5.4 (9)	2.9	75	2.9	62.4%
13	12	5.4 (9)	2.9	45	2.9	61.4%
14	12	5.4 (9)	2.9	105	2.9	65.9%

a- Commercial absolute ethanol 99.8% pure was used. The numbers within the brackets refer to ethanol/babassu oil molar ratio ($\chi_{EtOH/BO}$), based on a molar mass of 654.37 g mol^{-1} for BO [18];

b- Freshly prepared sodium ethoxide, concentration 0.152 mol L^{-1}; final (constant) concentration = 0.022 mol L^{-1};

c- Volume of the 0.15 mol L^{-1} HCl solution added at the end of the reaction to neutralize the base catalyst. This treatment applies only to the first washing;

d- Biodiesel yield, determined by viscosity after drying of the product (BO + BD).

3.3. Activities at ChemUSP

During all activities in the undergraduate laboratory of ChemUSP, the students of each school were accompanied by *at least five persons*, including, their teacher, two graduate students, one staff member from ChemUSP, and the laboratory technician. The 60 participating students were divided into 14 groups, each of four or five; they carried out the experiments in 3 different days, over a three-week period. These groups used different experimental conditions (of time and $\chi_{EtOH/BO}$) that we generated using the Statistica software. The activities at ChemUSP involved: synthesis, purification and (partial) drying of BD; determination of the acid number of BO and that of a recycled frying oil, and a visit to CAL.

For safety, we closely supervised the steps of the whole experiment, for details of the experiments see **Table 1**. These steps included: adjusting the temperature of the heating bath; assembly of the glassware; introduction of BO, EtOH and the catalyst (sodium ethoxide/EtOH) into the reaction flask; reflux of EtOH for the required time (45 to 105 minutes), cooling and washing of BD with NaCl solution, partial drying of BD. Because oil/water phase separation is relatively slow, we told the students no to dwell on mass of the produced BD, or its visual aspect after drying with $MgSO_4$, clear or slightly turbid. There were no accidents, except breaking one red spirit-filled immersion thermometer! During the EtOH reflux time, the students did two activities: determination of AN of fresh BO and a recycled frying oil, and a visit to CAL, in groups of 8 each, where they were introduced to analysis by GC/MS and HPLC. The visit to ChemUSP ended when the students turned in their BD samples. These were further dried by heating under reduced pressure (vacuum oven). We measured the viscosities of the samples, and the results were sent back to the schools, along with a calibration curve of viscosity x BD mass% (in mixtures of BO plus authentic BD) [6].

3.4. Activities in the Schools after the Visit to ChemUSP: Project Conclusion and Evaluation

After the visit to ChemUSP, the professors in the schools gave a post visit questionnaire Q-post, that is a modified version of Q-pre, with focus on BD. The answers to Q1-post are now focused on BD; the vegetable oils mentioned in Q2-post now include BO, because they used this oil at ChemUSP; the answers to Q3-post and Q4-post show greater awareness of the environmental impact of using diesel oil-BD blends instead of pure diesel oil, and knowledge of the industrial process for obtaining BD, respectively (see **Figure 3**).

In subsequent activities in the schools, the students made presentations about their visits to ChemUSP, and the chemistry teachers discussed with the students the following points: (i) the significance of large difference between the AN of a fresh oil (BO), and that after being used for frying (0.99-, versus 5.11 mg KOH/g oil, respectively), with emphasis on the adverse (health-related) effects of using oils and fats that were degraded/oxidized during repeated use in frying as, especially, in fast food restaurants [9]; (ii) the significance of the statistical data generated from the combined results of the students of the three HSs. This analysis produced (Vilfredo) Pareto chart, see **Figure 4**; the response surface shown in **Figure 5**, and the corresponding Equation 3, *vide infra*. According to Pareto principle, roughly 80% of the desired outcomes of processes, here BD production, are principally affected by 20% of the variables [19]. Consequently, in a process with several experimental variables, e.g., concentrations of the reactants, reaction time, reaction temperature, catalyst concentration, etc., it is more efficient to concentrate on those (20%) variables that affect the process outcome; *leading to material and labor saving, and generation of less waste*.

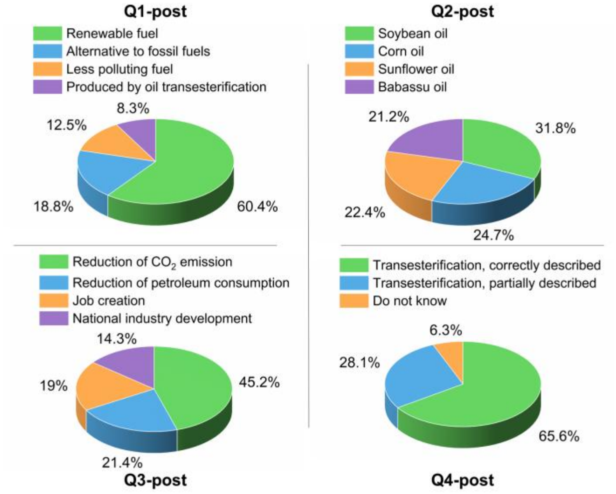


Figure 3. Summary of the students' answer to the post visit questionnaire. The questions were: what is biodiesel (Q1-post)?; what are the starting materials for making biodiesel (Q2-post)?; what is the importance of introducing BD to: (i) the environment (give two environmentally important effects resulting from the use of biofuels), (ii) the Brazilian economy (Q3-post)?; how is BD produced industrially (Q4-post)?

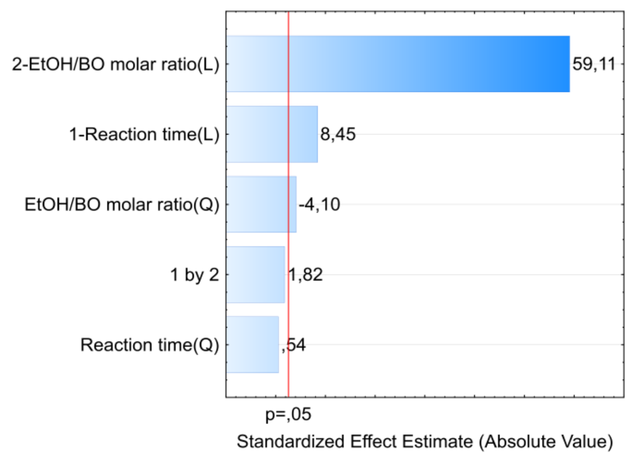


Figure 4. Pareto chart showing the effects of the reaction composition, given by $\chi_{EtOH/BO}$, and reaction time on the yield of biodiesel. The red vertical line shows the limit of significance above which the variable affects BD production. As indicated by the values of the horizontal lines, 59.11 and 8.45, the effect of increasing $\chi_{EtOH/BO}$ on BD yield is much larger than increasing the reaction time at the studied variables range. The letters (L) and (Q) at the end of the terms represents linear or quadratic, respectively

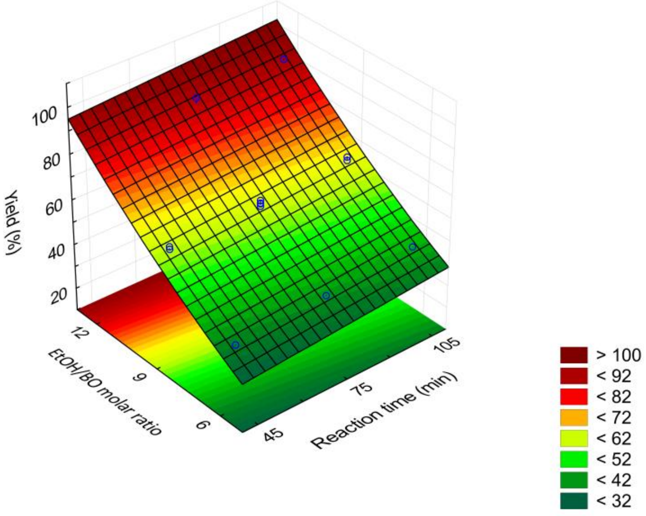


Figure 5. The response surface for the synthesis of biodiesel from babassu oil. The 3D graph shows the dependence of the BD yield (Z-axis) on the two experimental values studied, reaction time and composition (EtOH/BO molar ratio)

In our project, only two variables were tested namely, $\chi_{EtOH/BO}$ and reaction time (t), the catalyst concentration and reaction temperature (= b.p. of EtOH) were kept constant. Therefore, the Pareto chart in **Figure 4** shows clearly that under these conditions, the reaction composition affects BD yield much more that reaction time, probably because the transesterification reaction is an equilibrium that is shifted to product (BD) by using larger $\chi_{EtOH/BO}$. Note that the crossed terms, $\chi_{EtOH/BO}$ x t, and the quadratic one (reaction time)^2 are below the statistically significance (red vertical) line, hence are not important (for BD production). In fact, these terms were included in the analysis by the Statistica software to enhance the quality of the correlation; without having a physical meaning.

The students´ results were also depicted in a 3D plot, the response surface (**Figure 5**), showing the dependence of BD yield on reaction time and $\chi_{EtOH/BO}$. This representation is didactic because it is color-coded, starting from dark green to dark red, corresponding to low- to high BD yield, respectively. The satisfactory fit of a linear model to the data is due to the limited ranges of the variables, imposed by available laboratory time. Consequently, the reaction has not reached equilibrium. When reaction time is not a constraint, quadratic models fit the results of BD synthesis better, e.g., for waste cooking oil [20,21], palm oil [22,23], and sunflower oil [24]. The 3D plot generated the following equation (Eq. 3; R^2 = 0.994), where the regression coefficients (*based on reduced values*) show the much higher importance to BD yield of $\chi_{EtOH/BO}$, relative to reaction time (t), in agreement with Pareto graph of **Figure 4**.

$$\text{Biodiesel yield, m\%} = 38.15 + 5.90\,t + 39.0\,\chi_{EtOH/BO} + 8.7\,\chi^2_{EtOH/BO} \quad (3)$$

We were satisfied because the students evaluated the subject of this project positively, and appreciated the contact with ChemUSP/visit to CAL, as shown by the following selected excerpts: (i) This project showed what a twelfth-grade student can do, and increased my knowledge about the chemistry of biodiesel. I suggest that this project is run over a longer time, so that we have the opportunity to acquire more knowledge about the subject; (ii) A very good project, I wish that the University of São Paulo offers more similar opportunities, arrange meetings with university students, and invites us to classes about subjects of public interest; (iii) this project showed me interesting aspects of chemistry as a career; (iv) I liked the project a lot, because it corrected the impression that the university environment is something very different from that of the school.

4. Conclusions

ESD was introduced to students of three different HSs by using a hand-on approach, that involved pre- and post-activities in the HSs. The questionnaires given before and after the visit to ChemUSP showed an increased awareness of the students about the socioeconomic and environmental impacts of using diesel oil-BD blends. The activities at ChemUSP involved synthesizing BD, and contact with advance analytical instrumentation at CAL. It increased the interests of the students in green chemistry, especially as applied to solve an environmentally important problem, viz., reduction of greenhouse gas emission. This project shows applications of the principles of green chemistry: use of renewable feedstocks; use of statistics to achieve better yields [25]. We recommend its use due to the environmental relevance of BD, its simplicity, low cost, safety of the experimental part, and because it brings the school closer to the university.

ACKNOWLEDGEMENTS

We are grateful to the students who participated in this project. We thank Professor Dr. Pedro V. de Oliveira of ChemUSP for his support and encouragement, Professor Priscila Teixeira Rivero (Luiz G. Righini HS) for her help, Alexandre S. Guarezemini (ChemUSP), Flavio Crispim (Humboldt College) for their competent technical support in the undergraduate laboratory, Angelica Maria S. de Oliveira and Francenilda C. P. Ciferi for their help with visits logistics. We acknowledge FAPESP (grant 2014/22136-4) and CNPq (grants 306108/2019-4; 141853/2019-0) for research fellowships for O. A. El Seoud and N. Keppeler, respectively.

REFERENCES

[1] UNESCO, UNESCO Roadmap Education for Sustainable Development, (2014) 1–38. https://en.unesco.org/sites/default/files/roadmap_1.pdf.

[2] O. US EPA, Basics of Green Chemistry, Us Epa. (2022).

https://www.epa.gov/greenchemistry/basics-green-chemistry.

[3] UN environment programme, Facts about the climate emergency, UN Environment Programme. (2021). https://www.unep.org/facts-about-climate-emergency.

[4] United Nations, Education is key to addressing climate change, United Nations. (2016). https://www.un.org/en/climatechange/climate-solutions/education-key-addressing-climate-change.

[5] D.D. Dill, Cutting the Cake: The Relationship between School and College, The High School Journal. 60 (1997) 287–301.

[6] O. A. El Seoud, N. Keppeler, M. Helena Zambelli, Sustainable Fuels for High School Students: Synthesis of Biodiesel from an Amazon Region Oil (Babassu), J Lab Chem Educ. 11 (2023) 1–6. https://doi.org/10.5923/j.jlce.20231101.01.

[7] Marta Nogueira, Vendas de combustíveis por distribuidoras crescem 2,5% em 2022; diesel bate recorde, diz ANP, Cable News Network Brasil. (2023). https://www.cnnbrasil.com.br/economia/vendas-de-combustiveis-por-distribuidoras-cresce m-25-em-2022-diesel-bate-recorde-diz-anp/.

[8] H. Xu, L. Ou, Y. Li, T.R. Hawkins, M. Wang, Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States, Environ Sci Technol. 56 (2022) 7512–7521. https://doi.org/10.1021/acs.est.2c00289.

[9] R. Sterk, Food vs. fuel debate reemerges after surge in edible oils prices, Food Business News. (2021). https://www.foodbusinessnews.net/articles/19023-food-vs-fuel-debate-reemerges-after-surge-in-edible-oils-prices.

[10] M.M. Gui, K.T. Lee, S. Bhatia, Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock, Energy. 33 (2008) 1646–1653. https://doi.org/10.1016/j.energy.2008.06.002.

[11] A. da S. César, D.E. Werderits, G.L. de Oliveira Saraiva, R.C. da S. Guabiroba, The potential of waste cooking oil as supply for the Brazilian biodiesel chain, Renewable and Sustainable Energy Reviews. 72 (2017) 246–253. https://doi.org/10.1016/j.rser.2016.11.240.

[12] M.R. Teixeira, R. Nogueira, L.M. Nunes, Quantitative assessment of the valorisation of used cooking oils in 23 countries, Waste Management. 78 (2018) 611–620. https://doi.org/10.1016/j.wasman.2018.06.039.

[13] J.L. Serra, A.M. da C. Rodrigues, R.A. de Freitas, A.J. de A. Meirelles, S.H. Darnet, L.H.M. da Silva, Alternative sources of oils and fats from Amazonian plants: Fatty acids, methyl tocols, total carotenoids and chemical composition, Food Research International. 116 (2019) 12–19. https://doi.org/10.1016/j.foodres.2018.12.028.

[14] Rapid Transitions Alliance, The Rise of Brazil's Sugarcane Cars, Soapbox. (2018). https://rapidtransition.org/stories/the-rise-of-brazils-sugarcane-cars/.

[15] A.Y. Milanez, G.B. da S. Maia, D.D. Guimarães, C.L.A. Ferreira, Biodiesel e diesel verde no Brasil: panorama recente e perspectivas, Bndes. 28 (2022) 41–71. https://web.bndes.gov.br/bib/jspui/handle/1408/22585.

[16] A. Youssef, K. Madkour, C. Cox, B. Weiss, Comparative lethality of methanol, ethanol and mixtures in female rats, Journal of Applied Toxicology. 12 (1992) 193–197. https://doi.org/10.1002/jat.2550120308.

[17] Petroleum & Refinery, Distribution of ethanol production worldwide in 2022, by country, Statista. (2023). https://www.statista.com/statistics/1106345/distribution-of-global-ethanol-production-by-country/.

[18] M. GROOTVELD, C.J.L. SILWOOD, P. ADDIS, A. CLAXSON, B.B. SERRA, M. VIANA, HEALTH EFFECTS OF OXIDIZED HEATED OILS1, Foodservice Research International. 13 (2001) 41–55. https://doi.org/10.1111/j.1745-4506.2001.tb00028.x.

[19] BYJU'S, Pareto Chart, (2023). https://byjus.com/maths/pareto-chart/.

[20] H. Kumar, A.A. Renita, A. Anderson, Response surface optimization for biodiesel production from waste cooking oil utilizing eggshells as heterogeneous catalyst, Mater Today Proc. 47 (2021) 1054–1058. https://doi.org/10.1016/j.matpr.2021.06.244.

[21] L. Costarrosa, D. Leiva-Candia, A. Cubero-Atienza, J. Ruiz, M. Dorado, Optimization of the Transesterification of Waste Cooking Oil with Mg-Al Hydrotalcite Using Response Surface Methodology, Energies (Basel). 11 (2018) 302. https://doi.org/10.3390/en11020302.

[22] B.H. Hameed, L.F. Lai, L.H. Chin, Production of biodiesel from palm oil (Elaeis guineensis) using heterogeneous catalyst: An optimized process, Fuel Processing Technology. 90 (2009) 606–610. https://doi.org/10.1016/j.fuproc.2008.12.014.

[23] N.N. Saimon, N. Ngadi, M. Jusoh, Z.Y. Zakaria, A Two-Step SO3H/ICG Catalyst Synthesis for Biodiesel Production: Optimization of Sulfonation Step via Microwave Irradiation, Bulletin of Chemical Reaction Engineering & Catalysis. 16 (2021) 63–75. https://doi.org/10.9767/bcrec.16.1.9613.63-75.

[24] M. Athar, S. Zaidi, S.Z. Hassan, Intensification and optimization of biodiesel production using microwave-assisted acid-organo catalyzed transesterification process, Sci Rep. 10 (2020) 21239. https://doi.org/10.1038/s41598-020-77798-1.

[25] P.T. Anastas, J.C. Warner, Green chemistry: theory and practice, 2000th ed., Oxford University Press, Oxford, 1998.