Optimized biodiesel production from *Ricinus communis* oil using CaO, C/CaO and KOH catalysts under conventional and ultrasonic conditions

Ehsan Houshyar[1*], Mahmood Mahmoodi-Eshkaftaki[1], Askar Ghani[2], Renato Arazo[3]

(1. Department of Mechanical Engineering of Biosystems, College of Agriculture, Jahrom University, 74135-111, Jahrom, Iran;
2. Department of Horticultural Science, College of Agriculture, Jahrom University, 74135-111, Jahrom, Iran;
3. College of Engineering and Technology, University of Science and Technology of Southern Philippines, 9004 Philippines)

Abstract: This paper introduces a cheap local *Ricinus communis*, which grows in Jahrom, a warm region of southwest Iran, as a renewable energy source. Biodiesel production was investigated by employing CaO and C:CaO as heterogeneous catalysts and KOH as a homogenous catalyst. Conventional and ultrasonic-assisted methods were used considering different methanol to oil molar ratios (4:1, 6:1 and 8:1) and different temperatures (40˚C, 50˚C and 60˚C). The optimized production condition was assessed by response surface methodology (RSM). The results showed that the most suitable catalyst was C:CaO with a methanol to oil molar ratio of 6:1 and temperature of 60˚C. Using carbon with CaO increased biodiesel yield by around 20% compared to CaO alone. In all conditions, ultrasonic assistance improved biodiesel yield compared to the conventional method by around 11%. Furthermore, the biodiesel content increased with increasing ultrasonic power from 100 to 400 W. The properties of the produced biodiesel from Iranian castor oil meet the requirements of the EN 14214 biodiesel standard. Optimization of the biodiesel production under ultrasonic condition using RSM shows that the best temperature is 46.81℃ and the methanol to oil molar ratio is 5.25 by Cao:C catalyst.

Key words: biodiesel; bubble washing; optimized production; waste oil

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1 Introduction

Biodiesel, as a renewable and non-toxic source of energy, is mainly obtained from the transesterification of fats and oils. This fuel's chemical and physical properties are better than petroleum diesel and have less environmental effects than conventional diesel fuel. Some better properties are higher flash point, better lubricating efficiency, lower sulphur concentration and few polluting outputs (Busari and Olaoye, 2020). In engines, the unburned hydrocarbons and CO emissions are reduced by about 50% when petroleum-based diesel fuel is replaced with biodiesel (Fangsuwannarak et al., 2016). Although biodiesel has the potential to replace some percentage of petroleum diesel, it seems that the main barrier to widespread biodiesel production and consumption is the high price of plant oil and some

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***Corresponding author: Ehsan Houshyar,** Department of Mechanical Engineering of Biosystems, College of Agriculture, Jahrom University, Jahrom, Iran. Email: Houshyar.e@gmail.com.

processing technologies. In this paper, we introduce *Ricinus communis* as an oil plant that grows well in Jahrom city in Iran. The literature revealed that the optimum average temperature for castor production is 24˚C and 27˚C with the highest temperatures of 30˚C (Severino et al., 2012). However, we have found this crop at Jahrom climate with the mean, minimum and maximum annual temperatures of 20.8˚C, 11˚C, 44˚C, respectively which shows that Jahrom is a suitable place for *Ricinus communis* growing.

Some biodiesel production methods include pyrolysis, micro-emulsions and transesterification (Zhang et al., 2023). Most research have focused on alkali-catalyzed technology. Since the solid catalysts can be easily recovered and reused, the heterogeneous catalytic process seems better than the homogeneous process (Yadav and Sharma, 2018). Calcium oxide (CaO) is a suitable heterogeneous basic catalyst for biodiesel transesterification, leading to less wastewater than homogeneous catalysts (Leung et al., 2010). However, it should be used with some compounds like carbon to enhance the efficiency of CaO.

Jahrom is located near the south of Iran, having a warm climate. However, no study has been conducted to clarify the potential of biodiesel production from the available local *Ricinus communis* oil in this area. As far as we know, this is the first study on biodiesel production from *Ricinus communis* oil by introducing CaO and C:CaO catalysts. In addition, different methods (conventional and ultrasonic-assisted) and different temperatures under other methanol-to-oil molar ratios were considered.

2 Materials and methods

2.1 Seed gathering and oil extraction

The oil seeds were gathered from the local *Ricinus communis* plants cultivated in the warm climate of Fars province (Jahrom City, Southwest Iran). The minimum and maximum temperatures in this province are 11˚C and 44˚C, respectively. The annual precipitation is around 210 mm and the relative humidity reaches 42%. The seeds were dried for two weeks in the sunny open air. The cold mechanical pressing (40 rpm) was used to extract castor seed oil. Sediments and additional materials were removed from the oil using filtration. Then, the oil was stirred for 2 h at 100˚C to evaporate the water content to be ready for reaction in the biodiesel production procedure.

2.2 GC conditions

The fatty acid analysis was carried out based on the global method IOOC (Piravi-Vanak et al., 2009). The fatty acid biodiesel was prepared according to IOOC method (Piravi-Vanak et al., 2009). Methylated fatty acids were analyzed using gas chromatography (YL6500GC, Young-Lin Inc., Korea) equipped with a capillary column CP-Sil 18 (60 m × 0.25 mm; particle size) and flame ionization detector (FID). Hydrogen was used as the carrier gas, and the injection quantity was 1.2 μL with a flow rate of 4 mL min^{-1}. The temperature conditions of the chromatograph were as follows: injector 250˚C, oven 175˚C (isothermal condition) and detector 300˚C.

2.3 Ultrasonic processor equipment

A new ultrasonic set-up was used to carry out the research experiments, including a processor, sonotrode, and PC controller (Hielscher Model, UPC400T, USA). An ultrasonic processor (Hielscher Model UP400S, USA) was used to perform the transesterification reaction. The processor operated at 400 W and 30 kHz frequency. The titanium sonotrode (H22D, diameter = 22 mm, length = 100 mm) was used to transmit the ultrasound wave into the liquid (Hawash et al., 2009).

2.4 Esterification and transesterification reactions

Since the oil's acidity was higher than 1% (see Section 3.1.), the esterification reaction was employed to reduce the concentration of free fatty acids (FFAs) and convert them into biodiesel. The prepared filtered castor oil was reacted with a mixture of methanol and sulphuric acid at 60˚C for 1 h using a magnetic stirrer. Then, the mixture was poured into a separator funnel and kept at room temperature for 72

h. The main products, i.e. biodiesel and triglyceride, were separated from by-products, i.e. water, methanol and sulphuric acid. After this stage, the oil's acidity was expected to be lower than 1%, ready for the following process – transesterification.

In the next stage, the conversion of fatty acid methyl ester (FAME) from crude oil occurs in a process known as transesterification (Yadav and Sharma, 2018). One of this study's objectives was to investigate ultrasonic waves on biodiesel yield from castor oil. Effects of catalysts, temperatures, and methanol to oil molar ratio were also considered as variables of experiments. Accordingly, the experimental variables were: (1) two types of experimental condition: conventional and ultrasonic-assisted conditions, (2) three types of catalyst: CaO, C:CaO (2% activated carbon to support CaO) and KOH, (3) three levels of molar ratio of methanol to oil: 4:1, 6:1 and 8:1 v/v, and (4) three levels of temperature: 40˚C, 50˚C and 60˚C.

For the conventional treatment, the extracted and filtered crude oil was heated to convert triglycerides into di- and mono-glycerides and to remove FFAs. KOH was selected as a homogenous catalyst and methanol as an alcohol. Apparently, the alkaline metal alkoxides are selected as these are the most active catalysts, giving a very high yield (> 98%) in a short reaction time of about 30 min (Helwani et al., 2009). The KOH (grade 99%), CaO (grade 99%) and methanol (grade 99.9%) were supplied from Chemical Industries. The mixture of methanol and each catalyst was added to heated oil (50˚C) and mechanically mixed to obtain the maximum FAME production. In the conventional experiments, a mechanical mixer was used when temperature was controlled by a warm water bath.

For the ultrasonic treatment, the mixture of methanol and each catalyst was agitated using a magnetic stirrer for 5 min to form the methoxide and water. Then, *Ricinus communis* oil was mixed with the previously prepared methoxide in a conical flask. Afterward, the mixture was subjected to ultrasound waves. Subsequently, the solution was treated with concentrated sulfuric acid to stop the reaction immediately. Finally, three phases were observed: i.e. (a) water and methanol at the top, (b) biodiesel at the middle, and (c) glycerin at the bottom. A flask separator separated the biodiesel. The catalyst was separated by high-speed centrifugation. The excessive methanol was distilled using rotational evaporation under 150 rpm and 50˚C.

After removing the glycerin layer, a new bubble-washing process was used in this study (see Section 2.5). Next, the remained biodiesel was put into a refrigerator for next gas chromatography analyses.

2.5 Bubble washing of biodiesel

In bubble washing, a layer of water is at the bottom, and the biodiesel floats on top. An aquarium stone sits at the bottom of the tank producing bubbles. A pump was used to make air bubbles through the water and the biodiesel. Water was carried with the bubbles through biodiesel, dissolving impurities. When a bubble reached the top, it popped, and the water sunk back through the biodiesel, collecting more impurities as it went back down. Bubble washing reduces the risk of making an emulsion, especially on the first biodiesel washing when soap concentration is highest (Saranya and Shanthakumar, 2021). It needs much less water than other methods, such as water washing. However, the main disadvantage is the time it takes to complete (Starbuck and Harper, 2009).

Usually, a uniform tank is used for biodiesel bubble washing. A new bubble washing tank was designed in this study to reduce the washing time while increasing efficiency. The proposed tank included three stages, a layer of water at the bottom and biodiesel at the top poured in each stage. Two air stones were put on each stage, and all the stones were linked to a central pump. At the first washing, the pump was used at a low speed by pumping 10 m^3 h^{-1} air to gather the impurities gently. Next, the pump ran at a higher speed by pumping 35 m^3 h^{-1} air (as an evaporator) to reduce water and alcohol contents. In

order to increase the efficiency, the materials in the tank (including water and biodiesel) were warmed in the water bath (50˚C) surrounding the tank. The necessary time to washing biodiesel was around 8 h indicating that around 40% of the time can be saved with this tank compared to usual uniform tanks (Starbuck and Harper, 2009).

2.6 Determination of biodiesel properties

GC/MS (GC: VARIAN CP-3800; MS: VARIAN Saturn 2200) was used to analyze the FAMEs. After the separation of glycerin and washing and drying of biodiesel to remove impurities, the product's mass was measured. Considering the compositions of FAME, the iodine value (*IV*= gr) and saponification value (*SV*= mg) were calculated using Equations 1 and 2 (Kalayasiri et al., 1996):

$$IV = \frac{\sum(245 \times D \times A_i)}{MW_i} \quad (gr) \qquad (1)$$

Where:

A_i is the percentage, D is the number of double bonds and MW_i is the molecular mass of each component.

$$SV = \frac{\sum(560 \times A_i)}{MW_i} \quad (mg) \qquad (2)$$

According to the iodine value (IV) and saponification value (SV), cetane number (CN) and higher heating value (HHV) of FAMEs were calculated using Equations 3 and 4 (Krisnangkura, 1986):

$$CN = \frac{46.3+54.58}{SV-0.225} \times IV \qquad (3)$$

$$HHV = 49.43 - [0.041\ (SV) + 0.015\ (IV)] \qquad (4)$$

Kinematic viscosity at 40˚C was obtained using Cannon-Fenske viscometer. The pour point and cloud point were determined simultaneously by using Tanaka Mini Pour/Cloud Point Tester (Model MPC-101A). For flash point, Tanaka Automatic Cleveland Open Cup Flash Point Tester (Model ACO-5) was used. The measurement of the density was done by Metler-Toledo densimeter at 15˚C.

3 Results and discussion

3.1 Characteristics of extracted castor oil

The previous studies have shown that the oil content in castor seeds varies from 47% to 49% (Weiss, 2000) and rarely reaches 55% (Anjani, 2012), while the oil content of our local castor seeds was 44.5%. In another research, the reported oil content of different Iranian castor was 35%-56% (Alirezalu et al., 2011). Tables 1 and 2 show the FFAs compositions of the extracted castor oil in Iran and other countries. The profile of FFAs compositions shows the quality of the oil. The amount of palmitic and stearic acids, as saturated fatty acids, are 0.51% and 0.36%, respectively. It is reported that palmitic and stearic acids are in the range of 0.61%-1.6% and 1.13%-2.29%, respectively, in different Indian *Ricinus communis* oil (Lavanya et al., 2012). The amount of oleic acid, as a mono-unsaturated fatty acid, is 3.93% which is lower than that of peanut 53%, soybean 24.9%, rapeseed 33% and sunflower 25% (Ramos et al., 2009). The oleic to linoleic acid ratio (O/L acid ratio) is 1.2. Both the O/L ratio and IV reveal the stability and shelf life of the oil. Indeed, the oil with a higher O/L ratio and lower IV is more stable.

The amount of ricinoleic acid as a monounsaturated fatty acid is around 88%. A high level of ricinoleic acid up to 900 g kg^{-1} was reported earlier (Rojas-Barros et al., 2004). Although our local castor oil presents high oxidative stability since it includes high oleic acid, but high ricinoleic acid affects this characteristic (Knothe, 2008). It may also need much work for pharmaceutical applications due to the high level of ricinoleic acid (Rojas-Barros et al., 2004). However, the amount of ricinoleic acid in castor oil is lower than those reported in Angola and USA (Alirezalu et al., 2011).

The range of acid number of our castor oil was similar to the Malaysian castor oil of 4.9 mg KOH/g oil (Salimon et al., 2010). The saponification value of 180.8 mg KOH/g oil is close to the value reported by other studies (Awais et al., 2020; Salimon et al., 2010). Molecular weight, unsaturated fatty acid

components concentration, and the number of double bonds in the fatty acids all affect the SV and IV.

Table 1 Fatty acid composition (%) and properties of raw Castor oil from Iran

Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3	Ricinoleic C18:1
0.51	0.36	3.93	3.28	1.75	88.2
Acid number (mg KOH/g oil)	**Saponification value (mg KOH/g oil)**	**Iodine value g I_2/100 g oil**	**Carbonyl Number**	**Total Phenolic content (mg g^{-1})**	**Total tocopherol (mg g^{-1})**
4.73	180.8	85.3	5.3	118	85.8

Table 2 Fatty acid composition (%) of Castor oil in different countries (Alirezalu et al., 2011)

Location	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Ricinoleic acid
Angola	1	0.7	2.9	4.3	0.6	89.4
Brazil	1	0.8	3.3	4.2	0.5	88.9
India	1.1	1	3.1	4.7	0.5	88.4
USA	0.9	0.8	2	4.3	0.6	90.3
Iran	0.9-2.43	0.55-1.87	3.06-6.13	1.15-4.73	0.7-2.88	85.72-88.94

3.2 Properties of obtained biodiesel from castor oil

The obtained biodiesel has an acid number of 0.12±0.05 mg KOH/g oil (Table 3) which meets the requirements of standard ASTM D664 (0.5 at max). This value is close to that of other study by Knothe et al. (2012) as 0.148 mg KOH/g oil. However, it is lower than the acid number of biodiesel from Jatropha reported by Gonz ález (2016). The flash point of the castor oil biodiesel is 161.5˚C±2˚C which is close to the value reported by Cvengroš et al. (2006) at 167˚C. It is also comparable to that of biodiesel from sunflowers, with reported value of 164.5˚C (Barontini et al., 2015). But it was higher than the biodiesel from Atlas pistachio with 148 ˚C flash point (Samani et al., 2016).

The biodiesel cloud and pour points are -9 and -18, respectively. The literature review has shown that these properties can be varied in a wide range of -2 to -60 (Ahmad et al., 2007). The calculated CN value of local castor oil biodiesel was 52.9±0.5, which is suitably in a satisfactory range for engines. The result is similar to studies by Roy et al. (2020) and Silitonga et al. (2016). Difficult starting, exhaust smoke, and noise are the outcomes of using fuels with low CNs in diesel engines. Generally, the CN above 50 (min 51 according to EN 14214) is suitable for diesel engines.

The kinematic viscosity of the biodiesel is 7.12±0.05 cSt. The studies of Ijaz et al. (2016) obtained a kinematic viscosity of 2.45 cSt and Okechukwu et al. (2015) reported a value of 6.48 cSt of the biodiesel from castor oil in Pakistan and Nigeria, respectively. Some studies have reported higher values of around 11-13 cSt for the viscosity of biodiesel from castor oil (Knothe et al., 2012; Cvengroš et al., 2006).

Table 3 Biodiesel properties of Iranian Castor oil

Acid number (mg KOH/g oil)	Cetane number	Flash point (˚C)	Cloud point (˚C)	Pour point (˚C)	Sulfur content (mg kg^{-1})	Kinematic viscosity at 40˚C (cSt)
0.12±0.05	43.4±0.5	161.5±2	-9±1.1	-18±1.5	0.23±0.02	7.12±0.05

3.3 Effects of experimental conditions on the biodiesel yield

3.3.1. Effect of catalysts on the biodiesel production

Combination of C:CaO (2:3) resulted in highest biodiesel yield for both the conventional and ultrasonic-assisted methods. Figure 1 shows that biodiesel yield increased by around 12% for conventional and approximately 15% for ultrasonic-assisted samples when C:CaO was used compared to KOH. Carbon supported CaO resulted better since the biodiesel yield increased around 20% when C:CaO was used *vs.* CaO. Some studies have reported that carbon or fly ash increases the activity of CaO (Hadiyanto et al., 2016; Nurfitri et al., 2013).

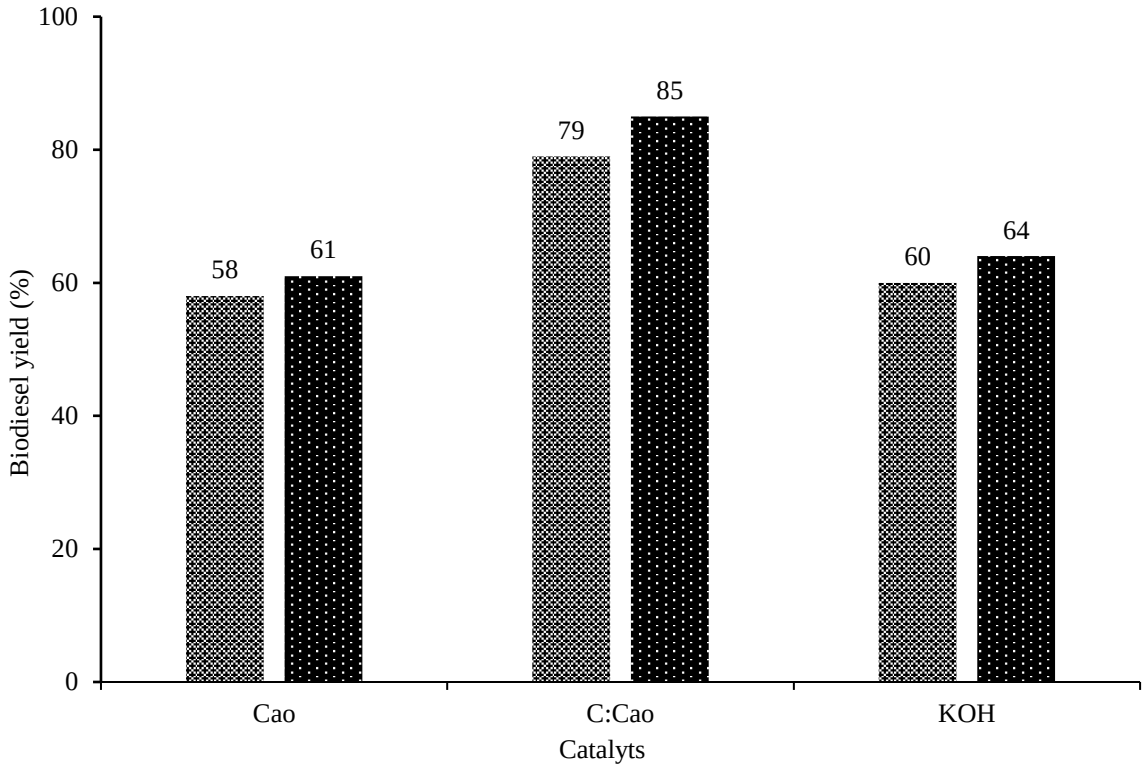


Figure 1 Biodiesel yield of different catalyst

3.3.2 Effect of temperature

Temperature effects on the biodiesel yield for both the conventional and ultrasonic methods considering different methanol to oil molar ratios using C:CaO is shown in Figure 2. Maximum yield is obtained at 60˚C of around 87.3% in the ultrasonic-assisted sample. The methanol is evaporated at temperatures above 65˚C, leading to bubbles forming and, consequently, lower conversion factor. The trends in this figure display that the conversion factor increases when the reaction temperature increases for both methods.

Our result is consistent with the study of Ijaz et al. (2016) in which they reached 84% biodiesel yield from castor oil at 60˚C in Pakistan. Chen et al. (2014), Manickam et al. (2014), and Choedkiatsakul et al. (2014) have reported that at 60˚C, biodiesel yield was maximum from palm oil. Nonetheless, these results differ from a study in which maximum biodiesel from Fishmeal plant waste oil is obtained at 55˚C (Maghami et al., 2014). It has been reported that in non-catalytic supercritical conditions (60˚C, 21 MPa, 90 min), the maximum yield of FAMEs from castor oil reaches 96.5% (Román-Figueroa et al., 2016), which is 10% higher than our maximum yield in the ultrasonic-assisted conditions.

It was found that the effect of temperature on the conventional method is more since the main mechanism in the ultrasonic method is cavitation, while collision between molecules is the main mechanism of conversion in the conventional method. Biodiesel yield is increased by around 6.9% from 40˚C to 60˚C for the ultrasonic method while it increased of around 9.3% for conventional method.

3.3.3 Effects of methanol to oil molar ratio on biodiesel production

The oil to alcohol ratio of 6:1 is found to be optimum for biodiesel production, leading to 79.2% and 75% biodiesel yield using ultrasonic-assisted and conventional methods, respectively. A similar result is reported from a study by Maghami et al. (2014) in which they obtained around 88% biodiesel from fishmeal waste oil employing a methanol-to-oil ratio of 6:1.

Increasing the methanol-to-oil ratio more than 6:1 decreases the conversion factor in conventional and ultrasonic-assisted methods. For the methanol-to-oil ratio of 4:1, ultrasonic power led to a higher yield

than the conventional method of around 2.3%. It was revealed that the obtained biodiesel using methanol to oil ratio of 8:1 is closer to ratio of 6:1 than the ratio of 4:1. However, it has a lower yield than the ratio of 6:1.

A wide range of suggestions for methanol to oil molar ratio of 4:1 to 70:1 can be found in the literature (Azeem et al., 2016), while it should be considered that optimum condition for biodiesel production is highly dependent on the type and amount of catalysts and oils. Usually, acid catalysts need higher methanol-to-oil molar ratios (Ennetta et al., 2022).

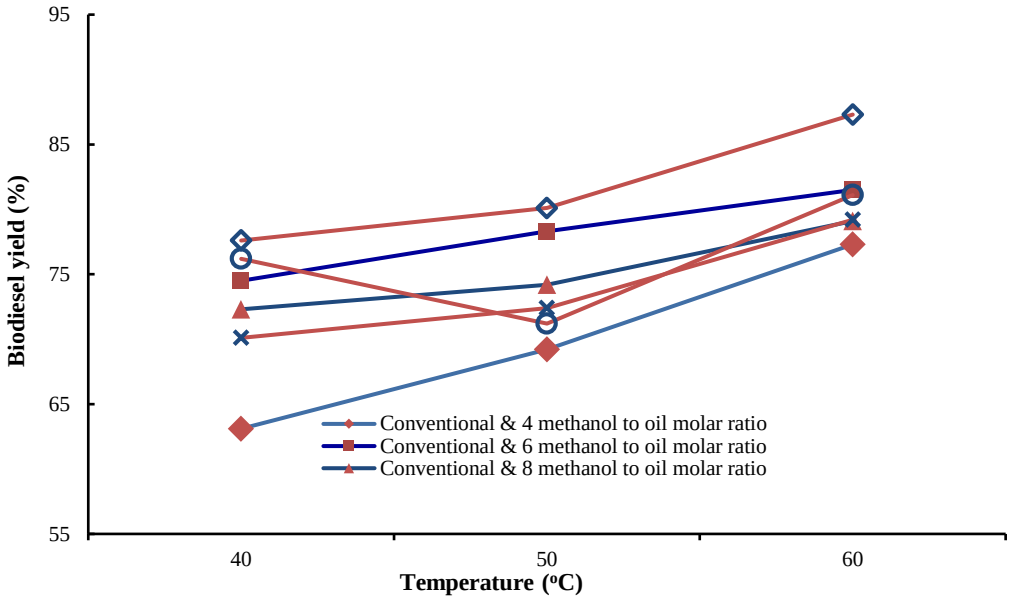


Figure 2 Effect of temperature on the biodiesel yield

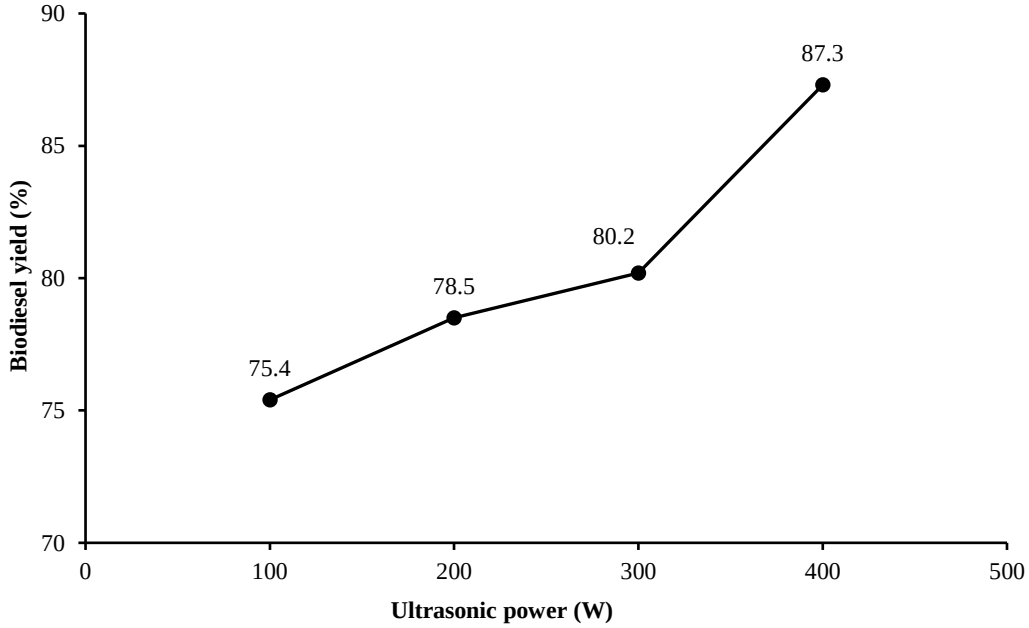


Figure 3 Effect of ultrasonic power on the biodiesel yield

3.3.4 Effect of ultrasonic power on biodiesel yield

Figure 3 shows that ultrasonic power has a direct effect on biodiesel yield. The average biodiesel yield at different ultrasonic powers is 80.35%±0.4%. At the same time, it reaches the highest value of 87.3%±0.2% biodiesel yield at 400 W power (methanol to oil ratio = 6:1 and temperature = 60 ℃ using C:CaO). The result is consistent with a study of Mootabadi et al. (2010) in which they stated that ultrasonic irradiation greatly influenced the reaction parameters of biodiesel production from palm oil, particularly for the obtained yield and reaction time.

The increasing trend is not constant from 100 W to 400 W power. The yield is enhanced of around 5% from 100 W to 300 W power while it increased by around 7% from 300 W to 400 W power (Figure 3). It can be said that biodiesel yield is more at 300 to 400 W power since both the energy density and cavitation activity were increased at this power which in turn caused to better mixing in the reactor. Ultrasound wave generates cavitation bubbles as it passes through the liquid (Naderloo et al., 2017).

3.3.5 Optimization of biodiesel production process

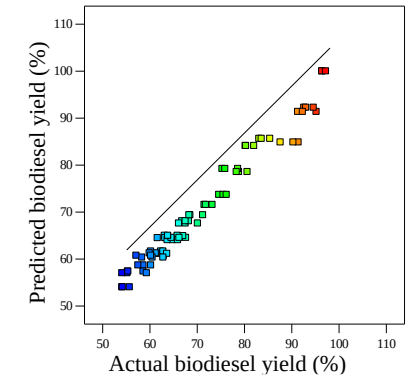
As mentioned above, the ultrasonic treatment could significantly improve biodiesel production compared to the control treatment. Therefore, ultrasonic treatment optimization was done to determine the best temperature, catalyst, and molar ratio of methanol to oil. In Figure 4, the result of response surface methodology (RSM) analysis that examined the relationship between the biodiesel production and temperature, catalyst, and mol ratio as described in the literature is shown (Mahmoodi-Eshkaftaki and Ebrahimi, 2019; Mahmoodi-Eshkaftaki and Rahmanian-Koushkaki, 2020). The catalysts 1, 2 and 3 were considered as Cao, C:Cao and KOH, respectively in optimizing models.

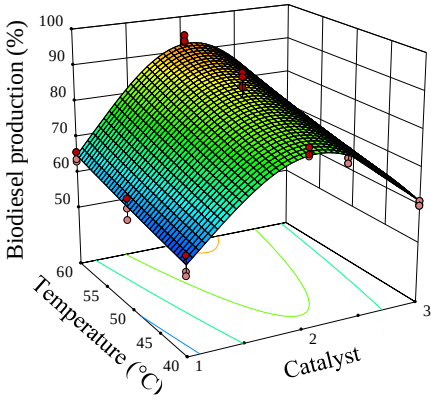
The quality of the model was statistically considered with a risk factor of 0.05 according to the coefficient of determination (R^2), adjusted R^2 (AR^2), and adequate precision (AP).

Values of R^2 and AR^2 are close to 1, and AP (signal-to-noise ratio) is higher than 4 (Mahmoodi-Eshkaftaki and Ebrahimi, 2019) in a well-fitted model. Different models were developed to optimize biodiesel production considering the catalyst (x_1), temperature (x_2), and alcohol-to-oil ratio (x_3), and the best one was selected as Equation 5. This model was reduced/ standardized. Thus, the coefficient of each term indicating significant effect to biodiesel product were considered and the non-significant terms (at level 10%) were removed from the models.

$$\frac{1}{Biodiesel+0.5} = 0.012 - 0.0005x_1 - 0.001x_2 - 0.0008x_3 + 0.0001x_1x_2 + 0.0001x_1x_3 + 0.004{x_1}^2 \quad (5)$$

The model p-value was significant at level 1%, R^2=0.97, AR^2=0.97, and AP=67.4. These statistical parameters showed high accuracy for this model. Predicted values versus actual values of the biodiesel production (F-value=377.82) in Figure 4 shows the high accuracy of the predicted model. Due to the inverse relationship among the biodiesel and input factors, the larger coefficients of the model terms, including x_2 indicated a higher effect of temperature on biodiesel production. Further, the molar ratio of alcohol to oil had a lower effect on biodiesel production. The trends of biodiesel production versus input factors are illustrated in Figure 4. As shown, an increasing trend of biodiesel production resulted from the interaction effect of temperature and molar ratio quantities. As the figure shows, CaO:C was the best catalyst in this study. Further, a temperature of 60 ℃ and methanol to oil molar ratio of 8 were suitable to increase biodiesel production. The optimum amounts of these inputs increased biodiesel production to 93%.





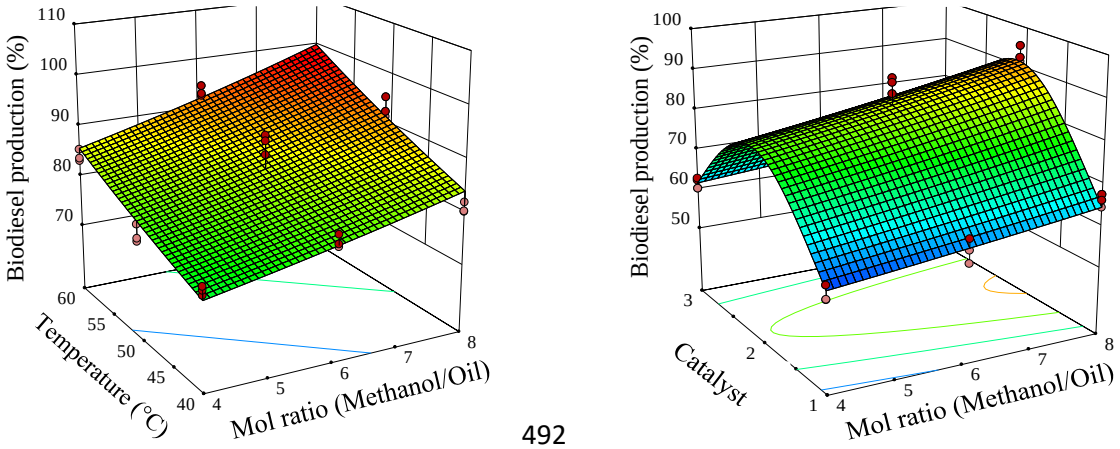


Figure 4 Accuracy of the biodiesel estimation model and effects of the input factors on biodiesel production

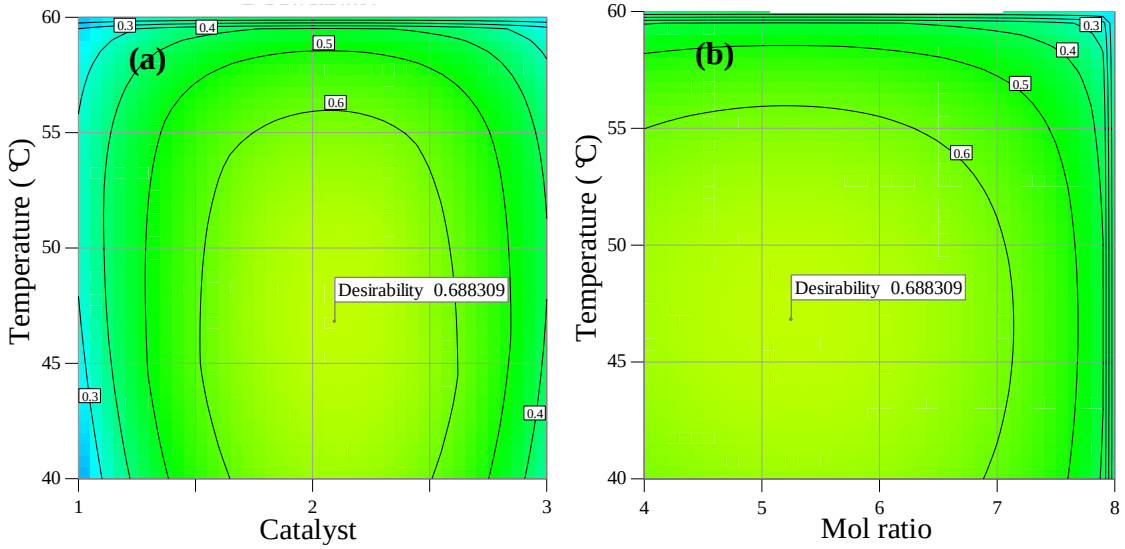


Figure 5 Desirable values versus input factors: (a) alcohol to oil molar ratio=5.25; (b) Catalyst=2.09 (Cao:C)

However, high temperature and alcohol to oil molar ratio increase energy consumption of the system. Therefore, the desirable condition of biodiesel production was determined with the following restrictions: minimizing temperature, minimizing alcohol to oil molar ratio, and maximizing biodiesel production. These limitations can increase biodiesel production with low energy consumption. Using these restrictions, the desirable factor was calculated as 0.69. The trends of satisfying factors versus input factors are illustrated in Figure 5 As shown, the highest desirability was determined for catalyst 2.09 (rounded as 2 equaled to CaO:C), the temperature of 46.81 ℃ and methanol to oil molar ratio of 5.25. These values increased biodiesel production to 80.77% (±2.78%) with low energy consumption.

4 Conclusion

Biodiesel is a clean energy obtained from renewable resources and can be used as a suitable alternative to non-renewable diesel fuels. The results conclude that the local Iranian *Ricinus communis* is a suitable plant for biodiesel production. However, it needs some modification to meet the necessary standards that can be used in diesel engines. Biodiesel yield was enhanced using C:CaO catalyst, methanol to oil molar ratio of 6:1, and temperature of 60 ℃. Ultrasonic technology improved biodiesel yield to around 5% to 12%, while a maximum yield of 87.3% was obtained at higher ultrasonic power at 400 W. It can be concluded that conventional biodiesel production coupled with ultrasonic power is an efficient method for biodiesel production, especially when local *Ricinus communis* is available. It is suggested that dual-frequency counter-current ultrasonic pulses may enhance biodiesel conversion from castor oil since Yin et al. (2017) reported that

they can obtain 96.3% biodiesel yield from soybean oil under this condition. It is highly recommended that local experts should work to improve the variety of *Ricinus communis* for higher oil yield since it is already tolerant to the warm and dry weather of the Jahrom area of Iran.

Compliance with ethical standards

Conflict of interests. The authors declare that they have no competing interests.

Competing interests

The authors declare that they have no competing interests.

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