

Production and optimization study of biodiesel produced from non-edible seed oil

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Abstract. The fuel demand is increasing globally. Conventional fuel is toxic and causes global warming and pollution. Therefore, biodiesel is being used as an alternative to petroleum fuel because it is non-toxic and can be renewable. Nowadays, the non-edible feedstock is gaining more attention for the production of biodiesel because it can grow anywhere on land, has low cost, and does not cause an imbalance in the food economy. This study deals with the biodiesel production and optimization of biodiesel from *Ricinus communis* oil using sodium hydroxide (NaOH) and potassium hydroxide (KOH) as solid base catalysts. The free fatty acid content (22.14% mg KOH/g) of castor oil calculated before transesterification indicated that the pretreatment of raw oil with acid was required for biodiesel synthesis. Therefore, the esterification process was used to reduce the free fatty acid content of castor oil from 22.14% to 0.84%. After that, the transesterification process was used for the production of biodiesel using a catalyst (NaOH and KOH). The four different parameter reactions (*i.e.* Ratio (alcohol to oil), Time, Temperature, and catalyst amount) were used to optimize the yield of biodiesel production. Firstly, NaOH was used as the catalyst and different reactions were done by making changes in all parameters to get maximum yield. The same procedure was done to get maximum yield using KOH as the catalyst. The maximum yield obtained using NaOH and KOH was 94.6% and 96.2% respectively. In the future, initiatives to develop market, policy support, and certification plans for sustainability play a vital role in innovative advancement, gaining market trust, and attracting investment for biodiesel. These efforts enable biodiesel as a renewable energy source in advancing in low-carbon and sustainable future.

Keywords: Biodiesel, *Ricinus communis* (castor oil), Transesterification, Catalysts, Optimization.

1 Introduction

Biodiesel is a renewable energy which is produced from different oil sources (such as vegetables, waste cooking, and animal oils) and is also produced from Algae through a process called transesterification [37]. It is also called Eco-diesel as it causes less environmental pollution [43]. Biodiesel is also produced to replace fossil fuels. The use of biodiesel also involves sustainability and the “Carbon Neutral Cycle” as the oil contains Carbon which is produced from Carbon dioxide which is taken up by plants from the air, so in the process of producing biodiesel Carbon dioxide is released from combustion and will be used by nature again for feedstock, this process is also called “Closed Carbon Cycle” [48].

Biodiesel has great storage properties so it can be stored easily unlike other diesel fuels. Like other diesel fuels, biodiesel has less chemical risk and another risk of handling storage and transportation. 70% cost of biodiesel production

depends on the selection of the feedstock [31, 44]. The main problem that arises in biodiesel production is production by the edible oils or seeds of plants. Therefore, to overcome this problem non-edible oils or seeds are used for the production of biodiesel. Microalgae are also used as an alternative source for the production of biodiesel as they succeed in yielding 1–80% oil under specific dry weight [2].

Transesterification is the process which is used to produce biodiesel with the help of the catalysts which can be Homogeneous or Heterogeneous. As the process of transesterification is reversible and has less rate of reaction, therefore we use a catalyst to increase the rate of reaction and end product (yield) [26, 27]. During transesterification, to increase the product rate the alcohol is used in excess amount. Mostly Methanol and Ethanol are used as a source of alcohol. Ethanol is used over methanol more because ethanol has fewer environmental objections and also it is renewable on the other hand methanol is toxic. Methanol is also preferred on the basis of its short chains and polar nature [47].

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The transesterification process can be of five types: (1) Base-catalyzed transesterification (the reaction in which strong base is used to produce biodiesel) [11], (2) Acid-catalyzed transesterification (the reaction in which strong acid is used to catalyze transesterification of triglyceride and it is also slow process compare to base-catalyzed) [13], (3) Enzyme transesterification (enzymes are used to produce ester from triglyceride) [21], (4) Supercritical transesterification (it is the catalyst-free reaction and occur at critical time of the reaction [38], and (5) Catalytic transesterification (catalysts are used to in the reaction to lower the activation energy so that rate of reaction can occur at faster pace) [48]. There are two types of catalysts used in the production of biodiesel (i.e Homogeneous and heterogeneous catalysts) [34]. Catalysts which have the same phase as the reactant are known as homogeneous and catalysts which have different phases from reactant are known as heterogeneous. Heterogeneous catalysts are more used than homogeneous because they are cheaper, less hazardous, good at stability and can be recycled from the product which causes a decrease in cost. The main problem with using heterogeneous catalysts is they require high surface area which is very costly [14, 24, 28].

As we look through the literature there were different oils and seeds *i.e. Ricinus communis* [46], *Pongamia pinnata* [18], *Jatropha curcus* [9], *Xanthium sibiricum* [20], *Raphanus sativus* [15], *Madhuca indica* [39], *Pistachia chinensis* [32], *Carthamus oxyacantha* [16], *Thevetia peruviana* [5], *Simmondsia chinensis* [35], *Linum usitatissimum* [6], *Melia azadarachta* [4], *Eruca sativa* [41], *Cannabis sativa* [25], and *Salvadora oleids* etc. used for the production of biodiesel [29].

Castor plants belong to the Euphorbiaceae family. It is also known as the castor bean plant. These plants have perennial herbs which may be single or branched stemmed. These plants are distributed into three regions i.e temperate, tropical and subtropical. Moderate fertile and slightly acidic soil is the ideal soil condition for these plants to grow on. Other than that, these plants can also grow on soil which is drained sandy loamy. These can tolerate temperatures from 7 °C to 27.8 °C and precipitation from 20 cm to 429 cm [30]. Africa is the native country for the plant. But now, these are cultivated in every part of the world. Africa also distributes this plant to many countries like Australia, Europe, North and South America and also countries with hot environmental conditions. *Ricinus communis* (castor oil) is found to have greater potential for oil production due to its mixed complex composition. In the structure of castor oil, C-12 contains a hydroxyl group and has ricinoleic acid which contains triglycerides of about 90% due to these unique physical and chemical properties it is considered as more useful. Being categorized as a potential source of biodiesel production in Brazil, its use in the research field is still limited. Because it is considered a weed in agricultural processes, the final viscosity range of castor oil in the production of biodiesel is still debatable. It has 45–50% oil content [19].

The purpose of the study is to produce biodiesel from a non-edible oil-yielding plant (*Ricinus communis*) using homogenous catalysts (NaOH and KOH) to examine the

outcome of various reaction parameters and check which parameters give maximum and optimised yield of biodiesel.

2 Materials and methods

2.1 Equipment and chemicals

Laboratory equipment used is Digital Weighing Balance, Teflon Magnetic Stirrer, Thermometer, pH Paper, Conical/Erlenmeyer Flasks, Beakers (100 and 500 ml), Filter Paper (Wattman 42), Aluminum Foil, Funnels, Sonicator (Sweep Zone technology, USA), Micropipette (Sartorius France) and Pasteur pipette, Centrifuge (B. Bran, Germany); Freezer 9170 WB M (Dawlance, Pakistan), Iron Stand, Incubator IC83 (Yomato, Japan), Electric Oil Expeller, Burette, Soxhlet Assembly, Magnetic Stirrers, Pestle mortar, Drying Oven. The chemicals include Sodium hydroxide, Potassium hydroxide, 99.9% pure Methanol and Sulfuric acid.

2.2 Oil extraction

The extraction of oil is done from the seeds of the plant. For that, firstly collection of plant shells was done by making several field trips. After collecting shells, the moisture and insects were removed by placing them in sunlight, after that separation of seed was done. After that, the washing of seeds was done using soft warm distilled water to remove any dirt then these seeds were dried at 55 °C in an oven. Then after drying these seeds were placed in the Soxhlet apparatus through which seed oil contents were determined [17].

2.2.1 Organic solvent extraction method

Soxhlet apparatus was used for the extraction of solvent. Organic solvent was used to remove chemical constituents present in sample seeds. By using a pestle and mortar, the dried seeds were crushed into fine powder. 250 ml of n-hexane was filled into the round bottom flask. After that, 5 g of powdered seed was filled in thimble and was heated for 5 h at 60 °C. During this process, the solvent was continuously reused and recovered. After that, the resulting wet sample was obtained and was again dried at 60 °C in an oven to evaporate the remaining solvent. After that, the weight of the sample was taken and the amount of oil extracted was calculated using the formula below;

$$\text{Percentage of oil content} = W4 = [(W3 - W1)/W2] \times 100 \quad (1)$$

Where; W1 = Weight of Empty Flask (beaker)
 W2 = Weight of Empty Flask + Powdered Sample
 W3 = Weight of Sample to be used
 W4 = Weight of Extracted Oil.

2.3 Filtration of oil

The impurities from extracted crude oil were removed by using the (Whatman No.42) filter paper.

2.4 Determination of FFA content in seed oil

The acid-base titration process was used to determine the free fatty acids (FFAs) of extracted oil. The collected oil was filtered as pre-treatment and after that acid-base titration method was done to determine its FFA contents. The FFA value was calculated by using the following equation.

$$\text{Acid Number} = \frac{56.1 \times M(a - b)}{W} \quad (2)$$

56.1 = Molar Mass of KOH

M = Molarity of base

W = Weight of sample

a = volume of titer for blank

b = volume of titer for oil sample.

2.5 Biodiesel synthesis

For the synthesis of biodiesel, the two-step method (esterification followed by transesterification) was carried out for castor oil samples in a laboratory. The percentage of biodiesel yield was determined by using equation (3).

Yield of Biodiesel

$$= \frac{\text{Gram of biodiesel produced}}{\text{Gram of oil sample taken for the reaction}} \times 100. \quad (3)$$

2.5.1 Acid catalyzed esterification

In the esterification process, concentrated sulphuric acid (H₂SO₄) was mixed with methyl alcohol and then added to oil (having a ratio of 1:6:1 respectively) in the reaction glass flask. The glass flask was heated for 1 h. The reaction was settled down for 2 h after the completion of the reaction. After 2 h, the two layers were formed from the resultant mixture. In two layers, the upper layer contains methanol and water and the lower layer contains esterified biodiesel [42].

2.5.2 Alkali catalyzed transesterification

The alkali-catalyzed transesterification reaction was conducted in a 250 ml round bottom flask equipped with a magnetic stirrer, reflux condenser, thermometer and sampling outlet. The 30 ml filtered oil was poured into a 250 ml glass beaker. The glass beaker was placed on a hot-plate and the oil was heated at 120 °C and then cooled to 60 °C. The solid base catalyst (NaOH and KOH) was mixed with methanol in different concentrations (0.50, 0.75, 1.0, & 1.25 (w/w) in a separate closed flask. After mixing methanol and catalyst, it was mixed with oil in different ratios the reactant mixture was placed on a hotplate and was stirred for different reaction times at different temperatures to study the various parameters to optimize the biodiesel yield. After that, the yield of biodiesel was calculated for all the parameters using the formula of percentage yield of biodiesel [23].



Figure 1. Castor oil plant seeds sample.

2.5.3 Separation

Decantation was used to remove the soap layer. Using a separating vessel crude biodiesel was collected and glycerin mass was transferred to another vessel.

2.5.4 Washing

The washing of crude biodiesel was done in a separate glass container. The glass container was filled with the last portion of the crude biodiesel and half by warm distilled water. The container was kept for 8 h or overnight for settling. The washing process was repeated three times.

2.5.5 Drying

After the washing of biodiesel, it was dried at 110 °C for 1.5–2 h in an oven to remove any remaining water present in it. After that, the yield of biodiesel was calculated using equation (3) presented above (Figure 1).

3 Results

3.1 Botanical description of castor oil (*Ricinus communis* L.)

The castor plant is a long-lasting herbaceous plant which seldom has a tree-like development, often branched-like development and mostly has a single stem. It has a length of 2.1–4.9 cm. The body of a plant frequently has a pink to reddish or purplish appearance. Size of stipules connate is 2–3.1 cm, petiole is 24–41 cm. Leaf description: the leaf appearance is radially 8–11 lobed, 34–55 × 33–60 cm, margin serrate. The flowering is very large sized up to 32 cm. Flower description: the stalk of the male flower is 4.8–16 mm, calyx folds 6–8.1 × 3–5.1 mm, stamens 6.2–7.9 mm. The shoot of female flower is 4.9–10.3 mm, sepals up to 4.8 mm, styles 2.1–4.9 mm. The pedicel of fruits is approx. 40 mm. Fruit description: the capsule is spheroidal, 1.4–2.6 cm, echinate; spines up is approx. 4.8 mm, often soft. The color of the seed is purple brownish, 6–13 mm.

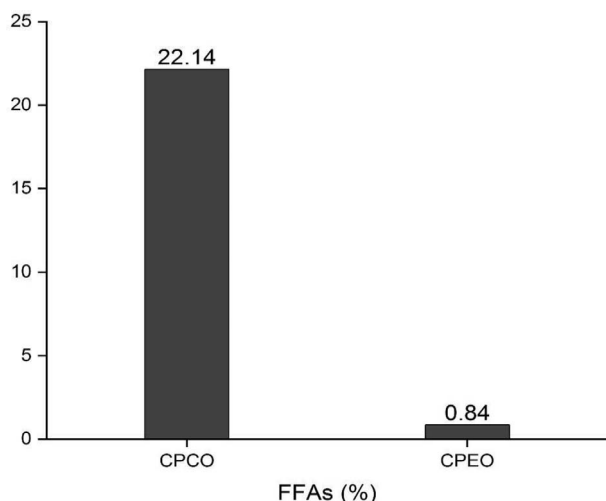
Table 1. Oil content (%) of castor oil using mechanical and organic solvent extraction methods.

Serial No.	Botanical name	English name	Family	Mechanical extraction (%)	Organic solvent extraction (%)
1	<i>Ricinus communis</i> L.	Castor oil plant	Euphorbiacea	25.54	45

Table 2. FFAs %age of crude oil and esterified oil.

Serial No.	English name	FFAs %age of crude oil	FFAs %age of esterified oil
1	Castor oil plant	22.14	0.84

CPCO = Castor plant crude oil; CPEO = Castor plant esterified oil.

**Figure 2.** FFAs %age of crude and esterified oil.

3.2 Extraction of oil

The oil contents of castor oil (*Ricinus communis* L.) were reported using an electric oil expeller, and organic solvent extraction (soxhlet apparatus) extraction methods. The determined extracted oil content in the castor oil plant is shown in Table 1.

3.3 FFAs content of crude oil and esterified oil

The free fatty acids content in crude and esterified castor oil was determined by acid-base titration using potassium hydroxide. The %age of FFA was calculated using equation (2) (Table 2 and Figure 2).

3.4 Biodiesel yield

The yield of biodiesel using solid base catalysts (NaOH and KOH) on castor plant oil is presented in Tables 3 and 4. In the case of NaOH, the maximum biodiesel yield using NaOH as base catalyst was obtained on parameters i-e methanol oil molar ratio (8:1), 1 wt.% catalyst amount, temperature 65 °C, and reaction time (1.5 h). Similarly, in the case of the KOH catalyst, the maximum biodiesel yield

Table 3. Maximum biodiesel yield from Castor oil using NaOH base catalyst, methanol oil molar ratio (8:1), temperature 65 °C, and reaction time (1.5 h).

Parameters	Biodiesel yield (%)
1 wt.% NaOH catalyst, 8:1 methanol to oil ratio at 65 °C for 1.5 h	94.6%

Table 4. Maximum biodiesel yield from Castor oil using KOH base catalyst, methanol oil molar ratio (6:1) at temperature 60 °C, and reaction time (1 h).

Parameters	Biodiesel yield (%)
1 wt.% KOH catalyst, 6:1 methanol to oil ratio at 60 °C for 1 h.	96.2%

using KOH as a base catalyst was obtained at parameters like methanol oil molar ratio (6:1), 1 wt.% catalyst amount, temperature 60 °C, and reaction time (1 h). The biodiesel samples from the castor oil plant using NaOH and KOH catalysts are shown in Figure 3.

3.5 Optimization of castor oil (*Ricinus communis* L.) reaction parameters using NaOH base catalyst

3.5.1 Influence of alcohol to oil ratio using NaOH catalyst on biodiesel yield

In the transesterification process, alcohol is used as the primary reactant for biodiesel production. To study this parameter, methanol was used in different concentrations of oil that are 2:1, 4:1, 6:1 and 8:1 and other parameters were taken as constant such as 1% (wt.) NaOH amount in methanol at 65 °C reaction temperature and 1.5-h reaction time. 58.2% of biodiesel yield was obtained at a low methanol to oil ratio of 2:1. This low yield is due to the less methanol present to react with triglyceride to produce biodiesel. So by increasing the methanol to oil ratio maximum yield of biodiesel can be obtained. Therefore, to get an optimized yield the methanol to oil ratio was increased

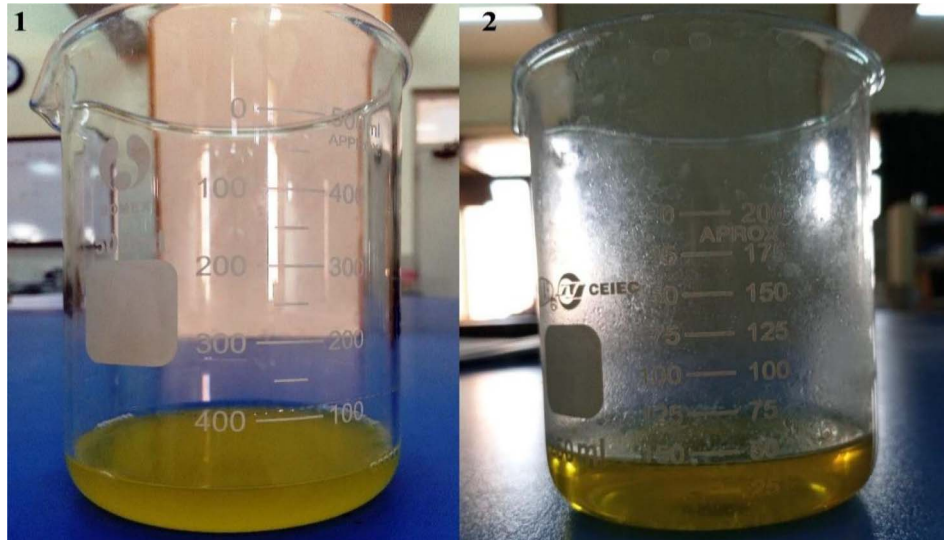


Figure 3. Castor oil biodiesel sample using (1) NaOH catalyst and (2) KOH catalyst.

to 4:1, 6:1 and 8:1. And it was seen that the maximum/optimum yield of biodiesel (94.6%) was obtained at 8:1. This is because when the methanol concentration increases, reaction starting pushing towards the equilibrium and more biodiesel yield is obtained due to this. Therefore, the 8:1 molar ratio of methanol to oil was selected as optimum. Other than that, if the ratio of methanol to oil was increased from its optimum limit that may result in a decrease in biodiesel yield and may be no yield can be obtained because of dilution of oil and methanol (Figs. 4–11).

3.5.2 Influence on biodiesel yield at different temperature using NaOH as catalyst

For the optimization of the yield of biodiesel, temperature was considered as the parameter to study. Therefore, during this parameter reaction the 8:1 of methanol to oil, NaOH amount of 1% (by wt.) and the reaction time of 1.5 h were considered as constant and temperature was changed to 45 °C, 55 °C, 60 °C and 65 °C. It was noticed that by increasing the temperature of the reaction from 45 °C to 65 °C, the biodiesel yield was also increased from 58.7% to 94.6%. It was noticed that by increasing the temperature the reaction got more soluble and more stabilized therefore at 65 °C 94.6% yield was obtained. It was also noticed that by increasing the temperature from 65 °C to 70 °C the yield of biodiesel decreases. Soap formation increases and may also result in the vaporization of methanol because of which the reaction cannot proceed. Therefore, it was concluded that the favourable range of reaction to occur is 65 °C and below 65 °C (Tables 5–12).

3.5.3 Influence of catalyst (NaOH) amount on the yield of biodiesel

Catalyst amount was studied as the third parameter to optimize biodiesel yield. It was noticed when the catalyst amount was below 0.50 wt.% the yield of biodiesel was

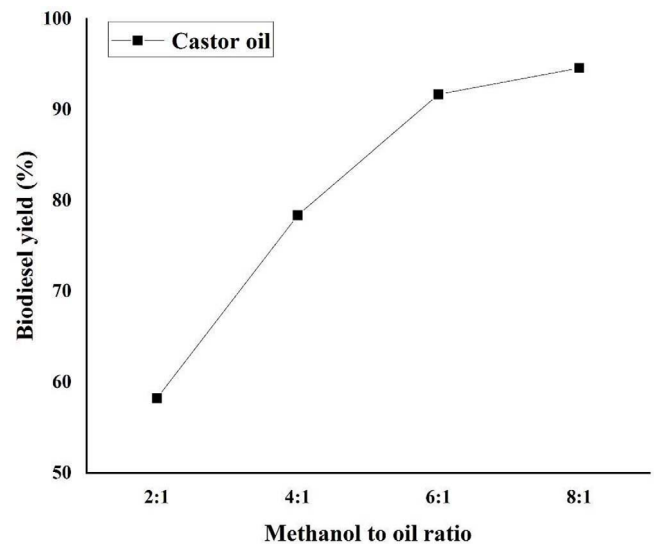


Figure 4. Graph of biodiesel yield on different methanol to oil ratio.

not obtained and also by increasing the catalyst amount from optimum the soap formation was achieved. However, when we increase the amount of catalyst to 1.0%, more triglycerides are converted into biodiesel. So for this parameter, the changes in the amount of NaOH were made to check its effect on biodiesel yield. Therefore, during this research 8:1 methanol to oil ratio, at 65 °C temperature and 1.5 h was taken as constant and the amount of catalyst was changed from 0.50 wt.% to 1.25 wt.%. The weight of oil used was considered as a base to calculate the amount of catalyst in percentage. It was calculated that the yield of the biodiesel also increased from 58.2% to 94.6% by adjusting the amount of catalyst from 0.50 to 1%, respectively. However, when the NaOH amount was increased from 1 wt.% to 1.25 wt.% the yield of biodiesel decreased

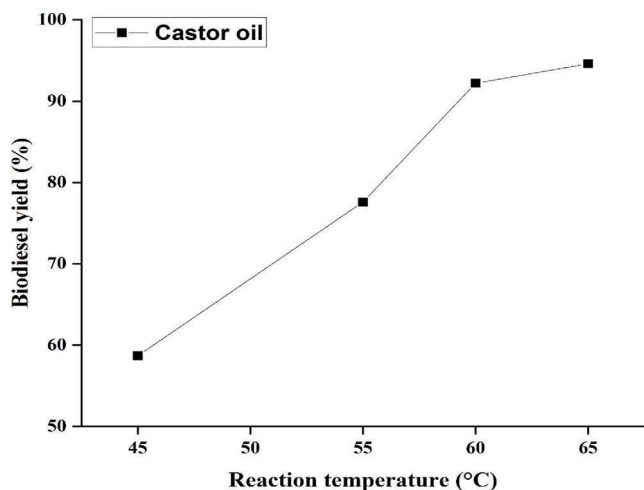


Figure 5. Graph of biodiesel yield on different temperature.

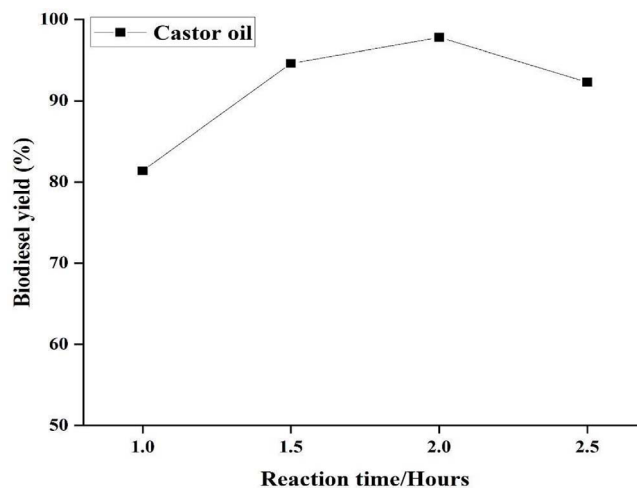


Figure 7. Graph of Biodiesel yield at different reaction time.

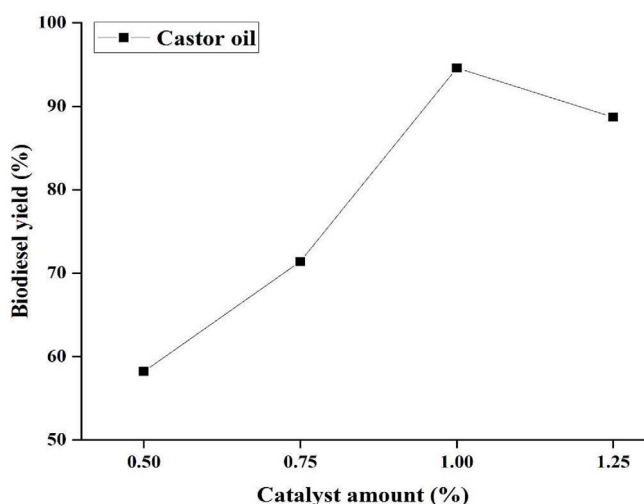


Figure 6. Graph of biodiesel yield using different amounts of catalyst %.

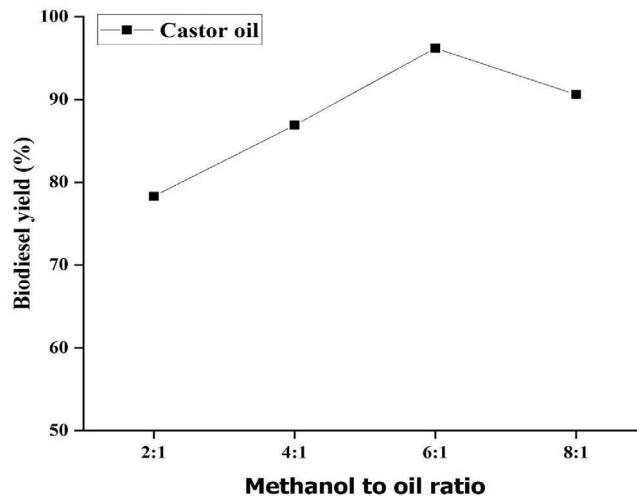


Figure 8. Graph of biodiesel yield on different methanol to oil ratio.

and soap formation was increased. Therefore, 1 wt.% amount of NaOH was considered as the optimum amount to obtain the maximum yield of biodiesel.

3.5.4 Influence of reaction time on biodiesel yield using NaOH as catalyst

For the last parameter reaction and optimizing the yield of biodiesel, the time of reaction was studied. Therefore, during this parameter study, 8:1 methanol to oil, 65 °C temperature and 1 wt.% NaOH amount was taken as constant and the duration of the reaction was changed from 1 h to 2.5 h. During the transesterification process, the yield of biodiesel is dependent on the time of reaction. The first reaction was given 1 h time because of which methanol and oil were not mixed properly therefore, the calculated yield was low. The maximum yield (94.6%) was obtained in 1.5 h reaction time. It was also noticed that by increasing

the time of reaction from 1.5 h to 2 h more yield (97.8%) can be obtained. It was also studied and noticed that if we give more time from optimum time to reaction the biodiesel yield decreases due to loss of esters bonding which was caused by reversible reaction. Therefore, the optimized reaction time for biodiesel yield was taken as 1.5 h.

3.6 Optimization of castor oil (*Ricinus communis* L.) reaction parameters using KOH base catalyst

3.6.1 Influence of alcohol to oil ratio on biodiesel yield using KOH catalyst

In the transesterification process, alcohol is used as the primary reactant for biodiesel production. For this parameter to study, methanol was used in different concentrations of oil that are 2:1, 4:1, 6:1 and 8:1 and other parameters were taken as constant such as 1% (wt.) KOH amount in methanol at 60 °C reaction temperature and 1 h reaction

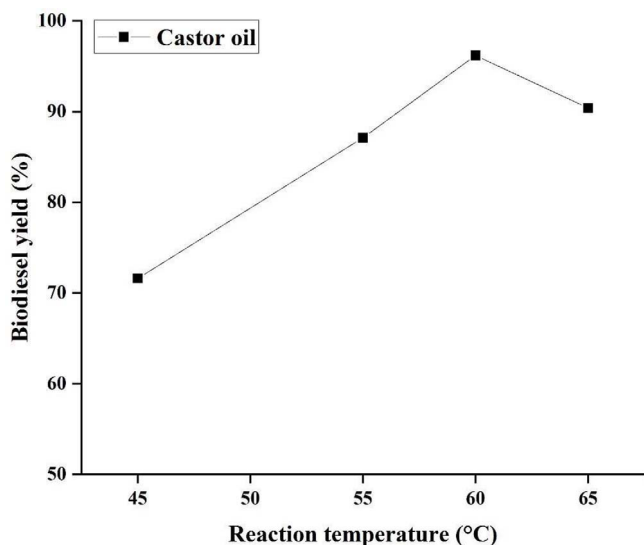


Figure 9. Graph of biodiesel yield at different temperatures.

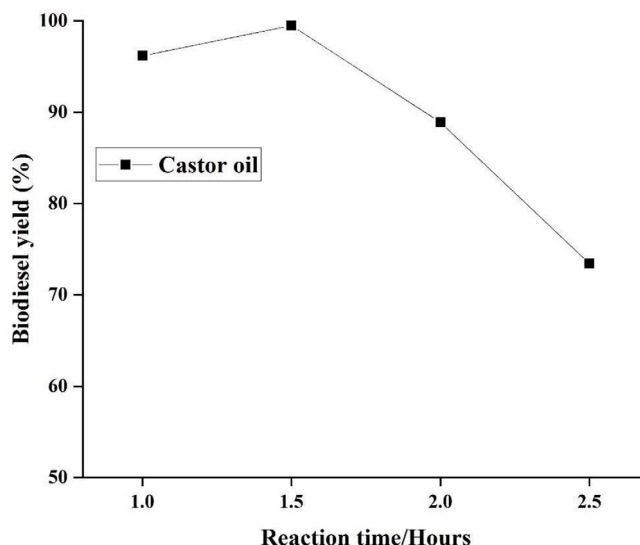


Figure 11. Graph of biodiesel yield on different reaction time.

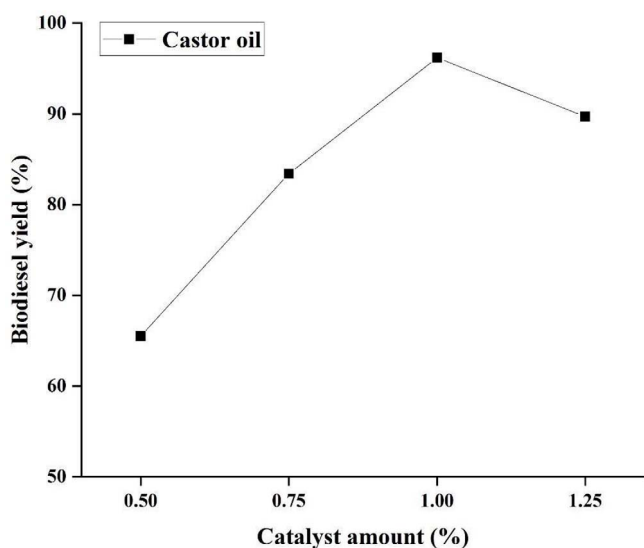


Figure 10. Graph of biodiesel yield at different catalyst amount %.

time. 78.3% of biodiesel yield was obtained at a low methanol to oil ratio of 2:1. This low yield is due to the less methanol present to react with triglyceride to produce biodiesel. So by increasing the methanol to oil ratio maximum yield of biodiesel can be obtained. Therefore, to get optimized yield the methanol to oil ratio was increased to 4:1, 6:1 and 8:1. And it was seen that the maximum yield of biodiesel (96.2%) was obtained at 6:1 because more triglyceride converted into biodiesel. Therefore, the 6:1 molar ratio of methanol to oil was selected as the optimum ratio. Other than that, if the ratio of methanol to oil was increased from its optimum limit that may result in decreased biodiesel yield or no yield can be obtained due to dilution of oil and methanol.

Table 5. Biodiesel yield (%) on different methanol to oil ratios using 1 wt.% NaOH amount at 65 °C temperature and for 1.5 h.

Serial No.	Methanol to oil ratio	Biodiesel yield %
1	2:1	58.2
2	4:1	78.4
3	6:1	91.7
4	8:1	94.6

Table 6. Biodiesel yield (%) at different temperatures using 1 wt.% NaOH amount, 8:1 methanol to oil ratio and 1.5-h reaction time.

Serial No.	Temperature	Biodiesel yield %
1	45 °C	58.7
2	55 °C	77.6
3	60 °C	92.2
4	65 °C	94.6

3.6.2 Influence on biodiesel yield using KOH catalyst at different temperature

To optimise of yield of biodiesel, temperature was considered as the next parameter to study. Therefore, during this parameter reaction the 6:1 of methanol to oil, KOH amount of 1% (by wt.) and the reaction time of 1 h were considered as constant and temperature was changed to 45 °C, 55 °C, 60 °C and 65 °C. It was noticed that by increasing the temperature of the reaction from 45 °C to 65 °C, the biodiesel yield was also increased from 58.7% to 96.2%. This change in the yield is due to the solubility of the reaction, as it was noticed that at 45 °C the reaction kinetics and solubility is less so less yield is obtained, but as the temperature is

Table 7. Biodiesel yield (%) on different catalyst (NaOH) amount % using 8:1 methanol to oil ratio, 65 °C temperature and 1.5-h reaction time.

Serial No.	Catalyst amount %	Biodiesel yield %
1	0.5	58.2
2	0.75	71.4
3	1	94.6
4	1.25	88.7

Table 8. Biodiesel yield (%) on different reaction times using 8:1 methanol to oil ratio at 65 °C temperature and 1 wt.% NaOH amount.

Serial No.	Time	Biodiesel yield %
1	1 h	81.4
2	1.5 h	94.6
3	2 h	97.8
4	2.5 h	92.3

Table 9. Biodiesel yield (%) using different methanol to oil ratios on 1% KOH amount at 60 °C temperature and 1 h reaction time.

Serial No.	Methanol to oil ratio	Biodiesel yield %
1	2:1	78.3
2	4:1	86.9
3	6:1	96.2
4	8:1	90.6

increased to 60 °C the kinetics and solubility of reaction increases and maximum yield is obtained. It was also noticed that by increasing the temperature from 65 °C to 70 °C the yield of biodiesel decreases, soap formation increases and may also result in the vaporization of methanol because of which the reaction cannot proceed. Therefore, a temperature of 65 °C and below 65 °C is considered as the favorable range.

3.6.3 Influence of catalyst (KOH) amount on the yield

Catalyst amount was studied as the third parameter to optimize biodiesel yield. It was noticed when the catalyst amount in the reaction was below 0.50 wt.% the yield of biodiesel was not obtained and also by increasing the catalyst amount from optimum the soap formation was achieved. So for this parameter, the changes in the amount of KOH were made to check its effect on biodiesel yield. Therefore, during this research 6:1 methanol to oil ratio, at 60 °C temperature and 1 h was taken as constant and the amount of catalyst was changed from 0.50 wt.% to 1.25 wt.%. The weight of oil used was considered as a base to calculate the amount of catalyst in percentage. It was

Table 10. Biodiesel yield (%) at different temperatures using 1% KOH amount, 6:1 methanol to oil ratio and 1 h reaction time.

Serial No.	Temperature	Biodiesel yield %
1	45 °C	71.6
2	55 °C	87.1
3	60 °C	96.2
4	65 °C	90.4

Table 11. Biodiesel yield % at different catalyst amounts using 6:1 methanol to oil ratio, 60 °C temperature and 1 h reaction time.

Serial No.	Catalyst amount %	Biodiesel yield %
1	0.5%	65.5
2	0.75%	83.4
3	1%	96.2
4	1.25%	89.7

Table 12. Biodiesel yield (%) on different reaction time using 6:1 methanol to oil ratio, 60 °C and 1% KOH amount.

Serial No.	Time	Biodiesel yield %
1	1 h	96.2
2	1.5 h	99.5
3	2 h	88.9
4	2.5 h	73.4

calculated that the yield of the biodiesel also increased from 65.5% to 96.2% by adjusting amount of catalyst from 0.50 to 1%, respectively. It was noticed that when the amount of catalyst was 0.5 wt.% the yield is less due to insufficient amount of catalyst, but as the amount of catalyst changed to 1 wt.% the catalytic activity increases and more triglycerides are converted into biodiesel. However, when the KOH amount was increased from 1 wt.% to 1.25 wt.% of the yield of biodiesel decreased to 89.7% because of an increase in soap formation. Therefore, 1 wt.% amount of KOH was considered as the optimum amount to obtain the maximum yield of biodiesel.

3.6.4 Influence of reaction time on biodiesel yield using KOH catalyst

For the last parameter reaction and optimizing the yield of biodiesel, the time of reaction was studied. Therefore, during this parameter study, 6:1 methanol to oil, 60 °C temperature and 1 wt.% NaOH amount was taken as constant and the duration of the reaction was changed from 1 h to 2.5 h. During the transesterification process, the yield of biodiesel

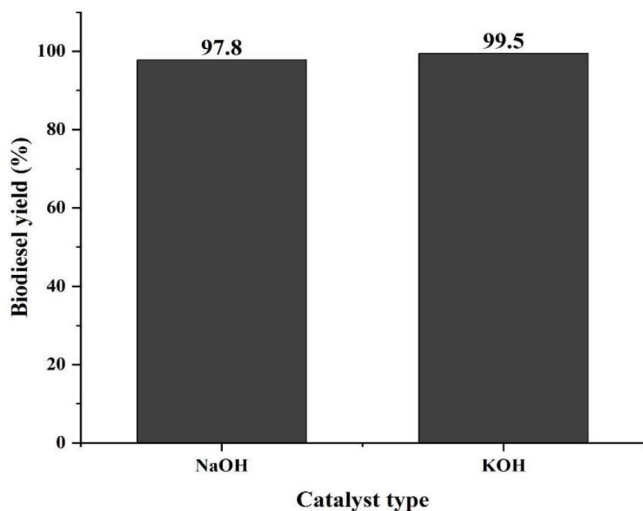


Figure 12. Effect of Catalyst Type on Biodiesel Yield.

is dependent on the time of reaction and the catalyst amount used in the reaction. During the first reaction at 1 h time, the maximum yield of biodiesel (96.2%) was obtained, this is due to less time given to reactant for conversion into biodiesel. It was also noticed that by increasing the time of reaction from 1 h to 1.5 h more yield (99.9%) can be obtained due to more time given the complete conversion of reactant occurs which produces maximum biodiesel yield. After obtaining the maximum amount of yield it was also studied and noticed that if we increase the time of reaction from 1.5 h, the biodiesel yield decreases due to loss of esters bonding which is caused by reversible reaction. Therefore, the optimised reaction time for biodiesel yield was taken as 1 h.

3.7 Optimized biodiesel production

Based on all the above experiments, it was concluded that more yield can be obtained from KOH as a catalyst than NaOH. This is due to the soap formation during the transesterification process using catalyst (NaOH) increases and it was less in KOH reactions. Figure 12 shows the biodiesel yield of castor oil using different catalysts (NaOH and KOH). The optimized yield of 97.8% using NaOH as catalyst was noticed on 8:1 alcohol to oil ratio, 1 wt.% catalyst amount at 65 °C temperature and for 2 h reaction time. The optimized yield of 99.5% was obtained using KOH as a catalyst on 6:1 alcohol-to-oil ratio, 1 wt.% catalyst amount at 60 °C and 1.5 h reaction time.

4 Discussion

Biodiesel is the type of fuel derived from plants seeds or oil, animal fats, minerals and algae materials. Biodiesel is used as the energy for renewable sources. These are also used as alternative fuels for fossil fuels [12]. According to ASTM international, biodiesel is a mixture of long-chain mono-allylic esters obtained from renewable resources.

The advantages of producing biodiesel are renewable fuel, is environmentally friendly, less toxic than diesel fuel, has less emission of carcinogenic substances and sulfur dioxide, has excellent lubricant properties and can easily blend with diesel fuel. The disadvantages of using biodiesel are high emission of nitrous oxide, high fuel consumption, high freezing point, less stable and cannot be stored for a long term [45]. To produce biodiesel from any biological resources i.e animal, plant and algae transesterification process is used. The process of transesterification for the synthesis of biodiesel involves the reaction between the feed-stock of oil and alcohol, the most likely is methanol, with catalytic medium. For the synthesis of the biodiesel the most commonly used solvent is methanol [48]. NaOH and KOH catalysts are most commonly used due to its minimized cost and easier availability. The reaction can proceed with the use of heterogeneous or homogeneous catalyst [8]. The choice of the method is depended upon the free fatty acid content of the oil. Different catalysts (may be classified as acid, enzymatic and basic) are used in transesterification process. Mostly used basic catalysts are sodium hydroxide and potassium hydroxide other than that, alkoxides such as sodium methoxide or ethoxide are also used. Mostly used acid catalysts are sulfonic, sulfuric and hydrochloric acids [1]. Other than that, enzymes are also used as the catalysts for the synthesis of biodiesel. Most commonly used enzyme for the biodiesel synthesis is Lipase [7]. The advantages of using homogeneous basic/alkali catalyst are high yield conversion, widely available, high rate of reaction and easily available [33]. In this research, non-edible oil of castor oil is used for the production of biodiesel. It is widely available in Pakistan. It grows to a length of 2.1 to 4.9 cm. Castor oil is also considered as diesel's alternative source because biodiesel production from castor oil has a high cetane number of 42.3. Also, the biodiesel from eucalyptus is environmentally friendly because of absence of sulfur and other component which pollutes the environment [22]. In this research, the calculated FFA content of *Ricinis communis* oil was 22.14 % and was reduced to 0.84% through the esterification process. After that the biodiesel production from castor oil is carried out by using base transesterification. In base transesterification, NaOH and KOH are used as the catalysts along with methanol to produce biodiesel [10, 36]. In this research, first NaOH is used to study different parameters of the biodiesel production to get the optimised results and then KOH was used to study different parameters [3]. Alcohol to oil ratio was the first parameter we conducted. In the first parameter, catalyst amount, temperature and time are taken as constant and different ratios of alcohol to oil were used (such as 2:1, 4:1, 6:1 and 8:1) to obtain the different yield of biodiesel. After getting maximum yield on ratio of 8:1 using NaOH and 6:1 using KOH, the other parameters were studied using these ratios. In second parameter, catalyst amount, alcohol to oil ratio and time were taken as constant and temperature was changed to 45 °C, 55 °C, 60 °C and 65 °C. In the third parameter, catalyst amount, alcohol to oil ratio and temperature were taken as constant and the time for each reaction was changed to 1 h, 1 h 30 min, 2 h and 2 h 30 min. In the fourth parameter, alcohol and oil ratio,

temperature and time were taken as constant and the catalyst amount was changed to 0.5%, 0.75%, 1% and 1.25% [40]. In the end, maximum yield (94.6%) using NaOH as a catalyst was noticed on 8:1 alcohol to oil ratio, 1 wt.% catalyst amount at 65 °C temperature and for 1.5 h' time. It was also noted that by increasing the time from 1.5 h to 2 h more yield of 97.8% can be obtained. The maximum yield (96.2%) was obtained using KOH as a catalyst on a 6:1 alcohol to oil ratio, 1 wt.% catalyst amount at 60 °C and 1 h reaction time and by increasing more time from 1 h to 1.5 h yield can be increased to 99.5%. The optimized yield of 97.8% using NaOH as a catalyst was noticed on 8:1 alcohol to oil ratio, 1 wt.% catalyst amount at 65 °C temperature and for 2-h reaction time. The optimized yield of 99.5% was obtained using KOH as catalyst on 6:1 alcohol to oil ratio, 1 wt.% catalyst amount at 60 °C and 1.5 h reaction time.

5 Conclusion

The current study encompasses the utilization of non-edible oil seed i-e *Ricinus communis* L. (castor seed plant) as efficient feedstock for biodiesel industry. The castor plant is reported to have highest oil content (45%–50%) with 22.14% free fatty acid content. Because of the highest FFA content of oil, castor oil was esterified with 1% concentrated H₂SO₄, which intimately reduces its FFA from 22.14% to 0.84%. The esterified oil was then transesterified using NaOH and KOH as catalyst. Maximum biodiesel yields 94.6% was achieved using NaOH with an 8:1 molar ratio of alcohol to oil, 1 wt.% NaOH amount at 65 °C and 1.5-h reaction time. While, using KOH maximum yield 96.2% was achieved with 6:1 molar ratio of alcohol to oil, 1 wt.% KOH amount at 60 °C and 1 h reaction time. Additionally, optimization study was performed by different parameter reactions i-e Alcohol to oil ratio, catalyst amount, temperature and time. During optimization, it was noticed that by increasing time to a certain point more yield can be obtained. In NaOH, a higher yield of 97.8% was obtained in 2 h. While in KOH, a higher yield of 99.5% was obtained on 1.5 h. Thus, *Ricinus communis* could be a feasible feedstock for producing sustainable an eco-friendly biodiesel on an industrial scale. Influenced by the advancements in the innovative technologies, sustainable practices, and varieties of feedstocks, biodiesel production holds a great promising future. In future, researchers can enhance the environmental sustainability and scalability of biodiesel production by improving the efficiencies of processes using nanotechnology and biotechnology. Researches can also use the emerging feedstocks like microbial oils and algae to improve scalability of biodiesel. Adopting the circular economy strategies and utilizing integrated biorefineries, contributes to the bio-based economy growth development by optimizing the resources and evaluating waste. In future, initiatives to develop market, policy support, and certification plans for sustainability play a vital role in innovative advancement, gaining market trust, and attracting investment for biodiesel. These efforts enables the biodiesel as a renewable energy source in advancing in low-carbon and sustainable future.

6 Summary

The current study encompasses the utilization of non-edible oil seed i-e *Ricinus communis* L. (castor seed plant) as efficient feedstock for the biodiesel industry. The esterified oil was then transesterified using NaOH and KOH as catalysts. Maximum biodiesel yields 94.6% was achieved using NaOH with 8:1 molar ratio of alcohol to oil, 1 wt.% NaOH amount at 65 °C and 1.5-h reaction time. While, using KOH maximum yield 96.2% was achieved with 6:1 molar ratio of alcohol to oil, 1 wt.% KOH amount at 60 °C and 1 h reaction time. During optimization, it was noticed that by increasing time to a certain point more yield can be obtained. In NaOH, a more yield of 97.8% was obtained in 2 h. While in KOH, a higher yield of 99.5% was obtained in 1.5 h.

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