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Optimization of Biodiesel Production Process from Borage (*Borago officinalis* L.) Oil Using Response Surface Method (RSM)

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ABSTRACT

A substantial share of the world's total energy production comes from fossil fuels. In addition to the declining availability of fossil fuel resources, the use of diesel fuel poses numerous environmental threats. Therefore, identifying diverse, renewable, and clean energy sources is essential to ensure the continued advancement of human society. In this study, the effect of four factors, including the molar ratio of alcohol to oil, the weight percentage of catalyst, temperature, and reaction time on the percentage of methyl ester conversion and biodiesel production yield from borage oil seed was investigated at three levels. Design Expert software, Response Surface Methodology (RSM), and Central Composite Design (CCD) were used for statistical analysis and process optimization. The highest desirable process yield was obtained under optimal conditions for biodiesel production, with a molar ratio of 1:8, a weight percentage of catalyst of 0.5, a reaction temperature of 60 °C, and a reaction time of 90 minutes. The biodiesel produced from borage oil through transesterification reaction had satisfactory results in terms of various parameters, including methyl ester content (99.94%), kinematic viscosity at 40 °C (4.1 cSt), density (0.8884 g/ml), flash point (163 °C), pour point (-3 °C), cloud point (-1.3 °C), acid number (0.08 mg KOH/g), and freezing point (-13 °C), in accordance with ASTM 6751-08 and EN 14214-08 standards.

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1. Introduction

A significant portion of all energy produced worldwide is supplied from fossil fuels (oil, coal, and natural gas) (Icaza *et al.,* 2021). However, these resources are limited and will come to an end in the near future (Zik *et al.,* 2020). In addition to the problem of the dwindling trend of fossil fuel resources, there are also numerous environmental threats associated with the use of diesel fuel (Kaur and Bhaskar, 2020). Therefore, identifying diverse, renewable, and clean energy sources for the continuous progress of human society is essential, and this has led to the emergence of industries such as bioenergy worldwide (Kalghatgi, 2018). Some of the plants of interest for biofuel production are oilseeds, and the fuel produced from them is called biodiesel (Moosavi *et al.,* 2018). The basis of biodiesel production is the transesterification reaction between oil or fat and alcohol in the presence of a strong catalyst (basic or acidic), and the products of this reaction are ester and glycerol. The modification of the chemical structure of plant oils through the transesterification reaction has led to the production of a product with properties very similar, and sometimes better, than diesel fuel (Sharma and Singh, 2009). However, given the high cost of primary resources and the technology for producing biofuels, it is necessary to optimize the process of producing these fuels. The conventional optimization method (one factor at a time) has been studied and has disadvantages such as the need for more experiments over a longer period of time and does not clarify the interaction effects of process variables. In contrast, the use of the response surface method in optimization studies provides details of the interaction effects of selected variables with fewer experiments (Manojkumar *et al.,* 2022). The response surface method is a set of mathematical and statistical techniques used to optimize processes where the desired response is influenced by several variables. This method predicts the natural process of optimization. With the help of this method, the number of experiments is reduced, and all regression coefficients and interaction effects of factors can be estimated. The RSM method has been used in the optimization of biodiesel production from Kasumbha seed (Nosheen *et al.,* 2022), oil Wild pistachio (*Pistacia atlantica* L.) (Ziyad *et al.,* 2022) and pawpaw (*Asiminia triloba.*) tree oil (Ngige *et al.,* 2023). RSM based on central composite design (CCD) has been reported in many studies for optimizing various processes (Baskar *et al.,* 2018).

The majority of biodiesel resources in the world are vegetable oils and animal fats. Currently, over 95% of global biodiesel production comes from edible vegetable oils, leading to competition between fuel and food industries due to the common role of these oils in providing food resources (Shaah *et al.,* 2021). Further research on non-edible resources and low-nutrient products capable of producing high biomass can help fill this gap. One of the plant sources with special potential for biodiesel production is the *Borago officinalis*. However, sources indicate that no studies have been conducted on this plant yet. The *Borago officinalis* L. is an annual herbaceous plant that grows up to 70-100 cm high and belongs to the Boraginaceae family. The origin of this plant is the Mediterranean region, but it has spread widely beyond its original habitat. This plant grows wild in Mediterranean countries, Europe, and North America (Selvi *et al.,* 2006). The seeds of borage are not edible, so biodiesel production from this plant does not threaten food security. It seems that this plant has good potential as a new source of non-edible oil for biodiesel production in bioenergy farms. The aim of this study was to evaluate the potential of biodiesel production from oil extracted from *Borago officinalis* seeds, and to investigate the effect of variables such as molar ratio of alcohol to oil, weight percentage of catalyst, temperature, and reaction time on the percentage of methyl ester conversion and optimize them.

2. Materials and methods

2.1. Extraction of borage seed oil

After harvesting the borage seeds (Figure 1) and cleaning and purifying them, the seed oil was extracted using a cold press extraction method (Figure 2). The cold press method is a fast and simple method for extracting seed oil that preserves the properties and composition of the oil, unlike the hot press method (Cakaloglu *et al.*, 2018). The seed yield of *Borago officinalis* Lin this study was 1020 kg/ha, and 362 kg/ha of oil was extracted from it.

Fig. 1. A view of the field of *Borago officinalis* L. cultivated in this research

Fig. 2. Cleaning *Borago officinalis* L. seed after harvesting and extracting seed oil by cold press method

2.2. Determination of fatty acid percentage

The type and percentage of fatty acids in borage oil and the content of methyl ester in borage biodiesel were determined by a gas chromatography-mass spectrometry instrument. Before the biodiesel extraction process, some required specifications of the extracted oil from European borage seeds, such as fatty acid composition (Littlewood, 2013), viscosity (Nawaz *et al.*, 2018), density (Sahasrabudhe *et al.*, 2017), and acid number (Batista *et al.*, 2016), were measured and evaluated by standard methods.

2.3. Preparation of methoxide solution

Methoxide refers to the mixture of catalyst and methanol. To prepare methoxide, according to the experiment's prepared diagram, potassium hydroxide catalyst with weight percentages of 0.5, 1, and 1.5 relative to the weight of the oil was mixed with methanol and placed on a shaker until the complete dissolution of the catalyst in methanol and homogeneity of the sample. The alcohol used in this study was Merck Germany's methanol alcohol with a purity of 99.9%. Also, 99.8% pure potassium hydroxide tablets from the same company were used as the catalyst (Fereidooni *et al.*, 2018).

2.4. Transesterification reaction

Transesterification is an organic reaction in which an alcohol group of R is exchanged with the ester group of R'. This process is performed by introducing an acid or base catalyst into the reaction mixture (Figure 3). After adding the methoxide solution to the borage oil at molar ratios of 1:4, 1:6, and 1:8, the samples were placed in heat-resistant, lidded containers and subjected to agitation by a stirrer heater at temperatures of 50, 60, and 70 °C for 60, 90, and 120 minutes. The sample agitation speed was constant at 600 rpm throughout the experiments. After the reaction and the formation of biodiesel, the samples were centrifuged for 5 minutes at a relatively high speed (6000 rpm) (Meher *et al.*, 2006) for purification. A decanter was used for further separation of biodiesel and glycerin from the conical flask, and due to its higher density than biodiesel, glycerin settled at the bottom of the flask after 24 hours, and the biodiesel was placed on top of the glycerin.

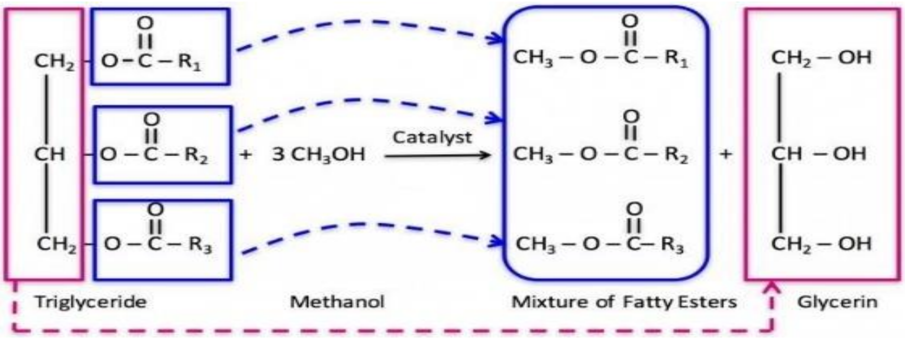

Fig. 3. Biodiesel production process

2.5. Biodiesel yield calculation

After obtaining pure biodiesel, the reaction yield of transesterification was calculated by weight (Equation 1) (Mohamad *et al.*, 2017):

$$\text{Reaction yield} = (\text{produced biodiesel weight} / \text{initial oil weight}) \times 100 \quad (1)$$

2.6. Standard fuel tests

The tests including methyl ester content, kinematic viscosity, density, flash point, pour point, cloud point, acid number, and freezing point were performed on the produced biodiesel and the results were compared with biodiesel standards in the United States ASTM D6751 and Europe EN14214. All the necessary tests for determining the methyl ester content and the properties of the produced biodiesel were carried out with laboratory equipment at the Energy and Environment Research Institute of the Iranian Oil Industry as one of the largest and most reputable oil research centers in the Middle East.

2.7. Statistical analysis and optimization of the biodiesel production process

Optimization of the variables of the trans-esterification process in this study was performed using response surface methodology and the statistical software Design Expert 8.0.6. The levels of each independent variable are presented in Table 1. In order to optimize the process, a composite central design in the form of a face centered design with 30 treatments was used. After selecting the design, the model equation was determined and its coefficients were predicted. The model used was the following quadratic model (Equation 2) (Aworanti *et al.,* 2013):

$$\mathrm{Y} = \beta_0 + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum\sum \beta_{ij} X_i X_j + \varepsilon \tag{2}$$

In this Equation, β_0, β_i, β_{ii} and β_{ij} are constant, linear, quadratic, and interaction effects, respectively. The independent variables are coded. ε is the residual or model error. (i) and (j) are the indices of the independent variables, and (i) is smaller than (j).

Table 1. Selected independent variables on Response Surface Method

Independent variables	Symbols	Levels of each factor		
		-1	0	+1
Reaction temperature (°C)	A	50	60	70
Reaction time (min)	B	60	90	120
Molar ratio (alcohol to oil)	C	1:4	1:6	1:8
Catalyst (wt.% KOH)	D	0.5	1	1.5

3. Results and discussion

3.1. Fatty acid composition and physicochemical properties of oil

The yield of *Borago officinalis* oil was 362.36 kg/ha. The fatty acid composition of vegetable oils plays a significant role in determining the quality of biodiesel. The analysis of oil compounds showed that *Borago officinalis* seed oil contains two categories of saturated and unsaturated fatty acids, with the ratio of unsaturated to saturated fatty acids being very high and desirable at 86 to 14. Palmitic acid (C16:0) with a share of 10% was the most important saturated fatty acid in the oil profile of this plant, followed by stearic acid (C18:0) with a share of 4%. The highest composition present in the oil was C18:2 unsaturated Acid (linoleic acid) (35%). C18:1 (oleic acid) (23%) and C18:3 (n6) (gamma-linolenic acid) (16%) were the second and third main compositions of *Borago officinalis* seed oil, respectively. Linoleic and oleic acids are two important fatty acids for obtaining high-quality biodiesel and desirable properties in terms of improving cold flow properties, oxidative stability, specific gravity, cetane number, and kinematic viscosity (as very important variables in determining biodiesel quality) (Nosheen *et al.,* 2018), which are present in significant percentages in *Borago officinalis* plant (Figure 4).

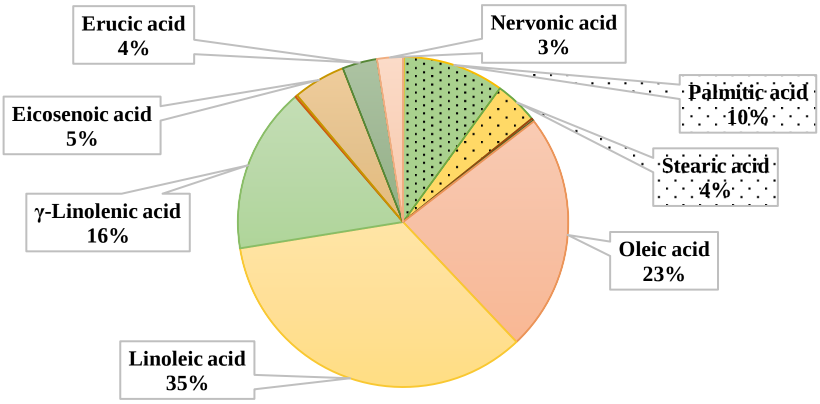

Fig. 4. Fatty acid composition of *Borago officinalis* L. seed oil

Figure 5 shows the GC spectrum of the fatty acid profile of *Borago officinalis* oil. It seems that the fatty acid profile of *Borago officinalis* oil is suitable for biodiesel production, as studies have shown that short-chain fatty acids containing high amounts of palmitic and oleic acids are suitable for biodiesel production due to less polymerization of fuel during combustion compared to fuels derived from multi-unsaturated fatty acids. The reason for this is less fuel polymerization during combustion compared to the fuel obtained from polyunsaturated fatty acids (Ziyad *et al.*, 2022).

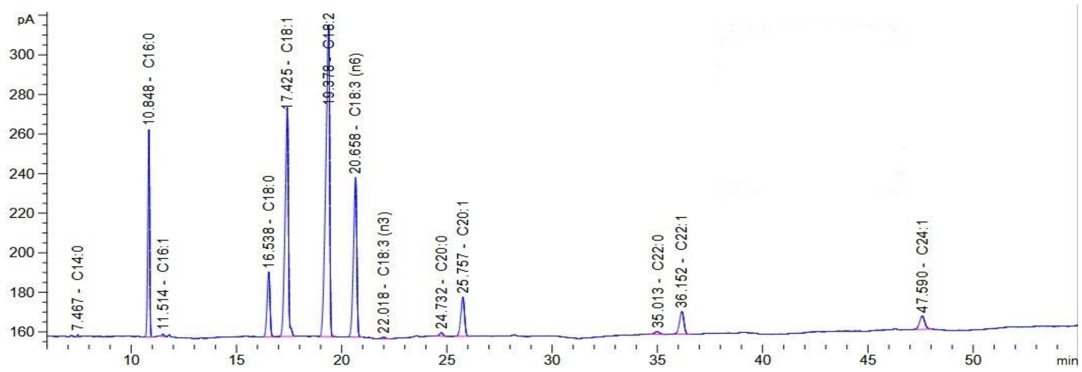

Fig. 5. GC spectrum of fatty acid profile of *Borago officinalis* L. seed oil

3.2. Biodiesel yield and fatty acid methyl ester analysis

The yield of methyl ester produced in 30 experiments varied between 60.3 to 99.94 percent. The evaluation of the amount of catalyst showed that 0.5 weight percent catalyst provides the best conditions for converting *Borago officinalis* seed oil into biodiesel, and higher amounts will cause an increase in soap reaction and a decrease in yield. The percentage of saturated and unsaturated fatty acids in the produced biodiesel in the experiments was variable between 17.09-17.75 and 82.25-82.91 percent, respectively. Previous studies have shown a significant correlation between the fatty acid composition and the optimization of transesterification efficiency (Chai *et al.*, 2014), and oils with higher proportions of monounsaturated fatty acids (palmitic and oleic acids) are suitable for biodiesel production. These acids are also the best in terms of oxidative stability and are suitable for use in cold weather (Benjumea *et al.*, 2011).

3.3. Quality control results of biodiesel fuel properties

According to the results of an investigation into the important properties of biodiesel produced according to the biodiesel standards in the United States ASTM D6751 and Europe EN14214, it was found that the produced biodiesel conforms to the relevant standards and can be confidently used in diesel engines. Table 2 shows the results of the measurement of the properties of the produced biodiesel according to the ASTM D6751 standard. Biodiesel produced from *Borago officinalis* seed oil contains more than 96.5 percent (99.94%) methyl ester and has passed the EN 14103 standard for biodiesel.

Table 2. The properties of biodiesel produced from *Borago officinalis* L. according to ASTM 6751-08 and EN 14214-08 standards

Properties	Test Method	Limit	Units	Measured value
Methyl ester content	EN 14103	>96.5	%	99/94
Kinematic viscosity of oil at 40°C	ASTM D445	-	cSt	30.2
Kinematic viscosity of biodiesel at 20°C	ASTM D445	-	cSt	11
Kinematic viscosity of biodiesel at 40°C	ASTM D445	1.9-6	cSt	4.1
Relative Density	ASTM D1298	0.860-0.900	g/ml	0.888
Flash Point	ASTM D93	>130	°C	163
Pour Point	ASTM D97	-	°C	-3
Cloud Point	ASTM D2500	<0.02	°C	-1.3
Total Acid Number	EN 14104	<0.5	mg KOH/g	0.08
Freezing Point	ASTM D2386	-	°C	-13

Viscosity is one of the most important properties of engine fuels, which plays the most important role in fuel injection, mixture formation, and combustion processes. High viscosity can cause disruption in the injection process and improper atomization (Canakci and Sanli, 2008). The permissible amount of viscosity for biodiesel is determined to be 1.9-6 cSt by ASTM and 3.5-5 cSt by EN. In fact, the purpose of transesterification reaction is to reduce the viscosity of the oil (Shahid and Jamal, 2011). Based on the results, the Viscosity of *Borago officinalis* biodiesel is within the standard range. Density also has a very important effect on the motor fuel injection system, just like viscosity. The amount of injected fuel, injection timing, and injection spray pattern are directly influenced by this parameter. Fuels with high density commonly increase the emission of suspended particles and Nox gases from the engine (Canakci and Sanli, 2008). In this study, the density of biodiesel was measured using the ASTM D1298 standard and the mass per unit volume method. The permissible amount of density in EN is 860-900 Kg/m3, while no range has been specified for it in ASTM. Based on the results, the density of *Borago officinalis* biodiesel is within the EN standard range. Flash point is very important for the safety of fuel storage and transportation. This temperature, which depends on the fuel volatility, is an important feature of fuel for engine startup and heating, and in general, a high flash point is desirable for fuel products (Szybist *et al.*, 2007). In this study, the flash point test was performed using the Open Cup Method according to the ASTM D93 standard. The minimum allowable flash point in ASTM is 130 ºC and in EN is 120 ºC. According to the results (Table 3), the flash point of *Borago officinalis* biodiesel complies with the above standards. Determining the pour point and cloud point for fuels used in cold regions is very important, and these indicators are more suitable for cold regions when they are lower (Starbuck and Harper, 2010). The cloud point is the temperature at which the first wax networks are created inside the fuel. The cloud point is very important to ensure the desired engine performance at low temperatures because the likelihood of the fuel delivery system clogging increases when the temperature drops below this point. The cloud point was measured according to the ASTM D2500 standard. The pour point is slightly higher than the freezing point and is the lowest temperature at which fuel flow can still be pumped (Canakci and Sanli, 2008). No permissible limit has been determined for freezing and pour points in ASTM and EN standards, and it should be determined separately for each region depending on the weather conditions. In this study, the freezing and pour points were determined for the produced biodiesel according to the ASTM D2386 and ASTM D97 standards, respectively. Researchers have shown that low acid numbers in oil and biodiesel improve the storage properties and oxidative stability of biodiesel (Bondioli *et al.,* 2002). In the present study, the acid number of borage biodiesel was much lower than the allowable limit of EN 14104 standard, and was equal to 0.08 mg KOH/g, indicating the high quality of produced biodiesel in terms of this index.

Table 3. ANOVA for Response Surface Redused Quadratic Model (Partial Sum of squares)

Source	Sum of squares	df	Mean square	F value	p-value Prob>F	
Model	1.98	19	0.10	15.78	<0.0001	significant
A-Temperature	0.033	1	0.033	4.98	0.0497	significant
B-Time	4.050E-003	1	4.050E-003	0.61	0.4520	
C-Catalyst	1.11	1	1.11	167.84	<0.0001	significant
D-Molar ratio	0.20	1	0.20	29.69	0.0003	significant
AB	2.250E-004	1	2.250E-004	0.034	0.8574	
AC	5.625E-003	1	5.625E-003	0.85	0.3781	
AD	0.053	1	0.053	8	0.0179	significant
BC	0.013	1	0.013	2	0.1877	
BD	0.12	1	0.12	17.48	0.0019	significant
CD	0.12	1	0.12	18.52	0.0016	significant
A^2	2.879E-005	1	2.879E-005	4.353E-003	0.9487	
B^2	1.411E-003	1	1.411E-003	0.21	0.6541	
C^2	0.072	1	0.072	10.88	0.0080	significant
D^2	4.498E-003	1	4.498E-003	0.68	0.4288	
ABC	3.025E-003	1	3.025E-003	0.46	0.5142	
ABD	1.600E-003	1	1.600E-003	0.24	0.6334	
ACD	2.500E-003	1	2.500E-003	0.38	0.5524	
BCD	0.084	1	0.084	12.72	0.0051	significant
ABCD	6.400E-003	1	6.400E-003	0.97	0.3485	
Residual	0.066	10	6.614E-003			
Lack of Fit	0.024	5	4.838E-003	0.58	0.7198	not significant
Pure Error	0.042	5	8.390E-003			
Cor Total	2.05	29				

3.4. Regression equation and statistical analysis results

The results of previous studies by other researchers have also shown that the yield and quality of biodiesel produced by transesterification reaction depends on various factors such as reaction time, molar ratio of alcohol to oil, reaction temperature and pressure, catalyst concentration and type, water content, and free fatty acid content in the oil (Paul and Adewale, 2018). The results of the analysis of variance of the data obtained from the experiments of the present study showed that the variables of molar ratio of alcohol to oil, catalyst weight percentage, and reaction temperature have a significant effect on the amount of produced methyl ester. Also, the interactive effects of the variables of molar ratio and time, molar ratio and temperature, and molar ratio and catalyst weight percentage have a significant effect on the amount of produced methyl ester (Table 3). The results of the optimization of the biodiesel production process showed that for a molar ratio of 1:8, catalyst weight percentage of 0.5, reaction temperature of 60 °C, and reaction time of 90 minutes, the highest desirable process yield (95.3%) was obtained. The experiment was repeated at the proposed point and the conversion percentage obtained was 94.4%, which is acceptable. From the data analysis, a regression equation between the independent variables (coded form) and the dependent variable (reaction yield) was obtained as a second-degree equation in equation (3). This equation is coded and can be used to predict the reaction yield under different working conditions and to diagnose it. The determination coefficient of the developed model is 96.77%, indicating the closeness of the predicted results to the actual data, meaning that 96.77% of the dependent variable changes depend on the independent variables and only 3% of the dependent variable cannot be explained by the independent variable, which proves the validity of the developed model.

$$\%\text{Yield} = 35.27 - 0.043A + 0.015B - 0.25C + 0.1D - 3.75 \times 10^{-3}AB + 0.019AC + 0.058AD - 0.029BC + 0.085BD - 0.087CD - 3.33 \times 10^{-3}A^2 - 0.023B^2 + 0.17C^2 + 0.042D^2 - 0.014ABC - 0.010ABD - 0.013ACD - 0.073BCD - 0.02ABCD \quad (3)$$

Temperature clearly affects the biodiesel production reaction. A higher reaction temperature can reduce the viscosity of the oil, resulting in a faster reaction and shorter reaction time. When the reaction temperature exceeds the optimal temperature, the yield of biodiesel decreases because the higher temperature accelerates the formation of glycerin from triglycerides. Also, it is important to note that the transesterification reaction temperature should always be lower than the alcohol boiling point to ensure that the evaporated alcohol does not escape from the reaction. Krishnakumar and Sivasubramanian (2016) stated that the transesterification reaction is the most desirable process for industrial biodiesel production because it requires a relatively low temperature, when examining the required conditions for biodiesel production from rubber seed. The optimal temperature conditions of 60 °C have also been reported for the production of biodiesel from safflower seeds (Kumar *et al.,* 2017), mahua (*Madhuca indica*) (Muthukumaran *et al.,* 2017), and pawpaw (*Asiminia triloba*) oil (Ngige *et al.,* 2023). Therefore, the result obtained in this study (60 °C as the optimal temperature) is consistent with the results presented by other researchers.

The conversion rate of fatty acid esters is proportional to the reaction time. Usually, with an alkaline catalyst, the maximum product yield is achieved in less than 90 minutes of reaction time, and then with more time, the equilibrium is established, and the reaction remains relatively constant. Nevertheless, exceeding the optimal reaction time will reduce the production of the product due to the reverse transesterification reaction, resulting in a decrease in esters and more conversion of fatty acids to glycerin. Muthukumaran *et al.* (2017), in optimizing biodiesel production from the mahua oil, reported the highest conversion efficiency (88.71%) at a reaction time of 90 minutes. Kumar *et al.* (2017) also achieved the optimal yield (93.8%) in the process of biodiesel production from safflower oil at a reaction time of 90 minutes. The result obtained for the optimal time in the present study (90 minutes) confirms the results of previous researches (Muthukumaran *et al.*, 2017; Kumar *et al.*, 2017).

The most important factor affecting biodiesel production is the concentration of the catalyst, and in this study, it had a greater effect on the yield of biodiesel than other variables. In the study by Kumar *et al.* (2017), the catalyst concentration was also the most influential parameter, with positive effects of 51.1% and 50.8% on the yield and viscosity of biodiesel, respectively. When the catalyst concentration is either too high or too low, the yield of biodiesel decreases. The use of a catalyst increases the rate of biodiesel production; however, an insufficient amount of catalyst leads to incomplete conversion of triglycerides to fatty acid esters. Increasing the catalyst beyond the required amount also reduces the efficiency of biodiesel production. This is because adding more catalyst causes the reaction of triglycerides with the alkaline catalyst and the formation of glycerin, which reduces product yield and makes separation difficult. In other words, in high amounts, saponification occurs, increasing the viscosity of the reactants and reducing the product yield. Dhanasekaran and Dharmendirakumar (2014), in their experiment on the production of biodiesel from waste cooking oil, concluded that the yield of biodiesel increases significantly from 0.5% to 1% catalyst weight concentration and decreases by 32% with increasing catalyst concentration to 1.5%. Thus, if the amount of catalyst exceeds the optimum level, glycerin production occurs, and the conversion percentage decreases. In this study, the optimal catalyst weight percentage was found to be 0.5%, and an increase beyond this amount led to a decrease in the production of methyl ester.

One of the most important factors affecting the performance of biodiesel production is the molar ratio of alcohol to triglyceride. According to the stoichiometric ratio, in the transesterification reaction, 3 moles of alcohol are required for every 1 mole of triglyceride, which leads to the production of 3 moles of fatty acid ester (biodiesel) and 1 mole of glycerol. However, to ensure that the oil used in the reaction is completely converted to ester, an extra amount of alcohol is used in the transesterification reaction so that a higher ratio of alcohol to triglyceride can result in the production of more ester in a shorter time. Therefore, if the alcohol to triglyceride ratio is greater than 3, the biodiesel product will increase. However, increasing this ratio beyond an optimal amount will not only fail to increase biodiesel production, but will also incur the cost of alcohol recovery after the reaction (Leung and Guo, 2006). In general, the optimal amount of this molar ratio is also dependent on the type of catalyst used in the reaction. The molar ratio of alcohol to triglyceride using an alkaline catalyst has been used in most studies at 6:1. However, when the percentage of free fatty acids in the oil used is high and an acidic catalyst is also used in the reaction, this molar ratio may increase to 15:1 (Leung and Guo, 2006). For example, Dai *et al.* (2014) reported the optimization conditions of the soybean biodiesel production process with a conversion efficiency of 99.04% at a molar ratio of 12:1 methanol to oil. Similarly, Hebbar *et al.* (2018) reported the optimization conditions for biodiesel production from *Bombax ceiba* oil, and Anwar *et al.* (2018) reported the optimal conditions for biodiesel production from *Carica papaya* oil at a molar ratio of 10:1 methanol to oil. However, in the production of biodiesel from cotton seed (Mujeli *et al.*, 2016), coconut oil (Pimngern and Punsuvon, 2017), and purslane seed (Hoseini *et al.*, 2019), the optimal methanol to oil ratio was reported to be 8:1. The optimal molar ratio of alcohol to oil in the current study was also found to be 8:1, which can confirm the above results. Figure 6 shows the interactive effect of temperature, reaction time, weight percentage of catalyst, and molar ratio on the percentage of methyl ester conversion (biodiesel production).

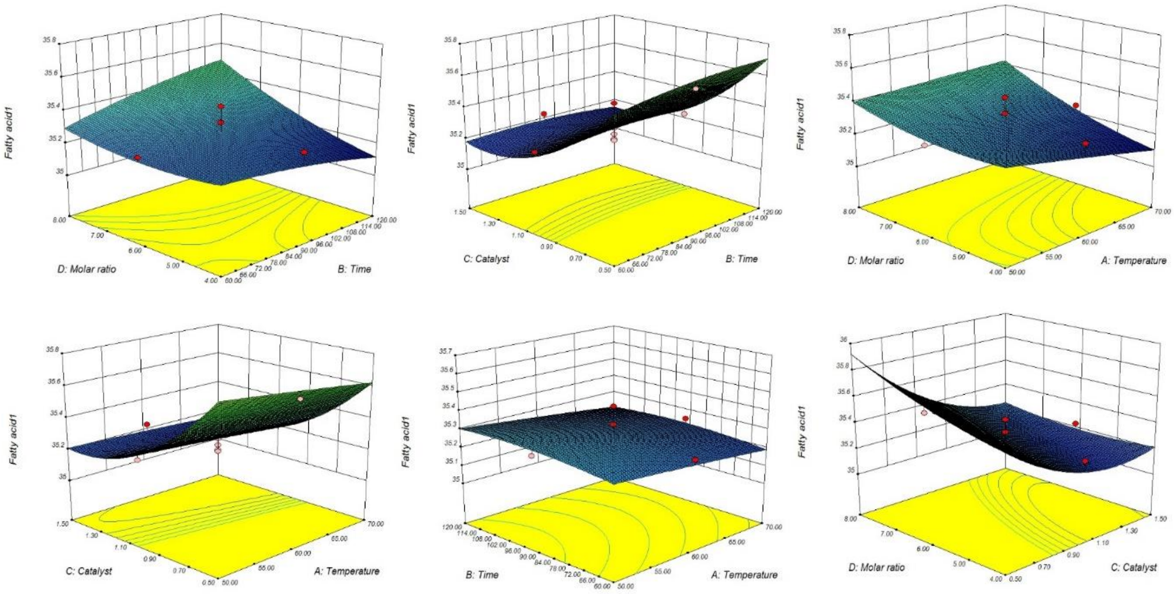

Fig 6. The interaction Effect of temperature, reaction time, wt.% catalyst and molar ratio on methyl ester conversion

The results of other researchers' experiments on various biodiesel sources show that the amount of tested variables depends on the type and quality of the oil and different reaction conditions. For example, Aladetuyi *et al.* (2014) obtained a suitable yield in biodiesel production from palm oil after 120 minutes of reaction time at a temperature of 100 °C and an alcohol ratio of 6. Kuwornoo and Ahiekpor (2010) achieved a high yield in 90 minutes of reaction time, while Mumtaz *et al.* (2014) obtained a suitable yield in biodiesel production from palm oil after 2.67 hours of reaction time. Although the composition of oil affects the transesterification reaction conditions, there is a good similarity and conformity between the results of this study and the results of other studies. Transesterification is carried out by reacting methanol with oil in the presence of a catalyst with the help of heat and within a specific time period. Therefore, in biodiesel production by transesterification, various properties such as the methanol to oil ratio, catalyst weight percentage, catalyst type, reaction temperature, and reaction time are influential. Generally, increasing the temperature, reaction time, catalyst concentration, and methanol to oil ratio increases the efficiency of biodiesel production, but this relationship is not linear, and if any of the considered factors is not properly selected, the percentage of oil conversion to biodiesel decreases (Singh *et al.,* 2018).

4. Conclusion

The results of this study showed that under optimal conditions for biodiesel production from *Borago officinalis* plant through transesterification reaction, a molar ratio of 1:8, catalyst weight percentage of 0.5, reaction temperature of 60 °C, and reaction time of 90 minutes, the highest desirable process yield (95.3%) was obtained. This plant can be a valuable source for producing renewable biodiesel fuel in the future.

Author Contributions

Conceptualization, S.K. and S.Z.; methodology, S.Z., S.K. and F.S.; software, S.Z. and F.S.; validation, S.K. and S.Z.; formal analysis, S.Z.; investigation, F.S.; resources, F.S.; data curation, F.S.; writing—original draft preparation, F.S.; writing—review and editing, S.K., S.Z. and G.H.; visualization, S.Z. and F.S.; supervision, S.K. and G.H.; project administration, S.K. and S.Z.; funding acquisition, F.S., S.K., S.Z and G.H. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

All data analyzed during this study are included in this published article.

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Ethical considerations

The authors avoided from data fabrication and falsification.

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Conflict of interest

The authors declare no conflict of interest.

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