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FULL LENGTH ARTICLE

Biodiesel production from *Sesamum indicum* L. seed oil: An optimization study

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Abstract Transesterification of *Sesamum indicum* L. oil was carried with methanol in the presence of sodium methoxide and the parameters affecting the reaction; vegetable oil/methanol molar ratio, catalyst concentration, reaction temperature and time were fully optimized by employing Central Composite Design method (CCD). A quadratic polynomial was developed to predict the response as a function of independent variables and their interactions and only the significant factors affecting the yield were fitted to a second-order response surface reduced 2FI model. At the optimum condition of 1:6 oil/methanol molar ratio, catalyst concentration of 0.75% and reaction time of 30 min, biodiesel yield of 87.80% was achieved. The selected fuel properties were within the range set by ASTM and EN bodies.

1. Introduction

The demand for energy is increasing at a substantial rate as the economy of the populous developing countries is growing. Currently, this high energy demand mainly depends on fossil fuel resources [1] but it is unsustainable and its exploitation leads to environmental degradation and increased emission of greenhouse gases. Hence, the use of alternative sources of energy, such as biofuels, is attracting the interest of researchers [2].

In recent years, biodiesel has gained international attention as a source of alternative fuel due to characteristics like high degradability, low toxicity and emission of carbon monoxide, particulate matter and unburned hydrocarbons [3,4]. Biodiesel is a mixture of alkyl esters and it can be used in conventional compression ignition engines, which need almost no modification. Biodiesel can be used as heating oil and also as fuel [5,6]. So far, this alternative fuel has been successfully produced by transesterification of vegetable oils and animal fats using homogeneous basic catalysts.

Currently, partially or fully refined and edible-grade vegetable oils, such as soybean, rapeseed and sunflower, are the predominant feedstock for biodiesel production [7,8], which obviously results in the high price of biodiesel. Therefore, exploring ways to reduce the cost of raw material is of much

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interest in recent biodiesel research. As a result, in some countries, non-edible oils such as *Jatropha curcas* or waste cooking oils [9–11] are preferred due to their low price.

Realistically, non-edible oils only cannot meet the demand of energy consumption therefore, it has to be supplemented from some edible oils. For example, the average US production of soybean oil from 1993 to 1995 was 6.8 billion kg, and in 2002, soybeans were harvested from more than 30 million hectares across the United States, which accounts for 40% of the total world soybean output [12]. This production capacity accounts for more than 50% of the total available bio-based oil for industrial applications. Also rapeseed is mostly grown in Europe, China and India and there are many published reports on the utilization of these seed oils as biodiesel fuels [13–15].

Beniseed (*Sesamum indicum* L), herbaceous plant in Nigeria as well as in India, China, Sudan, Burma, Bangladesh, Indonesia, Egypt, Tunisia, belongs to the family of *Pedaliaceae*. Sesame seed has one of the highest oil contents of any seed and is considered to be the oldest oilseed crop known to man, highly resistant to drought and has the ability of growing where most crops fail [16,17]. The seed colour varies from cream-white to charcoal black but it is mainly black. In Nigeria, the notable colours of sesame seed are white, yellow and black [18]. The major world producers include India, Sudan, China and Burma while Nigeria and Ethiopia are also major producers and exporters [19].

The fat of sesame is of importance in the food industry due to its flavour and stability, its oil has been found to contain sesamin and sesaminol lignans in its non-glycerol fraction, which are known to play an important role in the oxidative stability and antioxidant activity [20]. The main fatty acid composition of the oil is oleic (43%), linoleic (35%), palmitic (11%) and stearic (7%) acids, contributing about 96% of the total fatty acids [17,21]. It also contains some polyunsaturated fatty acids basically Omega 6 fatty acids but lacks Omega 3 fatty acids.

Sesame seed is cultivated and produced in large quantity in Nigeria, especially in the Northern part of the country and is under-utilized in some parts of the country. Therefore, there is a greater need to utilize some for energy purposes. Based on the recent statement that Nigeria envisions an energy transition from crude oil to renewable energy [22], we therefore investigated the oil of sesame seed as an alternative feedstock for the production of biodiesel fuel.

In this work, we produced our biodiesel from sesame oil through transesterification reaction in the presence of an alkali based catalyst and the factors affecting the reaction were fully optimized by following the factorial design and response surface methodology [23]. Limited reports on biodiesel production from the oil of *S. indicum* and its optimization using Central Composite Design technique exist in the literature [18,24].

2. Materials and methods

2.1. Materials

Seeds of *S. indicum* L. were bought from the open market, dried to an acceptable moisture level and milled with a laboratory milling machine. The oil-seed was then extracted with n-hexane using a soxhlet apparatus and characterized according to the AOCS official methods [25] (Table 1). Analytical grades of sulphuric acid, methanol (Beijing Chemical works), sodium hydroxide, and hexane (Xilong Chemicals) were used without any further purification. The reference standard of fatty acid methyl esters (methyl palmitate, methyl stearate, methyl linoleate and methyl linolenate) was purchased from accustandard, methyl oleate (J&K Chemicals) and monolein from the Tokyo Chemical Industry, while diolein and triolein (Sinopharm Chemicals) and glycerol standards were purchased from Xilong Chemicals Co.

Table 1 Central Composite Design for transesterification reaction.

Variables (coded factors)	Levels		
	−1	0	+1
Molar ratio of oil to methanol (X_1)	6:1	1:9	1:12
Catalyst/oil ratio (X_2)	0.75	1.00	1.25
Reaction temperature (X_3)	50	60	70
Reaction time (X_4)	30	60	90

2.2. Methods

2.2.1. Experimental procedure

Reactions were carried out in a 250 cm^3 two-necked batch reactor. The reactor was initially filled with the desired amount of oil, and then placed in the constant-temperature oil bath equipped with reflux condenser, stopper and heated to a predetermined temperature. The catalyst, sodium methoxide was generated by dissolving anhydrous sodium hydroxide in methanol and the resulting solution was added to the agitated reactor. At the

Table 2 Physical and chemical parameters of *Sesamum indicum* oil.

Parameters	Values
% Yield	61.99 ± 0.37
Colour	Light yellow
State at room temperature	Liquid
Specific gravity (25 °C)	0.8525 ± 0.03
Viscosity at 40 °C (mm^2/s)	22.63
Acid value (mgKOH/g)	3.15 ± 0.58
FFA (%)	1.58 ± 0.29
Saponification value (mgKOH/g)	142.2 ± 2.40
Iodine value (mg I/g)	86.15 ± 1.63
Peroxide value (mgO_2/g)	2.8 ± 0.00

Table 3 Fatty acid composition of *Sesamum indicum* oil.

Fatty acid	% Composition
Caproic acid (6:0)	7.80
Palmitic acid (16:0)	6.80
Stearic acid (18:0)	8.98
Oleic acid (18:1)	28.54
Linoleic acid (18:2)	39.73
Linolenic acid (18:3)	0.31
Lignoceric acid (24:0)	4.59
Others	3.25