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Ailanthus altissima (tree of heaven) seed oil: Characterisation and optimisation of ultrasonication-assisted biodiesel production

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ABSTRACT

The non-edible oil from *Ailanthus altissima* (tree of heaven) seeds has potential as a novel feedstock for biodiesel production in Iran. In this study, *Ailanthus altissima* seed oil (AAO) has been investigated as a novel feedstock for biodiesel production. Ripe *Ailanthus altissima* seeds were collected from the Tarbiat Modares University campus and, after drying, their oil was extracted using a Soxhlet extraction system. The maximum oil content of the seeds was found to be ~38%. The physical and chemical characteristics of the AAO were investigated. Biodiesel was prepared using an ultrasonic setup. In order to obtain the highest yield of biodiesel, the production process was optimised using a response surface methodology (RSM) model. Reaction parameters such as the molar ratio of methanol to oil, reaction time, and catalyst loading were studied. The biodiesel yield was 92.26% under the optimised conditions, i.e., a methanol-to-oil molar ratio of 8.50:1, a catalyst loading of 1.01 wt%, and a reaction time of 4.71 min. The biodiesel prepared from *Ailanthus altissima* oil complies with the criteria dictated by ASTM D6751 standards. Thus, this seed oil can be introduced as a new feedstock for biodiesel production in Iran.

1. Introduction

Increases in population and industrialisation have significantly increased the demand for energy [1,2]. One of the sectors in which energy is consumed most significantly is the automotive sector, specifically in internal combustion diesel engines. Diesel engines often use fossil resources and mineral-based fuels. The use of fossil fuels produces significant amounts of pollutants during combustion due to their chemical structures [3–5]. Thus, fossil fuels emit pollutants at considerable levels, causing damage to the environment and endangering human health [6]. One strategy to reduce emissions from diesel engines is to use bio-based fuels. There are a variety of bio-based fuels, one of which is vegetable oil. Vegetable oils are a reliable source of biofuels [7–11]. The amount of pollutants produced from vegetable oils is significantly less than that from fossil fuels [7,12]. However, vegetable oils cannot be used directly as fuels in diesel engines owing to their chemical structures. Different methods to improve the properties of vegetable oils have been investigated by various researchers. One common method used to improve the properties of vegetable oils is transesterification. Upon processing the vegetable oil, it is converted into biofuel, also called biodiesel [13–15]. Numerous studies have been conducted on the production of biodiesel from vegetable oils [16–25].

Anwar et al. [26] produced biodiesel using okra (*Hibiscus esculentus*) seed oil. Transesterification was performed with $NaOCH_3$as the catalyst. The results of this study showed that the optimal conditions for biodiesel production were a 7:1 methanol-to-oil molar ratio, a 1.00% (*w/w*) $NaOCH_3$ catalyst loading, a reaction temperature of 65 °C, and a 600 rpm agitation intensity. Under these conditions, the rate of okra seed oil conversion into biodiesel was reported to be 96.8%. The results of this study also showed that the biodiesel produced had suitable physical and chemical characteristics for general use. Morshed et al. [27] investigated the potential of rubber seed oil (RSO) to produce biodiesel in Bangladesh. In their research, the oil was first extracted by a mechanical method and the oil content was reported to be 49%. The RSO samples and the produced biodiesel were analysed using ^1H NMR spectroscopy to confirm the conversion of the oil into biodiesel. According to the results of this study, the rate of RSO to biodiesel conversion was 86%. Furthermore, the results indicated that the rubber produced from RSO had good chemical and physical properties for biodiesel production. Qiu et al. [28] produced a new type of biodiesel using mixed soybean oil and rapeseed oil. In their research, the effects of different parameters, such as the molar ratio of methanol to oil, reaction time, reaction temperature, and catalyst loading, on the biodiesel conversion rate were investigated. The results showed that when the

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molar methanol-to-oil ratio was 5:1, the biodiesel conversion rate was the highest (94%). The results of this study also showed that the highest rate of conversion was obtained when the reaction temperature was 55 °C, the catalyst loading was 0.8%, and the reaction time was 2 h. Upon examining the properties of the fuel produced, it was found that it showed potential as an alternative to diesel. Lavanya et al. [29] examined various castor genotypes (*Ricinus communis* L.) for biodiesel production. In their research, 15 castor genotypes were collected from different regions of India. The chemical and physical structures of the oils obtained from different castor genotypes were compared. The results of the study showed that genotypes 48-1 and DCH-200 had high oil contents, low iodine values (IVs), and high cetane numbers. Nehdi et al. [30] examined garden cress (*Lepidium sativum* Linn.) seed oil in terms of the properties required for biodiesel production. The oil content of garden cress seed oil was reported to be 26.77% and the extracted oil contained 42.23% polyunsaturated fatty acids and 39.62% monounsaturated fatty acids. The results of alkali-catalysed transesterification experiments showed that the biodiesel conversion rate was ~96%. The physical and chemical properties of the biodiesel produced from garden cress seed oil was within the range of the American Standard for Testing and Materials (ASTM) standards. Maniam et al. [31] used decanter cake as a feedstock for biodiesel production. In their research, ultrasound was used to perform the transesterification reaction. The oil content of the decanter cake was reported to be 11.5%. In this research, boiler ash was used as a catalyst. The results showed that when the reaction was carried out at 55 °C and the reaction time was 1 h, the conversion was 85.9 wt%. Karabas [32] used crude acorn (*Quercus frainetto* L.) kernel oil as a feedstock for biodiesel production. The Taguchi method was used to optimise the biodiesel production process, and different variables were examined in this regard, including the molar ratio of methanol to oil, catalyst loading, reaction time, and reaction temperature. It is worth mentioning that potassium hydroxide was used as a catalyst in this research. Results of the optimisation showed that when the methanol-to-oil molar ratio, catalyst loading, reaction temperature, and reaction time were 8:1, 0.7 wt%, 40 °C, and 40 min, respectively, the highest conversion rate of oil to biodiesel (90%) was achieved. Modiba et al. [33] examined the chemical and physical characteristics of biodiesel produced from baobab (*Adansonia digitata* L.) seed kernel oil. In their research, several variables (methanol-to-oil ratio, catalyst-to-oil ratio, reaction time, and reaction temperature) were studied in order to optimise the biodiesel yield. The results showed that under optimal conditions (i.e., methanol-to-oil ratio = 30 wt%, reaction temperature = 60 °C, reaction time = 1 h, and catalyst-to-oil ratio = 1.4 wt%), the biodiesel yield was 96 wt%. The physical and chemical characteristics of the biodiesel produced from baobab seed kernel oil showed that the produced biodiesel was consistent with the requirements of EN and ASTM standards. Nehdi et al. [34] examined *Rhazya stricta* Decne seed oil in terms of physical and chemical characteristics for biodiesel production. In their study, the rate of triacyl glycerol conversion to the corresponding methyl esters was measured by ^{1}H NMR analysis. The results of the study showed that the rate of biodiesel conversion was ~97%.The results also showed that the biodiesel produced from *Rhazya stricta* Decne seed oil had acceptable physical and chemical properties compared to those of most biodiesels produced. Michelin et al. [35] produced biodiesel from Macauba coconut oil using ultrasound irradiation technology. In this study, the effects of different variables (oil-to-ethanol molar ratio, temperature, output irradiation power, and enzyme concentration) on the reaction yield were assessed. The results of this study showed that solvent-free enzymatic transesterification can replace conventional alkali-catalysed and/or traditional enzymatic methods for biodiesel production. In addition, analysis of the produced biodiesel revealed that under a mild irradiation power supply, a temperature of 65 °C, and a reaction time of 30 min, the reaction yield was ~70%. Kumar et al. [36] optimised the transesterification process to produce biodiesel from *Manilkara zapota* (L.) seed oil, taking into account four variables, i.e., methanol-to-oil molar ratio, reaction time, reaction temperature, and catalyst loading. In their research, the Taguchi method was used for optimisation, and the chemical and physical properties of the *Manilkara zapota* (L.) seed oil and the biodiesel produced were studied comprehensively. Results of the study showed that, under optimal conditions (reaction temperature = 50 °C, reaction time = 90 min, methanol-to-oil molar ratio = 6:1, and catalyst loading = 1 wt%), the yield was 94.83%.After examining several variables, it was found that the methanol-to-oil molar ratio had the greatest effect on biodiesel production. Analysis of its physicochemical properties revealed that the biodiesel produced from *Manilkara zapota* (L.) seed oil meets the global standards for biodiesel (EN 14214). Sáez-Bastante et al. [37] assessed the physical and chemical properties of *Sinapis alba* as a feedstock for biodiesel production. Analysis of alba oil by gas chromatography showed that it has suitable properties for biodiesel production. Furthermore, the physical and chemical characteristics of biodiesel produced from alba oil are consistent with the requirements of EN 14214 standards. Samani et al. [38] studied the feasibility of biodiesel production from *Pistacia atlantica* Desf. oil. In their research, ultrasonification technology was used to perform the transesterification process. When the amplitude and pulse of the ultrasonic treatment were increased, the methyl ester content of the product increased. Additionally, when the methanol-to-oil molar ratio was increased within the range 5:1–6:1, the methyl ester content of the product increased. A review of the physical and chemical characteristics of the biodiesel produced from *Pistacia atlantica* Desf. oil revealed that the characteristics of the biodiesel produced were consistent with the requirements of EN 14214 standards. In 2017, Hasni et al. [39] used response surface methodology (RSM) to study the variables affecting biodiesel production from *Brucea javanica* seed oil. The results showed that under optimal conditions (methanol-to-oil ratio = 6:1, reaction temperature = 65 °C, catalyst loading = 1 wt%), the biodiesel yield was 94.34%. An investigation of the physical and chemical properties of the biodiesel produced from *Brucea javanica* seed oil revealed that it met the requirements of ASTM D6751 and EN 14214 standards. García-Martínez et al. [40] optimised the variables affecting biodiesel production from tobacco (*Nicotiana tabacum*) seed oil using RSM to improve the biodiesel production process. The results of the research showed that, under optimal conditions, the fatty acid methyl ester (FAME) yield was ~91%. The results of the study showed that the physical and chemical properties of the produced biodiesel were consistent with the requirements of EN 14214 standards.

This review of pervious studies reveals that many of the resources used to produce biodiesel are edible oils. More than 95% of biodiesel is produced from edible oils, leading to concerns that many problems with the sourcing of feedstocks may arise. The use of edible vegetable oils or first-generation feedstocks for biodiesel production has been of great concern recently. Biodiesel production from edible oils results in food resources being changed into fuels. Thus, the large-scale production of biodiesel from edible oils could cause a global imbalance in food supply and demand. Furthermore, this problem may cause serious ecological problems as countries around the world begin cutting down forests for plantation purposes. Thus, the use of edible oils as a feedstock for biodiesel production could cause deforestation and damage to wildlife. Therefore, non-edible vegetable oil feedstocks have become more attractive for biodiesel production [16,41]. Non-edible oil feedstocks have several advantages over edible oils in term of biodiesel production. Non-edible oils contain toxic components that make them unsuitable for human consumption [42]. This means that the production of non-edible oils does not require ideal conditions. Therefore, unproductive land, fallow lands, roads/field boundaries, degraded forests, and irrigation canals can be used for the production of non-edible oil crops. Consequently, biodiesel production from non-edible oils may become a feature of major economic improvement programs for poor rural areas [43].

In the present study, a type of non-edible oilseed (*Ailanthus altissima*) was studied for application to biodiesel production. *Ailanthus*

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