A Comprehensive Analysis of Oil Extraction Technologies for Optimized Biodiesel Production

ABSTRACT: There is acritical need for energy diversification due to over depended on fossil fuel and its daunting challenges. These impedimentslinked with fossil fuels have stirred the search for another energy sources and biodiesel is oneof the potential alternatives. Biodiesel is renewable, non-toxic, environmental-friendly and an economically viable choice to solve the diminishing fossil fuels and its harmful environmental effect. It can be made from seeds oil plant, vegetable oils, animal fats, waste oils and algae. Here arevariousmeans for the production of the biodiesel oil which comprises; mechanical, chemical/solvent and enzymatic oil extraction methods etc.Report from the open literatures revealed that, all the extraction methods have its own advantages and disadvantages but in all, oil expeller machine which is based on mechanical means of extracting oil from the common wastage seeds oil plant prove to be efficient especially for large scale extraction.Thus, for efficient oil extraction from wastage seeds oil plant,oil expeller machine is appropriate. This research seeks to discuss an improve ways of maximum oil yield with an expeller machine from the wastage seeds oil plant commonly available in our environment.

Key Words:biodiesel production process, oil extraction methods, seeds oil, screw press oil expeller

1. INTRODUCTION

Generally, energy is an essential element of industrialization and socio-economic development of any country. The petroleum deposits in certain regions of the world are fast diminishingon daily basis and at the current usage rate, these sources will soon be exhausted. Recently, due to the shortage of fossil fuels throughout the world, crude oil price increase and impact of these fuels in polluting the environment, biodiesel is attracting increasing attention as a potential substitute and renewable fuel for diesel engines worldwide [1].

The choice of biodiesel as an alternative fuel has been getting a lot of attention throughout the world owing to its renewable, biodegradable as well as its environmentally friendly nature. It produces lower pollutant emissions, possesses a high flash point, better qualities of lubrication and high cetane number with very close physical and chemical characteristics to those of conventional diesel fuel. This allows its use either as pure biodiesel (B100) or mixed with petroleum-based diesel fuel at a ratio of between 5–20%, (B5–B20) with very few technical adjustments or no modifications. Burning of biodiesel fuel does not contribute to a rise in the level of carbon dioxide in the atmosphere and does not pose a danger to the ozone layer [2].

The biodiesel produced from renewable resources could help to minimize the fossil fuel burning and CO_2 production. Biofuels and bio products produced from plant biomass mitigate global warming. This is as a result of the CO_2 released during combustion being equal to the CO_2 tied up by the plant during photosynthesis and does not add up to the net CO_2 in the atmosphere [3]. Therefore, an increase in biodiesel production by trans-esterification may lead to an excess of glycerol production as a by-product. The glycerol is mostly used in medical, pharmaceutical and personal care applications [4].

Over the years, several review articles have been published by many researchers onthe extraction of oil for biodiesel production [5]. However, in this research we shall discuss efficient ways of maximum oil yield with an expeller machine from the oil seeds. The review paper seeks to present; first,thevarious ways of oil extraction for biodiesel production. It goes further to compare oil extraction process of automatic screw press oil expeller and the manual oil expeller process. The problem associated with each oil extraction processes were identified and their respective appropriate remedies were proffered in the course of this review. It further considered an overview of biodiesel focusing on theproduction methods of the biodiesel.

2.0 Feedstock preparation

The initial phase of oil extraction commences with seed preparation. This process involves removing the outer layers of the fruit to expose the kernels or seeds, followed by drying to reduce moisture content [6]. The seeds are then separated from the fruits, and for those fruits that do not naturally split open, manual cracking is employed. To achieve the ideal moisture content for optimal oil extraction, the kernels or seeds are predominantly dried either in the sun or in an oven, depending on the prevailing weather conditions. Following the drying process, the separated seeds or kernels undergo sieving, cleaning, and are subsequently stored at room temperature in preparation for the extraction of their oil content, as documented in various literature sources [7, 8, 9].

2.1 Oil Extraction from Seeds

One crucial element in biodiesel production is the extraction of oil, and various methods and techniques for oil extraction have been documented in studies such as [10,11,12,13]. These methods encompass mechanical, chemical/solvent, enzymatic oil extraction, as well as microwave-assisted extraction, supercritical fluid extraction, and accelerated solvent extraction. This article focuses on the mechanical method, specifically comparing the manual oil extraction machine process with the automatic oil extraction process. Additionally, improvements to the machinery will be explored to address and enhance the oil production process

2.2 Oil Extraction Methods

This section provides an overview of the prevalent oil extraction techniques. These methods encompass chemical/solvent extraction, enzymatic extraction, microwave-assisted extraction, supercritical fluid extraction, accelerated solvent extraction, and mechanical extraction.

2.2.1chemical/solvent

Solvent extraction, also known as leaching, is the procedure through which oil is separated from a solid using a liquid solvent, as documented in studies [7,14]. Various factors influence the chemical leaching process, including particle size, the type of liquid solvent employed, temperature, and the mixing speed of the system. In order to increase the interfacial area between the feedstock and the solvent, a tiny particle size is desired. For unrestricted circulation, the solvent should have a low viscosity. Temperature plays an important role as it makes the oil more soluble, which influences the rate of extraction. According to [15], mixing speed is another crucial component that affects the process by increasing the rate of diffusion, which subsequently facilitates material transfer from the particle surface.

It's interesting to note that the solvent extraction method has its own set of advantages and disadvantages. While it has been proven to be a highly effective process with a high yield and consistent performance, it does come with a relatively higher production cost compared to mechanical press methods due to the expense associated with the solvent, as highlighted by [16].

2.2.2 EnzymaticExtraction

This approach involves the crushing of seeds followed by the utilization of enzymes for oil extraction [17]. There is also the potential to integrate aqueous enzymatic oil extraction with other methods for oil retrieval. Despite the promising aspects of this method, its practical application encounters challenges such as the requirement for de-emulsification in subsequent processing, extended incubation periods, and elevated enzyme expenses [18, 19]. Affinity chromatography and perfusion chromatography are two techniques that can simplify downstream processing, and the immobilization of enzymes helps in reducing overall costs and minimizing enzyme losses [20].Nevertheless, the immobilization of enzymes may result in decreased reaction rates due to steric hindrance. Moreover, the utilization of solvents like n-hexane not only amplifies wastewater generation and the emission of volatile organic compounds but also presents hazards owing to the flammability and toxicity of n-hexane [21]. To address these issues, an alternative extraction method, such as an aqueous enzymatic oil system coupled with ultra-sonication pre-treatment, is recommended [18,22]. The principal merits of enzymatic oil extraction are its eco-friendliness and the absence of volatile organic compounds. However, a notable drawback associated with this technique is the prolonged processing time, as highlighted by [17].

2.2.3 Microwave-Assisted

Microwave-assisted extraction, also referred to as microwave extraction in accordance with [23], represents a novel extraction method that combines traditional solvent extraction with microwave technology. This technique is acclaimed for its numerous advantages compared to alternative extraction methods. These advantages encompass reduced extraction costs, expedited processing times, diminished solvent usage, heightened extraction efficiency, improved product quality at a reduced

expense, decreased energy consumption, and lower CO_2 emissions [24]. The literature showcases numerous instances where successful applications of microwave-assisted extraction, documented by various researchers, have substantiated these advantages [25, 26, 27, 28]. However, as noted by [29], a drawback of microwave-assisted extraction is that certain plants may not be suitable due to the potentially damaging effects of high microwave energy levels on plant structures.

2.2.4 Supercritical fluid extraction

The supercritical fluid extraction method is employed to eliminate the reliance on organic solvents and to enhance the speed of extraction. According to the literature [30], supercritical fluid extraction using CO_2 offers numerous advantages over solvent extraction. This method utilizes CO_2 as a solvent, which is non-toxic, cost-effective, nonflammable, and environmentally friendly, enabling the extraction of almost 100% oil [31]. Nevertheless, the primary drawback of supercritical fluid extraction lies in the high production costs. This is attributed not only to the use of high-pressure equipment but also to the necessity of freeze-drying raw materials to reduce moisture to values below 20%, as a high concentration of water in the fluid phase adversely affects oil yield [32, 33].

2.2.5 Accelerated solvent extraction

Accelerated solvent extraction, also known as pressurized solvent extraction, represents a contemporary method for oil extraction utilizing organic or aqueous solvents under elevated temperatures and pressures [10]. It has been noted that higher temperatures expedite the extraction rate, while increased pressure prevents boiling beyond the normal boiling point of the solvent.

In accelerated solvent extraction, both time and solvent consumption are significantly reduced compared to other solvent extraction methods [34]. This efficiency is evident in the extraction of various materials, including wheat germ and flaxseed hulls, as indicated in the literature [35].

However, accelerated solvent extraction comes with its own set of drawbacks, including a very high initial cost, extensive preparation requirements, the need for specialized equipment and skills, the potential for solvent contamination, and the limitation to processing only kernels, as reported in [36, 37].

2.3 Mechanical screw press oil extraction

The traditional and widely used technique for large-scale oil extraction is mechanical screw press oil extraction. As outlined in the research conducted by [38], this method can be carried out through the utilization of either a manual press or an engine-driven screw press.

2.3.1 Manual Oil Expeller

Manual oil expeller involves the extraction of oil through manual effort, utilizing human energy. This stands in contrast to the automatic oil expeller process, where oil is pressed out of plant seeds with the assistance of an oil expeller machine. In the manual expeller method, the raw materials (seeds, nuts, and fruits) are crushed into a powder either by manually pounding the feedstock with a mortar and pestle or by using a grinding machine. Subsequently, water is sprinkled on the powder. The resulting paste is preheated in an oven to facilitate the oil flow from the cake. Following preheating, the paste is placed into a sleeve bag and subjected to a hydraulic press to enhance the extraction of oil from the cake. However, this oil extraction process is recognized as a labor-intensive and cumbersome method.

2.3.2 Automatic Screw Press Oil Expeller

The screw press oil expeller stands out as a more efficient method of oil extraction compared to all other techniques. Seeds are introduced through a hopper, crushed, and conveyed by a rotating screw within a press barrel. The continuous movement of the screw shaft transports the feedstock, causing pressure to rise to the necessary level. This heightened pressure increases friction inside the screw press, generating heat that reduces the viscosity of the oil in the crushed seeds, thereby enhancing the oil flow rate. The oil and cake are typically collected at the oil outlet and press cake exit.

Mechanical extraction, specifically through the use of automatic screw press oil expellers, offers several advantages over alternative extraction methods, as emphasized in studies [7, 39]. These advantages are particularly evident in the form of low operating costs and the production of high-quality, light-colored oil with a low concentration of free fatty acids (FFAs), as documented in [40]. Correspondingly, research findings indicate that powered screw presses can extract between 68 and 80 percent of the oil from seed oils [41]. However, it does exhibit a comparatively lower oil yield when compared to solvent extraction, as demonstrated in [42], leaving some oil in the cake after the extraction process.

Furthermore, a prior investigation [43] revealed that chemical/solvent approaches result in increased oil yield, albeit with associated drawbacks of higher costs and environmental issues due to the use of hazardous and flammable solvents, restricting its applicability. Hence, there is a necessity for research aimed at refining and bolstering the screw press oil extraction method, given its aforementioned merits over alternative extraction techniques, as outlined in Table 1. This research is crucial to enhance its effective utilization in the biodiesel production sector.

Table 1. Merits and demerits of oil extraction methods [10,6, 43].

Method of Oil Extraction	Merits	Demerits
Mechan	✓ No environmental problem regarding the use of mechanical method	• Rel

ical	✓ No potential for solvent contamination ✓ Relatively inexpensive after initial capital costs ✓ Minor consumable costs	ativ ely dirt y pro ces s • Oil not co mpl etel y extr act ed fro m the cak e • Filtr atio n or deg um min g pro ces s of oil is req uire d

		• Operators require experience to achieve best results
chemical/solvent	✓ Repeatable and reproducible results and process ✓ High oil yields ✓ Relativ	• Less sought after than virgin oil • Potential for solvent

		ely simple and quick ✓ Hexane can be recovered and reused, reducing cost significantly	contamination • Safety issues and environmental concerns regarding the use of hexane • Very costly if the hexane can not be

		recovered
enzymatic	✓ No negative effect on the environment. ✓ The method is sustainable	• Requires high cost of enzyme and incubation time. • Requires de-emulsification during down-stream operations

		.
microwave-assisted	✓ It eliminates the emission of carbon dioxide (CO2). ✓ Only a fraction of the energy is needed in comparison to traditional heating methods.	• Not suitable for cases where the solvent or desired compound is non-polar or possesses volatility.
supercritical fluid extraction	✓ Supercritical conditions result in increased extraction due to improved solubility with the solvent. ✓ Employing CO2 as a solvent renders the process more cost-effective, given the readily available and non-flammable nature of CO2.	• The elevated temperature and

		pressure necessary for the supercritical technique contribute to an overall increase in costs.
accelerated solvent extraction	✓ Both time and solvent usage are substantially decreased in comparison to alternative solvent extraction methods.	• The initial cost is exceptionally high, and extensive prepar

		ation is necessary. • Specialized equipment and expertise are necessary. • There is a risk of contamination from solvents.

2.4 Summary

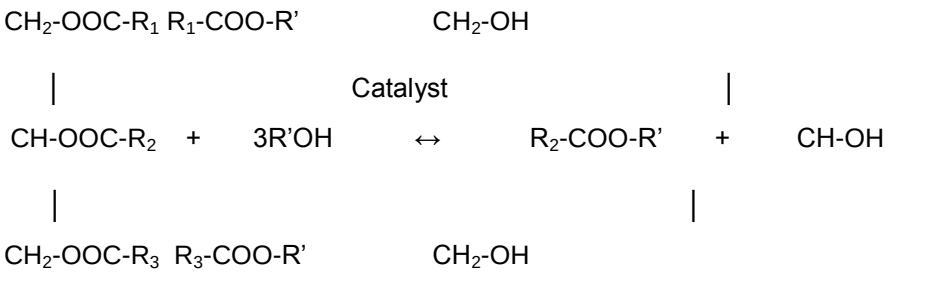
Based on analysis above, the following improvement are available

The production of biodiesel oil from seeds can be achieved through either an automatic or manual method. When using the automatic method, the friction inside the screw press generates heat which reduces the viscosity of the oil, increasing the oil flow rate. However, this method lacks a preheater, resulting in lower oil yield and some oil remaining in the cake, which leads to wastage. On the other hand, the manual method involves crushing the feedstock into a powder, sprinkling water to create a paste, and preheating it in an oven for around an hour to reduce the paste's viscosity. After preheating, the paste is taken to a presser to extract oil from the cake. Despite being labor-intensive, the manual method yields more oil compared to the automatic process.

This research aims to bridge the gap between automatic and manual methods by incorporating a heater or heating element in the crushing chamber of the automatic machine. This integration is intended to reduce the viscosity of the paste, resulting in increased oil production, reduced processing time, and a more streamlined oil.

3.0Overview and History of the Use of Biodiesel Fuels

Biodiesel, as per the definition provided by [44], refers to the mono-alkyl ester of long-chain fatty acids obtained from renewable lipid sources, such as vegetable oils or animal fats. This fuel is characterized as non-toxic, biodegradable, and renewable, with the capacity to be produced from various organic sources, including both fresh and waste vegetable oils, animal fats, and oilseed plants [45]. The biodiesel formation process, as outlined by [46, 47], is as follows:



Transesterification reaction for biodiesel production [46,47]

The utilization of biologically derived fuels, such as vegetable oil, traces back to Rudolf Diesel in 1896, who initially employed peanut oil in an Internal Combustion Engine. Another early proponent of biofuels was Henry Ford, a pioneer in automobile manufacturing, who designed his first car model to run on

ethanol. Despite the visionary expectations of these inventors that their innovations would be sustained by plant-derived fuels, petroleum gained preference due to its economic advantages and widespread availability. However, the oil crisis of the 1970s, coupled with environmental concerns, reignited interest in biofuels [48].

From the 1980s onward, there was significant discourse on the use of vegetable oil as a fuel [49]. Bartholomew introduced the idea of utilizing food crops for fuel, asserting that petroleum should be viewed as the "alternative" fuel, with vegetable oil and alcohol serving as viable alternatives. He emphasized the necessity for some form of renewable energy to replace non-renewable resources [50].

Vegetable oil, obtained from diverse plants, can be categorized as either suitable for consumption or non-consumable. The exploration of non-edible plant sources is driven by the intention to avoid contributing to the rising costs of edible oils. The conversion of biodiesel from edible seeds has the potential to worsen their scarcity and lead to increased prices, given their dual utilization as both food and fuel. Non-edible plants are notably appealing due to their abundant availability in various regions and their cost-effectiveness in specific countries [51]. An overview of biodiesel production from non-edible raw materials is outlined in Table 2.

Table 2**.** Non-ediblefeedstock for biodiesel synthesis.

Feedstock	Catalyst	Temperature (◦C)	Time (min)	Oil to Alcohol Ratio	Yield (%)	Reference
Mahua oil	KOH	-	-	6:1	98	[52]
Mahua oil	KOH	60	30	4:1	-	[53]
Karanja oil	NaOH	50	70	-	84	[54]
Jatropha oil	KOH	55	60	9:1	90–95	[45]
Jatropha oil	H_2SO_4	60	120	9:1	80	[45]
Canola oil	KOH	50	60	9:1	90–95	[45]
Rubberseed oil	NaOH	-	-	9:1	80	[55]
Honne oil	KOH	45–65	30–150	4:1	89	[56]

3.1Methods of Biodiesel Production Process

Numerous researchers have exerted considerable effort to advance biodiesel production methods, with ongoing studies aimed at enhancing product yields, refining fuel properties, and reducing production costs [57, 58, 59]. The use of straight vegetable oils in engines presents challenges such as fuel filter clogging, poor atomization, and incomplete combustion due to their high viscosity, density, and inadequate volatility. The conversion of vegetable oils into biodiesel can be achieved through four

methods: heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification. Among these approaches, transesterification stands out as an extensive, convenient, and highly promising method for mitigating the issues associated with straight vegetable oils, such as viscosity and density. However, it introduces additional processing costs due to the chemical reactions and process heat inputs involved in the transesterification process [60].

3.1.1 Pyrolysis

"Pyrolysis" denotes a chemical process involving the application of thermal energy in the absence of nitrogen or air. Diesel fuels closely resemble the liquid residues resulting from the thermal decomposition of vegetable oils. The pyrolysis product shares calorific values akin to diesel fuel but exhibits lower viscosity, flash point, and pour point. However, the pyrolyzate possesses a diminished cetane number. Although pyrolyzed vegetable oils contain satisfactory levels of water, sedimentation, and sulfur, their ash content, carbon residual, and pour point fall short of desired standards[61]. The pyrolysis procedure can be categorized into three subtypes depending on the operating conditions: flash pyrolysis (1050 - 1300 K), fast pyrolysis (850 - 1250 K), and conventional pyrolysis (550 - 900 K) [62, 63, 64]. Due to its energy-intensive nature and associated drawbacks, researchers need to explore more pragmatic and cost-effective approaches for biodiesel production.

3.1.2 Micro-emulsification

The creation of micro-emulsions emerges as a potential remedy for addressing the challenges related to vegetable oil viscosity and certain atomization properties, as documented in the studies by [65, 66]. Micro-emulsions exhibit characteristics of being transparent and thermodynamically stable colloidal dispersions, featuring droplet sizes within the range of 100 to 1000 nm. These emulsions may consist of vegetable oils, alcohol, a surfactant, a cetane improver, and/or an ester and a dispersant (co-solvent), with or without the addition of diesel fuel. Microemulsions involving hexanol, octanol, and butanol all meet the maximum viscosity standards for diesel fuel. Notably, 2-octanol has demonstrated effectiveness as an amphiphile for the micellar solubilization of methanol in triolein and soybean oil [67, 68, 69, 70]. Conversely, research conducted by [71, 72] suggests that the use of micro-emulsified diesel in diesel engines may lead to common issues such as carbon deposits, nozzle failure, and incomplete combustion.

3.1.3 Dilution

Vegetable oils can be thinned by incorporating substances like ethanol, solvents, or diesel fuels, resulting in reduced density and viscosity. The addition of 4% ethanol to diesel fuel enhances brake power, torque, and thermal efficiency while requiring less fuel, specifically for braking. Due to its lower boiling point compared to diesel fuel, ethanol may aid combustion by generating an unburned mix spray [73]. A published study indicates successful blending of vegetable oils with diesel by researchers. During World War II in Europe, vegetable oil, either in its pure form or combined with diesel, was utilized as fuel [74].In

1980, Caterpillar Brazil Company achieved full power without modifying the engine by blending 10% vegetable oil with diesel in the pre-combustion chamber. Furthermore, positive results are documented when combining vegetable oil and diesel in a 20:80 ratios. In 1982, a successful test of a diesel engine was conducted using a 5% diesel mixture consisting of 95% spent cooking oil [75]. As per a study [76], operating the engine with a 50% blend of Jatropha curcas oil (JCO) did not pose significant operational challenges.

In August 1982, a conference convened in Fargo, North Dakota, aiming to explore the development, methodology, and limitations associated with using vegetable oil as a fuel, notwithstanding ongoing research efforts [72, 77]. Diesel fuels, being mobile and possessing high heat content (approximately 80%), are more suitable for dilution or mixing with liquids. The efficacy of blending is diminished for substances with elevated viscosity, low volatility, and a high unsaturated carbon chain. Running engines exclusively on vegetable oil leads to issues such as coking and trumpet formation, carbon deposition, oil ring sticking, thickening, and gelling of lubricating oil. Future considerations for alternative fuels will predominantly focus on the production of biodiesel while effectively addressing these challenges [75, 78].

3.1.4 Transesterification

Transesterification stands out as one of the most convenient techniques for biodiesel production, involving the conversion of vegetable oil or any triacylglycerol with alcohol in the presence of a catalyst. This process results in the formation of alkyl esters (biodiesel) and glycerol [79]. Numerous researchers have explored various biodiesel production methods and consistently identified transesterification as the most favorable one [80]. Biodiesel produced through this approach exhibits fuel properties that fall within the specifications of EN 14214 and ASTM D6751 standards. Transesterification has demonstrated fuel properties characterized by higher cetane numbers, reduced emissions, and enhanced combustion efficiency. However, the notable drawback of this method is the requirement for excess methanol [78]. The ongoing quest for optimal conditions for transesterification, along with the pursuit of cost-effective and environmentally friendly catalysts, remains a significant concern for the industrial-scale production of biodiesel.

Transesterification method can be carried out by two ways according to literature [81].

(a) Catalytic transesterification.

(b) Supercritical methanol transesterification.

3.1.4.1 Catalytic transesterification

The process known as "Catalytic Transesterification" involves the reaction of a triglyceride (fat/oil) with an alcohol in the presence of a catalyst, resulting in the formation of esters and glycerol. A triglyceride comprises a glycerin molecule as its base, with three long-chain fatty acids attached. The properties of

the oil or fat are dictated by the type of fatty acids linked to the glycerin, and, consequently, the characteristics of the biodiesel can be influenced by the nature of these fatty acids [60, 82, 83, 84, 85].

3.1.4.2 Super critical transesterification

The simple transesterification processes mentioned earlier face two challenges, namely, being relatively time-consuming and requiring the separation of the catalyst and saponified impurities from the biodiesel. The first issue arises from the phase separations within the vegetable oil/alcohol mixture, which can be addressed through vigorous stirring. These challenges are not encountered in the supercritical method of transesterification. This lack of issues may be attributed to the absence of a tendency for the two-phase formation of the vegetable oil/alcohol mixture, resulting in a single phase due to the reduction in the dielectric constant of alcohol in the supercritical state (at 340°C and 43 MPa). Consequently, the reaction is completed in a remarkably short time, typically within 2-4 minutes. Moreover, since no catalyst is employed, the purification of biodiesel becomes much simpler, hassle-free, and environmentally friendly [86, 87, 88, 89, 90].

3.2Effect of Reaction Parameters on Transesterification

The production efficiency of biodiesel through the transesterification process is influenced by various operational parameters, encompassing factors such as the presence of moisture and free fatty acids (FFA), reaction time, reaction temperature, catalyst, and the molar ratio of alcohol to oil [48].

The effect of reaction parameters on transesterification are discussed as follows:

3.2.1 Effect of free fatty acid (FFA) and moisturecontent (MC)

The presence of FFAs and water consistently yields detrimental effects, as their presence leads to soap formation, catalyst consumption, and reduced catalyst effectiveness, ultimately resulting in a lower conversion rate. In catalyst-based methods, water's presence adversely affects the yields of methyl esters. In acid-catalyzed transesterification, the formation of fatty acids can occur. These free fatty acids then react with the alkaline catalyst, producing soaps that hinder the separation of biodiesel, glycerin, and wash water. Research findings from [91, 92, 93] emphasize that achieving a high-quality biodiesel with a complete base-catalyzed reaction requires a free fatty acid value lower than 2%. As per [94], an increased water content in waste cooking oil accelerates the hydrolysis reaction and simultaneously diminishes ester formation. In response to this issue, the supercritical methanol method was proposed, noting that water has less influence in this approach [91]. Hence, to achieve a 90% biodiesel yield, the water content should not surpass 0.5%, and this factor is more critical in an acid-catalyzed reaction than in a base-catalyzed reaction [95].

3.2.2 The effect of molarratio and alcohol type

The biodiesel yield percentage increases with a higher alcohol-to-oil molar ratio, reaching an optimal yield of 85% at a ratio of 6.1. However, going beyond this ratio does not necessarily lead to an increase in biodiesel yield; instead, it may escalate production costs and, consequently, the pump price of biodiesel. While the stoichiometric molar ratio of methanol to triglyceride for transesterification is 3.1, higher molar ratios are employed to enhance solubility and promote increased contact between triglyceride and alcohol molecules. Elevated molar ratios contribute to greater ester conversion within a shorter timeframe. Another crucial factor influencing methyl ester yield is the choice of alcohol-to-triglyceride type. In general, short-chain alcohols such as methanol, ethanol, propanol, and butanol can be utilized in transesterification reactions to achieve high methyl ester yields. Among them, methanol stands out due to its simple chemical structure, resulting in superior yields compared to butanol and ethanol [96, 97, 98]. Figure 1 illustrates the impact of the oil-to-alcohol ratio on biodiesel yield.

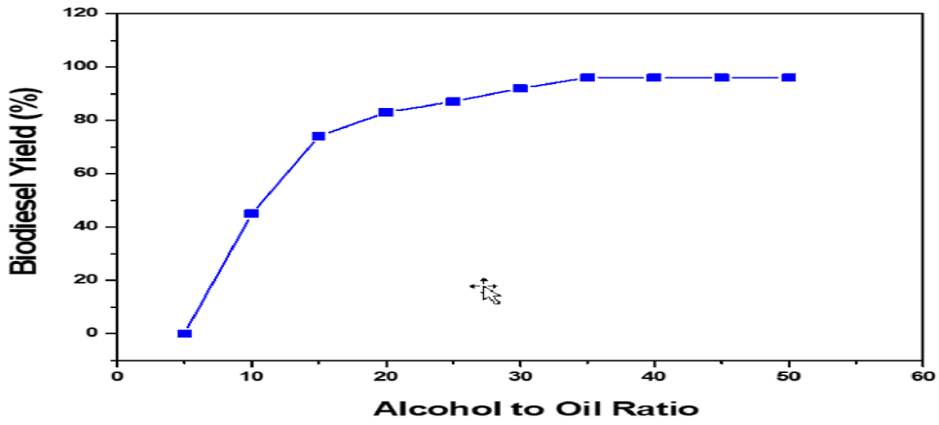


Figure 1. Oil to alcohol ratio effect on biodiesel yield, Source [91].

Figure 1 illustrates the influence of the oil-to-alcohol ratio on supercritical transesterification, where carbon dioxide serves as the solvent and methanol as the co-solvent. The experiment maintained a consistent temperature of 280 ◦C. Notably, the biodiesel yield exhibits a positive trend for approximately 23 minutes during the experiment. This occurrence is attributed to findings from previous studies [91], indicating that an excessive amount of alcohol leads to product contamination, increases overall process costs, and consequently reduces the total biodiesel production.

3.2.3 The effect of catalyst

Alkali-catalyzed transesterification exhibits significantly higher speed compared to acid-catalyzed transesterification, contributing to its commercial success. The Transmethylation process occurs 4000 times more rapidly with an alkaline catalyst than with an equivalent amount of an acidic catalyst. This heightened efficiency is attributed to the lesser corrosive nature of alkaline catalysts on industrial equipment compared to acid catalysts. The concentration of the catalyst also plays a role in biodiesel yield. However, surpassing an optimal catalyst concentration is not economically advantageous, as it leads to increased residues in the biodiesel, escalating the washing costs [99, 100]. Literature has

reported that excessive catalyst usage can result in emulsions, leading to higher viscosity and complicating the biodiesel recovery process [101]. Moreover, research conducted by [102] revealed that elevating KOH conversion from 2% to 12% resulted in an increase in biodiesel output from 20% to 95%. Similarly, a study conducted by [65] determined that a 1 weight percent catalyst yielded the highest production of jatropha biodiesel. Figure 2 depicts the impact of catalyst concentration on biodiesel production. The graph indicates that the biodiesel yield initially increases with the rise in the concentration of alkali catalysts (NaOH and KOH) but subsequently decreases after reaching a peak value.

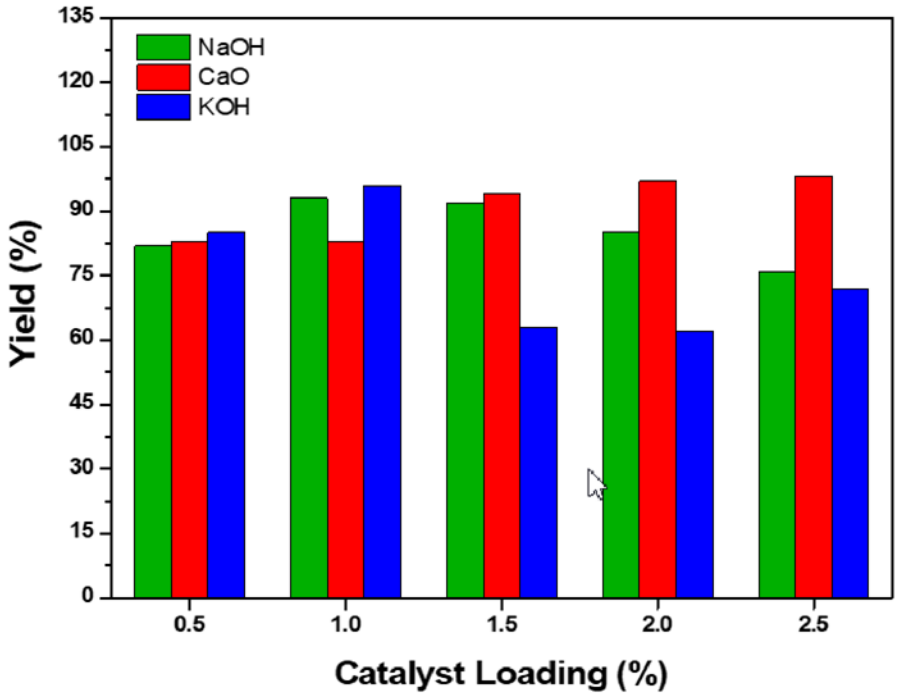


Figure 2. Influence of catalyst concentration on biodiesel yield [104,105].

3.2.4 The effect of reaction temperature and time

Transesterification exhibits variations in reaction temperatures based on the type of oil involved. The reaction temperature significantly impacts the reaction rate, with room temperature allowing completion given sufficient time, while higher temperatures expedite the reaction. Typically, the reaction is carried out at atmospheric pressure around the boiling point of methanol (60 to 70oC). However, a further temperature increase adversely affects the conversion process. Previous studies [106, 107, 108] indicate that, at ambient temperatures, the reaction proceeds effectively using an alkaline catalyst, with low temperatures having no impact on conversion but significantly affecting biodiesel recovery. Research by [109] also noted that temperature enhances the reaction rate up to an optimal level.

Figure 3, derived from prior research by [91], illustrates the impact of temperature on FAMEs composition in the presence of a co-solvent (CO2). The rise in temperature increases the energy of reacting molecules, and as transesterification is inherently endothermic, elevated temperatures favor the reaction. The graph suggests that the optimum temperature range for transesterification lies between 250 and 350 ◦C. Further temperature escalation may result in the thermal decomposition of the product.

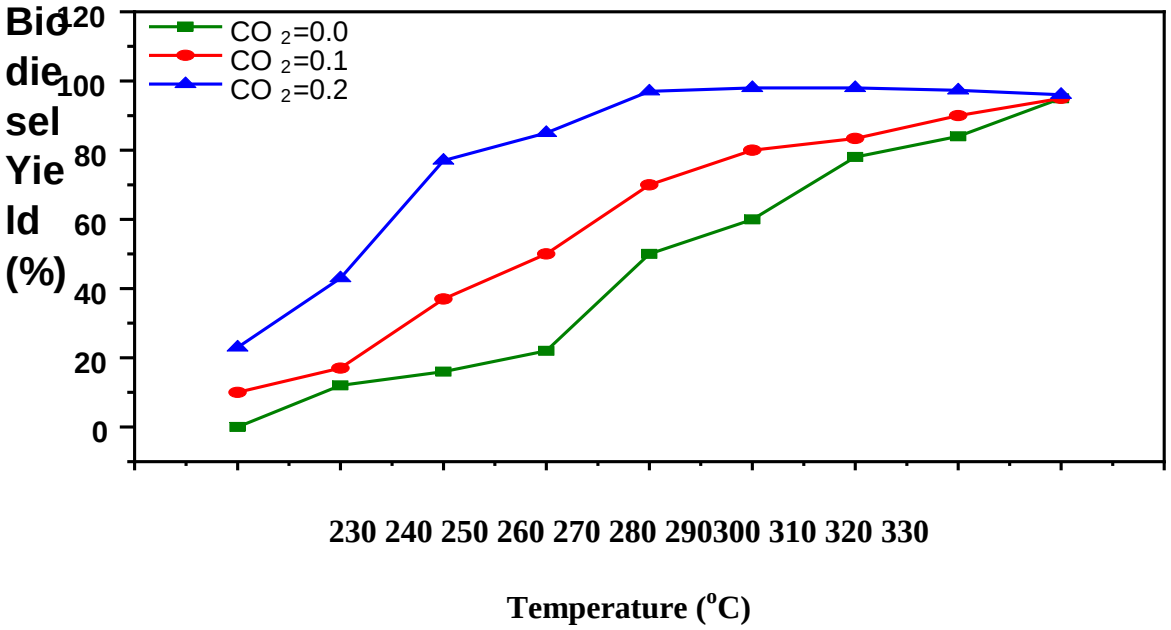


Figure 3.CO_2 and temperature effect on biodiesel yield [91].

Figure 4 illustrates a gradual increase in the concentration of fatty acid methyl ester as the reaction progresses over an extended duration. Initially, the reaction proceeds at a relatively slow pace, which can be ascribed to minimal stirring and limited dispersion of oil and solvent. The primary site of the reaction is predominantly the exterior surfaces of the oil and triglycerides.

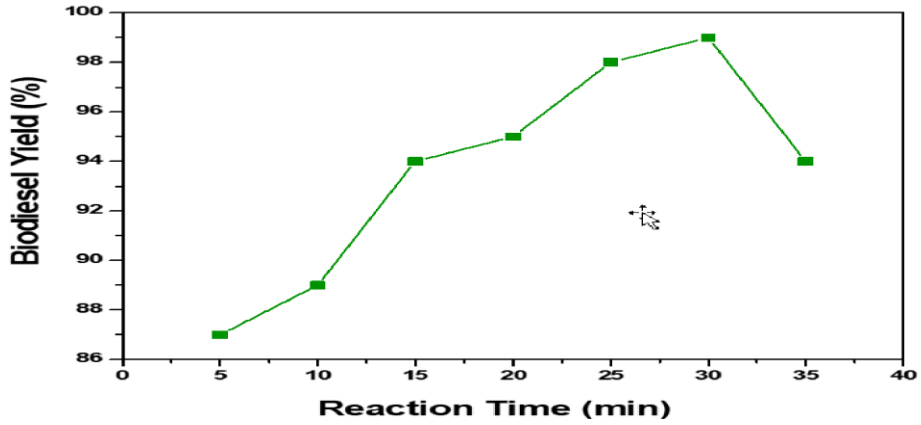


Figure 4.Influence of reaction time on biodiesel production [109, 110].

As depicted in Figure 4, the graph indicates that an extended reaction time leads to an augmentation in the concentration of fatty acid alkyl esters in the product. Nevertheless, this impact is noticeable only up to a 30-minute reaction time. Beyond 30 minutes, the reaction yield becomes indifferent to the reaction time. This is attributed to the equilibrium being already attained at the 30-minute mark, as reported by [111, 112]. It is advisable to conduct supercritical transesterification within a reaction time range of 6 to 12 minutes and conventional transesterification within a range of 30 to 60 minutes.

According to literatures report, table 3shows the effect of various parameters on biodiesel synthesis.

Table 3.Effect of different parameters on biodiesel synthesis.

Feedstock	Molar Ratio	Time (min)	Catalyst Loading	Temperature (°C)	Agitation Speed (rpm)	Type of Transesterification	Yield (%)	Reference
Palm oil	6:1 (methanol)	60	1% KOH	60	600	Homogeneous base	88	[113]
	6:1	60	1% NaOH	60	600		93	[113]
	9:1	480	8.5% KOH	65–75	-		96.2	[114]
	10:1	-	0.4% KOH	70–110	-		98	[115]
Jatropha oil	10:1	480	9% KOH	60–80	-	Homogeneous base	96.8	[102]
Waste frying Oil	4.83:1 to 9.65:1	300–480	1–4%	50–65	-		87.3	[116]
Soybean oil	12:1	60	6% CaFeAl	60	270	Heterogeneous transesterification	90	[117]
Jatropha oil	3:7	180	1% H_2SO_4	65	400	Homogeneous acid and base	21.2	[118]
	3:7		1% NaOH	50	400		90.2	
Waste cooking oil	3:7	180	1% H_2SO_4	65	400	Homogeneous acid and base	21.2	[119]
	3:7	180	1% NaOH	50	400		90.6	
Canola oil	3:1 to 8:1	25–75	0.2–1.2% KOH	30–70	100–600	Homogeneous base	-	[120]
Mustard oil	-	30	KOH	40–60	450	Homogeneous base	-	[121]
Sunflower Oil	6:1	90–330	1% CaO	23–60	-	Heterogeneous	91	[122]
	6:1							
	12:1	-	0.06–0.34	23–60	400	Homogeneous base	99	[123]
	24:1							
Peanut oil	30:1	30–360	-	250–310	500	Supercritical transesterification	>90	[124]
Waste lard	6:1	20	4–6 wt.% enzyme	50	-	Ultrasound assisted transesterification	96.8	[125]

Silybum Marianum seed oil	6:1	75	4–6% sulfonated solid acid catalyst	60	600	Carbon acid esterification and homogeneous base transesterification	96.9	[126]
Canola oil	6:1	-	0.5% KOH	45	-	Homogeneous base	95	[127]
Used frying Oil	6.03:1	120	0.55% KOH	60–100	-	Homogeneous base	-	[128]
Rapeseed oil	3.5:1 to 42:1	120	-	200–500	-	Supercritical transesterification	95	[129]
Neem oil	10:1	60	10% CZO	55	-	Heterogeneous transesterification	97.1	[130]

4.0 Biodiesel Fuel Specification

The most recent standard for B100 biodiesel is ASTM D6751-078 or D6751, where ASTM stands for the American Society of Testing and Materials. This organization comprises manufacturers of engines and fuel injection systems, fuel producers, and users, and its standards are officially recognized in the United States by governmental entities, including state agencies, to ensure fuel quality. Biodiesel fuels failing to meet these specifications are deemed unsuitable for use in Internal Combustion Engines (ICE). To ensure quality, Nigeria, through its Nigerian biofuel policy and incentives, has legislatively established the Standard Organization of Nigeria (SON) and the Department of Petroleum Resources (DPR), both of which have subsequently adopted the ASTM standard. Currently, B20 biodiesel blend has received commercial approval for use in ICEs, though it is not readily available in the open market. Table 3 demonstrates that biodiesel shares similar physico-chemical properties with conventional diesel fuel and typically does not require engine modification for diesel engines.

Top-notch fuel is generated through the correct blending of diesel fuel that meets all specifications with biodiesel that also fulfills those criteria, following appropriate fuel management procedures. The outcome is a superior diesel fuel proven to operate efficiently in nearly any unmodified diesel engine. Nevertheless, the use of substandard fuels, including biodiesel, may lead to performance issues or equipment damage [131,132, 133, 134, 135, 136].

4.1 ASTM and EN Biodiesel Specification

Table 4 presents a comparative examination of the physico-chemical properties of several biodiesel standards utilized in gas turbines across Europe and the American continent. The differences in the

values observed for various fuel properties can be largely attributed to the climatic conditions prevalent in each specific country.

Table 4 Specification of biodiesel standard [1,137,138, 139, 140, 141]

Properties	**ASTM D6751**	**EN 14214**
Density (15 ^{o}C, g/cm^{3})	NS	0.86–0.90
Kinematic viscosity (40 ^{o}C, mm^{2}/s)	1.9 – 6.0	3.5 – 5.0
Cetane number	47 min	51 min
Flash point (^{o}C)	130 min	120 min
Sodium (ppm) Potassium (ppm)	Na & K combined 5 (max)	Na & K combined 5 (max)
Acid value (mg of KOH/g)	0.50 max	0.50 max
Iodine value (g I_2 /100 g)	NS	120 (max)
Total sulfur (ppm)	15 max	10 max
NS: not specified. Max: maximum. Min: minimum.		

5.0 Conclusion

As the demand for energy continues to rise with population growth and economic expansion, the depletion of fossil fuels, the primary energy source, becomes a pressing concern. Given the current consumption rate, these fossil fuel reserves are anticipated to diminish. However, rising crude oil prices and environmental pollution concerns associated with traditional fuels have propelled biodiesel into the spotlight as a promising alternative and renewable fuel for diesel engines worldwide. Consequently, there is an urgent need to enhance the oil extraction process for biodiesel production. Various oil extraction methods are employed to extract oils from seeds, with oil expellers falling into this category. This discussion has covered two types of oil expellers: automatic screw press and manual.

While each oil extraction method discussed has its advantages, this research aims to bridge the gap between automatic and manual methods. The recommendation involves incorporating a heater or heating element into the crushing chamber of automatic expeller machines. This addition aims to reduce oil viscosity in the paste, resulting in increased oil production, reduced processing time, and improved overall production efficiency.The study delineates four methods for biodiesel production: Heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification. Among these approaches, transesterification emerges as one of the most practical techniques for biodiesel production. This method involves reducing the viscosity of oil or fat using an acid or base catalyst in the presence of methanol or ethanol. However, the biodiesel yield in the transesterification process is influenced by various process parameters, including the presence of moisture and free fatty acids (FFA), reaction time, reaction temperature, catalyst, and the molar ratio of alcohol to oil.

References

1. Basumatary. S, (2014) “Yellow oleander (Thevetia Peruviana) seed oil biodiesel as an alternative and renewable fuel for diesel”: Inc. J. Chem Tech Res., vol.7, no. 6, PP. 2823-2840.
2. Ragul Karthick Elangoa, Kiruthika Sathiasivana, Chandrasekaran Muthukumaranb, (2019) “Transesterification of castor oil for biodiesel production: Process optimization and characterization”: Microchemical Journal, 145, 162-1168.
3. Nuria Sánchez, Ramiro Sánchez, José M. Encinar, Juan F. González, Gloria Martínez, (2015), “Complete analysis of castor oil methanolysis to obtain biodiesel”: Fuel, 147, 95-99
4. Brusca. S, Galvagno. A, Lanzafame. R, marinoCugnoGarrano. A and Messina. M, (2015) “Performance analysis of biofuel fed gas turbine”, Energy procedia, vol. 81, PP. 493-509.
5. YadessaGonfaKeneni and Jorge Mario Marchetti (2017) “Oil extraction from plant seeds for biodiesel production”, AIMS Energy, 5(2): 316-340.
6. Jahirul MI, Brown JR, Senadeera W, et al. (2013) “Optimisation of bio-oil extraction process from beauty leaf (Calophylluminophyllum) oil seed as a second-generation biodiesel source”. Procedia Eng 56: 619–624.
7. Atabani AE, Silitonga AS, Badruddin IA, et al. (2012) A comprehensive review on biodiesel as an alternative energy resource and its characteristics. Renew Sust Energ Rev 16: 2070–2093.
8. Boey PL, Ganesan S, Maniam GP, et al. (2011) Ultrasound aided in situ trasnesterification of crude palm oil adsorbed on spent bleachin clay. Energ Convers Manage 52: 2081–2084.
9. Achten W, Verchot L, Franken YJ, et al. (2008) Jatropha bio-diesel production and use. Biomass Bioenerg 32: 1063–1084.
10. Bhuiya M, Rasul M, Khan M, et al. (2016) “Prospects of 2nd generation biodiesel as a sustainable fuel—Part: 1 selection of feedstock, oil extraction techniques and conversion technologies. Renew Sust Energ Rev 55: 1109–1128.

11. Nosy (2011) Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: a review. Renew Sust Energ Rev 15: 131–149.
12. Baskar, G.; Kalavathy, G.; Aiswarya, R.; Selvakumari, I.A (2019). Advances in bio-oil extraction from nonedible oil seeds and algal biomass. In Advances in Eco-Fuels for a Sustainable Environment; Woodhead Publishing Series in Energy: Cambridge, UK, 2019; pp. 187–210. [Google Scholar]
13. Divine Bup Nde, Anuanwen Claris Foncha (2020) "Optimization Methods for the Extraction of Vegetable Oils": A Review Processes 2020, 8(2), 209; https://doi.org/10.3390/pr8020209
14. Yusuf, A.K., Mamza, P.A.P., Ahmed, A.S. and Agunwa, U. (2015). Extraction and characterization of castor seed oil from wild Ricinus communis L. International Journal of Science, Environment and Technology, 4(5): 1392-1404.
15. Yusuf, N.; Kamarudin, S.; Yaakub, Z (2011). Overview on the current trends in biodiesel production. Energy Convers. Manag. 2011, 52, 2741–2751.
16. Muzenda, E., Kabuba, J., Mdletye, P. And Belaid, M. (2012). Optimization of process parameters for castor oil production. Proceedings of the World Congress on Engineering 2012 Vol. III WCE 2012, July, 4-6, 2012, London, U.K.
17. Mahanta P, Shrivastava A (2004) Technology development of bio-diesel as an energy alternative. Department of Mechanical Engineering, Indian Institute of Technology. Available from: http://www.newagepublishers.com/samplechapter/001305.pdf.
18. Rattanaphra, D.; Srinophakun, P. (2010) Biodiesel production from crude sunflower oil and crude jatropha oil using immobilized lipase. J. Chem. Eng. Jpn. 2010, 43, 104–108.
19. Ahmad, F.B.; Zhang, Z.; Doherty, W.O.; O'Hara, I.M (2019). The prospect of microbial oil production and applications from oil palm biomass. Biochem. Eng. J. 2019, 143, 9–23.
20. Oltean-Dumbrava, C.; Watts, G.R.; Miah, A (2013). Transport infrastructure: Making more sustainable decisions for noise reduction. J. Clean. Prod. 2013, 42, 58–68.
21. Lee, S.L.; Wong, Y.C.; Tan, Y.P.; Yew, S.Y (2015). Transesterification of palm oil to biodiesel by using waste obtuse horn shell-derived CaO catalyst. Energy Convers. Manag. 2015, 93, 282–288.
22. Tang, D.Y.Y.; Yew, G.Y.; Koyande, A.K.; Chew, K.W.; Vo, D.-V.N.; Show, P.L (2020). Green technology for the industrial production of biofuels and bioproducts from microalgae: A review. Environ. Chem. Lett. 2020, 18, 1967–1985.
23. Hao JY, Han W, Xue BY, et al. (2002) Microwave-assisted extraction of artemisinin from Artemisia annua L. Sep Purif Technol 28: 191–196.
24. Cardoso UGA, Juárez BGP, SosaMorales ME, et al. (2013) Microwave-assisted extraction of essential oils from herbs. J Microwave Power E 47: 63–72.
25. Kittiphoom, S. and Sutasinee, S. (2015). Effect of microwaves pretreatment on extraction yield and quality of mango seed kernel oil. International Food Research Journal, 22(3):960-964.

26. Mgudu, L., Muzenda, E., Kabuba, J. And Belaid, M. (2012). Microwave assisted extraction of castor oil. International Conference on Nanotechnology and Chemical Engineering (ICNCS 2012), December, 21- 22, Bangkok, Thailand.
27. Moreno, A.O., Dorantes, L., Galindex, J. And Guzman, R.I. (2003). Effect of different extraction methods on fatty acids, volatile compounds and physical and chemical properties of avocado (Persea americana Mil) oil. Journal of Agricultural and Food Chemistry, 51:2216-2221.
28. Balasubramanian, S., Allen, J.D., Kanitkar, A. And Boldor, D. (2010). Oil extraction from Scenedesmusobliquus using a continuous microwave system – design, optimization and quality characterization. Bioresource Technology, 102:3396- 3403.
29. Uquiche, E., Jerez, M. and Ortiz, J. (2008). Effect of treatment with microwaves on mechanical extraction yield and quality of vegetable oil from Chilean hazelnuts (Gevuina avellana Mol). Innovative Food Science and Emerging Technologies, 9(4): 495 – 500.
30. Khattab RY, Zeitoun MA (2013) Quality evaluation of flaxseed oil obtained by different extraction techniques. LWT Food Sci Techno 53: 338–345.
31. Akanda MJH, Sarker MZI, Ferdosh S, et al. (2012) Applications of supercritical fluid extraction (SFE) of palm oil and oil from natural sources. Molecules 17: 1764–1794.
32. Rubio RN, Sara M, Beltrán S, et al. (2008) Supercritical fluid extraction of the omega-3 rich oil contained in hake (Merluccius capensis-Merluccius paradoxus) by-products: study of the influence of process parameters on the extraction yield and oil quality. J Supercrit Fluid 47: 215–226.
33. Rubio RN, Sara M, Beltrán S, et al. (2012) Supercritical fluid extraction of fish oil from fish by-products: a comparison with other extraction methods. J Food Eng 109: 238–248.
34. Dunford NT, Zhang M (2003) Pressurized solvent extraction of wheat germ oil. Food Res Int 36: 905–909.
35. Oomah BD, Sitter L (2009) Characteristics of flaxseed hull oil. Food Chem 114: 623–628.
36. Sarip MSM, Morad NA, Yamashita Y, et al. (2016) Crude palm oil (CPO) extraction using hot compressed water (HCW). Sep Purif Technol 169: 103–112.
37. Ali M, Watson IA (2014) Comparison of oil extraction methods, energy analysis and biodiesel production from flax seeds. Int J Energ Res 38: 614–625.
38. Ketan S. Tekale, Yashodip K. Chaure, Akshay R. Kapre, Shailesh Kumar, Praveen K. Mali (2017). Design and Development of Groundnut Oil Extracting Machine by Human Pedal Flywheel Motor Concept. International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 - 0056
39. Ramachandran S, Singh SK, Larroche C, et al. (2007) Oil cakes and their biotechnological applications-a review. Bioresource Technol 98: 2000–2009.
40. Carr, R.A. (1976). Refining and degumming system for edible fats and oils. Journal of American Oil Chemists' Society (JAOCS), 55:766-770.

41. Afia Mehboob, Shafaq Nisar, Umer Rashid, Thomas Shean Yaw Choong, Talha Khalid and Hafiz Abdul Qadeer (2016), “Reactor designs for the production of biodiesel”. International Journal of Chemical and Biochemical Sciences (ISSN 2226-9614)
42. Buenrostro, M. And Lopez-Munguia, C. (1986). Enzymatic extraction of avocado oil. Biotechnology Letters, 8:505-506.
43. Zulqarnain Muhammad Ayoub, Mohd Hizami Mohd Yusoff, Muhammad Hamza Nazir, Imtisal Zahid, Mariam Ameen, Farooq Sher, Dita Floresyona and Eduardus Budi Nursanto (2021), A Comprehensive Review on Oil Extraction and Biodiesel Production Technologies. https://www.mdpi.com/journal/sustainability.
44. Marchetti JM (2012) A summary of the available technologies for biodiesel production based on a comparison of different feedstock's properties. Process Saf Environ 90: 157–163.
45. Patil PD, Deng S (2009) Optimization of biodiesel production from edible and non-edible vegetable oils. Fuel 88: 1302–1306.
46. Azad A. K., Rasul M. G., Khan M. M. K., Subhash C. Sharma, Rubayat Islam (2014) “Prospect of Moringa seed oil as a sustainable biodiesel fuel in Australia”: A review. Procedia Engineering 105 (2015) 601 – 606
47. Krishna Kini H., Hanock S. Dsouza, N. Satheesh Kumar (2016) “Investigation of Properties of Different Blends of Castor and Pongamia Biodiesels and Their Performance in a Compression Ignition Engine” Energy and Power 2016, 6(1A): 8-14, DOI: 10.5923/c.ep.201601.02
48. Highina B.K, Bugage I.M and Umar B. (2012) “Liquid biofuels as alternative transport fuels in Nigeria” petroleum technology development Journal Vol.1 PP. 1-15.
49. Bartholomew D, (1981) “Vegetable oil fuel”, JAOCS 58,286A-288A. Biotechnological preparation of biodiesel and its high valued derivatives.
50. Fangrui M and Milford A.H, (1999), “Biodiesel production: A review”, Bioresource Technology, PP 289-293
51. Arjun B. C, Martin S. T, Suzanne M. B, Watts K. C, and Islam M. R, (2008), “Non-Edible Plant Oils as New Sources for Biodiesel Production”, Int. Journal of Molecular Science.
52. Sani, Y.M.; Raji-Yahya, A.O.; Alaba, P.A.; Aziz, A.R.A.; Daud, W.M.A.W. (2015). Palm frond and spikelet as environmentally benign alternative solid acid catalysts for biodiesel production. Bio Resources 2015, 10, 3393–3408.
53. Ghadge, S.V.; Raheman, H. (2005). Biodiesel production from mahua (Madhuca indica) oil having high free fatty acids. Biomass Bioenergy 2005, 28, 601–605.
54. Srivastava, P.; Verma, M. (2008). Methyl ester of karanja oil as an alternative renewable source energy. Fuel 2008, 87, 1673–1677.
55. Ramadhas, A.; Jayaraj, S.; Muraleedharan, C. (2005). Biodiesel production from high FFA rubber seed oil. Fuel 2005, 84, 335–340.

56. Venkanna, B.; Reddy, C.V. (2009). Biodiesel production and optimization from Calophylluminophyllum linn oil (honne oil)—A three stage method. Bioresour. Technol. 2009, 100, 5122–5125. [PubMed]
57. Demirbas, A. (2008) Comparison of transesterification methods for production of biodiesel from vegetable oils and fats. Energy Conversion and Management, 49:125–130.
58. Koh M.Y., Ghazi T.I. (2011). A review of biodiesel production from Jatropha curcas L. oil, Renew. Sust. Energ. Rev. 15 (5) (2011) 2240–2251.
59. Ong H.C., Mahlia T.M., Masjuki H.H., Norhasyima R.S. (2011). Comparison of palm oil, Jatropha curcas and Calophylluminophyllum for biodiesel: a review, Renew. Sust. Energ. Rev. 15 (8) (2011) 3501–3515.
60. Barnwal B.K and Sharma M.P (2005) "Biodiesel Production Process" (visited November 28th, 2022) shodhganga.inflibnet.ac.in/bitstream/10603/37613/9/09...
61. Atabani A.E., Silitonga A.S., Badruddin I.A., Mahlia T.M., Masjuki H., Mekhilef S., (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics, Renew. Sust. Energ. Rev. 16 (4) (2012) 2070–2093.
62. Sujata Brahma, Biswajit Nath, Bidangshri Basumatary, Bipul Das, Pankaj Saikia, Khemnath Patir, Sanjay Basumatary (2022) "Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production" Chemical Engineering Journal Advances.
63. Karmakar B., Halder G. (2019). Progress and future of biodiesel synthesis: advancements in oil extraction and conversion technologies, Energy Convers. Manag. 182(2019) 307–339.
64. Balat M. (2007). Production of biodiesel from vegetable oils: a survey, Energy Sources Part A 29 (10) (2007) 895–913.
65. Vivekpantidar; Abhishek Chandra; Man Singh; R.K. Kale (2014). Journal of scientific & Industrial Research, Vol. 63, 2014, pp 461-464.
66. Yusuf N.N.A; Kamarudin S.K.; Yaakub Z. (2011). Energy Conversion and Management, 2011, Vol.52(7):2741-2751
67. Alemayehu Gashaw, Tewodros Getachew, AbileTeshita Mohammed (2015) "A review on biodiesel production as alternative fuel" (visited November 25th, 2022) https://www.researchgate.net/publication/302961082
68. Arifin, S.F. (2009) Production of Biodiesel from Waste Cooking Oil and Red Palm Oil Using Batch Transesterification Process, Universiti Malaysia Pahang, Thesis
69. Raghavendra Prasada, S.A (2014) "A Review on CNSL Biodiesel as an Alternative fuel for Diesel Engine". International Journal of Science and Research 3 (7): 2028-2038.
70. Ma F., Hanna M.A., (1999). Biodiesel production: a review, Bioresour. Technol. 70 (1) (1999) 1–5.
71. Parawira, W. Scientific Research and Essays (2010), 5(14), 1796-1808.
72. May Ying Koh; TiniaIdatyMohd. Gazi, (2011). Renewable and Sustainable Energy Reviews, 2011, Vol. 15(5):2240-2251.

73. Kaisan M.U., Abubakar S., Ashok B., Dhinesh Balasubramanian, Narayan S., Ivan Grujic & Nadica Stojanovic (2018) “Comparative analyses of biodiesel produced from jatropha and neem seed oil using a gas chromatography–mass spectroscopy technique”, Biofuels, DOI: 10.1080/17597269.2018.1537206
74. Nye M.J., Williamson T.W., Deshpande W., Schrader J.H., Snively W.H., Yurkewich T. P., French C.L., (1983). Conversion of used frying oil to diesel fuel by transesterification: preliminary tests, J. Am. Oil Chem. Soc. 60 (8) (1983) 1598–1601.
75. Ramadhas A.S., Jayaraj S., Muraleedharan C.J., (2004). Use of vegetable oils as IC engine fuels-A review, Renew. Energy 29 (5). (2004) 727–742.
76. Pramanik K., (2003) Properties and use of Jatropha curcas oil and diesel fuel blends in compression ignition engine, Renew. Energy 28 (2) (2003) 239–248.
77. Misra R.D., Murthy M.S., (2010). Straight vegetable oils usage in a compression ignition engine-A review, Renew. Sust. Energ. Rev. 14 (9) (2010) 3005–3013.
78. Leung D.Y., Wu X., Leung M.K., (2010). A review on biodiesel production using catalyzed transesterification, Appl. Energy 87 (4) (2010) 1083–1095.
79. Rezania S., Oryani B., Park J., Hashemi B., Yadav K.K., Kwon E.E., Hur J., Cho J., (2019). Review on transesterification of non-edible sources for biodiesel production with a focus on economic aspects, fuel properties and by-product applications, Energy Convers. Manag. 201 (2019), 112155.
80. Fadara O.A., Falowo O.A., Ojumu T.V., Betiku E., (2021). Process optimization of microwave irradiation-aided transesterification of kariya seed oil by Taguchi orthogonal array: pawpaw trunk as a novel biocatalyst, Biofuel Bioprod. Biorefin. 15 (4) (2021) 1006–1020.
81. EdzaNekhavhambeHembe E. Mukaya Diakanua B. Nkazi (2019) “Development of castor oil–based polymers”: A review Journal of Advance Manufacturing and Processing.
82. Mishra V.K. Goswami, R., (2018). A review of production, properties and advantages of biodiesel, Biofuels 9 (2) (2018) 273–289.
83. Gupta J., Agarwal M. Dalai, A.K., (2019). Intensified transesterification of mixture of edible and nonedible oils in reverse flow helical coil reactor for biodiesel production, Renew. Energy 134 (2019) 509–525.
84. Mohammadshirazi A., Akram A., Rafiee S., Kalhor E.B., (2014). Energy and cost analyses of biodiesel production from waste cooking oil, Renew. Sustain. Energ. Rev. 33 (2014) 44–49.
85. Rao K.S., Ramakrishna A., (2015). Cost estimation analysis of biodiesel production from waste chicken fat, Int. J. Appl. Eng. Res. 10 (4) (2015) 8963–8970.
86. Teresa M. Mata, Antonio Martins (2010) “Biodiesel Production Processes” (visited November 26th, 2022) https://www.researchgate.net/publication/280728855
87. Al-Zuhair, S. (2007), Production of biodiesel: possibilities and challenges, Biofuels, Bioproducts Biorefining 1(1): 57–66.

88. Chen, W., Wang, C., Ying, W., Wang, W., Wu, Y. and Zhang, J. (2009). Continuous production of biodiesel via supercritical methanol transesterification in a tubular reactor. part 1: thermophysical and transitive properties of supercritical methanol, Energy. Fuels 23: 526–32.
89. Soetaert, W. and Vandamme, E.J. (2009). Biofuels. John Wiley & Sons Ltd.
90. Madras, G., Kolluru, C. and Kumar, R. (2004). Synthesis of Biodiesel in supercritical fluids, Fuel 83(14–15): 2029–33.
91. Mathiyazhagan. M and Ganapathi. A, (2011) "Factors Affecting Biodiesel Production", Review Article, (visited December 12th, 2018) www. cabdirect. org/cabdirect/abstract/20123239897
92. Demirbas, A. (2008). Biodiesel: a realistic fuel alternative for diesel engines. Springer Verlag.
93. Pinzi S., Leiva D., Arzamendi G., Gandia L.M., Dorado M.P., (2011). Multiple response optimization of vegetable oils fatty acid composition to improve biodiesel physical properties, Bioresour. Technol. 102 (15) (2011) 7280–7288.
94. Arun, N., Sampath, M., Siddharth, S., Prasaanth, R. A. (2011) Experimental Studies of base catalyzed transesterification of karanja oil. Journal of Energy and Environment, 2(2): 351–356.
95. Lotero, E., Liu, Y., Lopez, D. E., Suwannakarn, K., Bruce, D. A., Goodwin, J. G. (2005) Synthesis of biodiesel via acid catalysis. Industrial and Engineering Chemistry Research, 44(14): 5353–5363.
96. Edward N.O and Peggy A.O (2013), "Optimization of biodiesel production from non-edible seeds of Delonxregia (Gulmohr)", International Journal of Bioresource Technology Vol.1, PP 1-8
97. Leung DYC, Guo Y. (2006). Transesterification of neat and used frying oil: optimization for biodiesel production. Fuel Process Technol; 87:883–90.
98. Jagadale, S. S., Jugulkar, L. M. (2012) Review of Various Reaction Parameters and Other Factors Affecting on Production of Chicken Fat Based Biodiesel, International Journal of Modern Engineering Research, 2(2), 407-411.
99. Guo Y. 2005. Alkaline-catalyzed production of biodiesel fuel from virgin canola oil and recycled waste oils. PhD dissertation, Department of Mechanical Engineering, the University of Hong Kong, Hong Kong; p. 184.
100. Kansedo, J.B. (2009) Synthesis of Biodiesel from Palm Oil and Sea Mango Oil Using Sulfated Zirconia Catalyst. Msc thesis, Universiti Sains Malaysia.
101. Rashid, U.; Anwar, F. (2008). Production of biodiesel through optimized alkaline-catalyzed transesterification of rapeseed oil. Fuel 2008, 87, 265–273.
102. Madhuvilakku, R.; Piraman, S. (2013) Biodiesel synthesis by TiO2–ZnO mixed oxide nanocatalyst catalyzed palm oil transesterification process. Bioresour. Technol. 2013, 150, 55–59.
103. Akhihiero, E.; Oghenejoboh, K.; Umukoro, P. (2013) Effects of process variables on transesterification reaction of jatropha curcas seed oil for the production of biodiesel. Int. J. Emerg. Technol. Adv. Eng. 2013, 3, 388–393.
104. Alamu, O.; Waheed, M.; Jekayinfa, S. (2007) Biodiesel production from Nigerian palm kernel oil: Effect of KOH concentration on yield. Energy Sustain. Dev. 2007, 11, 77–82.

105. Pullen, J.; Saeed, K. (2015) Investigation of the factors affecting the progress of base-catalyzed transesterification of rapeseed oil to biodiesel FAME. Fuel Process. Technol. 2015, 130, 127–135.
106. Eevera T, Rajendran K, Saradha S. (2009). Biodiesel production process optimization and characterization to assess the suitability of the product for varied environmental conditions. Renew Energy; 34:762– 5.
107. Ogbu, I.M. Ajiwe, V.I.E. (2013) Biodiesel Production via Esterification of Free Fatty Acids from Cucurbita Pepo L. Seed Oil: Kinetic Studies. International Journal of Science and Technology, 2(8), 616-621.
108. Anitha, A., Dawn, S.S. (2010) Performance Characteristics of Biodiesel Produced from Waste Groundnut Oil using Supported Heteropolyacids. International Journal of Chemical Engineering and Applications, 1(3), 261-265.
109. Ishak, M.A.M.; Nawawi, W.I.; Jawad, A.H.; Ani, A.; Zakaria, Z.; Ismail, K. (2017) In-Situ Transesterification of Jatropha Curcas L. Seeds for Biodiesel Production Using Supercritical Methanol. In MATEC Web of Conferences; EDP Sciences: Les Ulis, France, 2017.
110. Freedman, B.; Butterfield, R.O.; Pryde, E.H. (1986) Transesterification kinetics of soybean oil 1. J. Am. Oil Chem. Soc. 1986, 63, 1375–1380.
111. Farobie, O.; Leow, Z.Y.M.; Samanmulya, T.; Matsumura, Y. (2016) New insights in biodiesel production using supercritical 1-propanol. Energy Convers. Manag. 2016, 124, 212–218.
112. Hossain, A.; Boyce, A. (2009) Biodiesel production from waste sunflower cooking oil as an environmental recycling process and renewable energy. Bulg. J. Agric. Sci. 2009, 15, 312–317.
113. Shahbazi, M.R.; Khoshandam, B.; Nasiri, M.; Ghazvini, M. (2012) Biodiesel production via alkali-catalyzed transesterification of Malaysian RBD palm oil–Characterization, kinetics model. J. Taiwan Inst. Chem. Eng. 2012, 43, 504–510.
114. Zhang, L.; Sheng, B.; Xin, Z.; Liu, Q.; Sun, S. (2010) Kinetics of transesterification of palm oil and dimethyl carbonate for biodiesel production at the catalysis of heterogeneous base catalyst. Bioresour. Technol. 2010, 101, 8144–8150. [PubMed]
115. Yunus, R.; Fakhru'L-Razi, A.; Ooi, T.L.; Biak, D.R.A.; Iyuke, S.E. (2004) Kinetics of transesterification of palm-based methyl esters with trimethylolpropane. J. Am. Oil Chem. Soc. 2004, 81, 497–503.
116. Birla, A.; Singh, B.; Upadhyay, S.N.; Sharma, Y.C. (2012) Kinetics studies of synthesis of biodiesel from waste frying oil using a heterogeneous catalyst derived from snail shell. Bioresour. Technol. 2012, 106, 95–100. [PubMed]
117. Lu, Y.; Zhang, Z.; Xu, Y.; Liu, Q.; Qian, G. (2015) CaFeAl mixed oxide derived heterogeneous catalysts for transesterification of soybean oil to biodiesel. Bioresour. Technol. 2015, 190, 438–441.
118. Jain, S.; Sharma, M. (2010) Kinetics of acid base catalyzed transesterification of Jatropha curcas oil. Bioresour. Technol. 2010, 101, 7701–7706. [PubMed]

119. Jain, S.; Sharma, M.; Rajvanshi, S. (2011) Acid base catalyzed transesterification kinetics of waste cooking oil. Fuel Process. Technol. 2011, 92, 32–38.
120. Likozar, B.; Levec, J. (2014) Effect of process conditions on equilibrium, reaction kinetics and mass transfer for triglyceride transesterification to biodiesel: Experimental and modeling based on fatty acid composition. Fuel Process. Technol. 2014, 122, 30–41.
121. Issariyakul, T.; Dalai, A.K. (2012) Comparative kinetics of transesterification for biodiesel production from palm oil and mustard oil. Can. J. Chem. Eng. 2012, 90, 342–350.
122. Vujicic, D.; Comic, D.; Zarubica, A.; Micic, R.; Boskovic, G.C. (2010) Kinetics of biodiesel synthesis from sunflower oil over CaO heterogeneous catalyst. Fuel 2010, 89, 2054–2061.
123. Reyero, I.; Arzamendi, G.; Zabala, S.; Gandía, L.M. (2015) Kinetics of the NaOH-catalyzed transesterification of sunflower oil with ethanol to produce biodiesel. Fuel Process. Technol. 2015, 129, 147–155.
124. Cheng, J.; Li, Y.; He, S.; Shen, W.; Song, Y.; Liu, Y. (2008) Reaction Kinetics of Transesterification between Vegetable Oil and Methanol under Supercritical Conditions. Energy Sources Part a Recover. Util. Environ. Eff. 2008, 30, 681–688.
125. Adewale, P.; Dumont, M.-J.; Ngadi, M. (2016) Enzyme-catalyzed synthesis and kinetics of ultrasonic assisted methanolysis of waste lard for biodiesel production. Chem. Eng. J. 2016, 284, 158–165.
126. Fadhil, A.B.; Aziz, A.M.; Al-Tamer, M.H. (2016) Biodiesel production from Silybum marianum L. seed oil with high FFA content using sulfonated carbon catalyst for esterification and base catalyst for transesterification. Energy Convers. Manag. 2016, 108, 255–265.
127. Clark, W.M.; Medeiros, N.J.; Boyd, D.J.; Snell, J.R. (2013) Biodiesel transesterification kinetics monitored by pH measurement. Bioresour. Technol. 2013, 136, 771–774.
128. Berrios, M.; Martín, M.; Chica, A.F.; Martin, A. (2010) Study of esterification and transesterification in biodiesel production from used frying oils in a closed system. Chem. Eng. J. 2010, 160, 473–479.
129. Encinar, J.M.; Pardal, A.; Sánchez, N. (2016) An improvement to the transesterification process by the use of co-solvents to produce biodiesel. Fuel 2016, 166, 51–58.
130. Gurunathan, B.; Ravi, A. (2015) Process optimization and kinetics of biodiesel production from neem oil using copper doped zinc oxide heterogeneous nanocatalyst. Bioresour. Technol. 2015, 190, 424–428. [PubMed]
131. National Renewable Energy Laboratory (2009), “Biodiesel Handling and use Guide”, (visited January 22nd, 2019) http://www.nrel.gov/vehicles and fuels/Pdfs/43672.pdf
132. Dario Alviso, Guillermo Artana, Thomas Duriez. (2020), “Prediction of biodiesel physico-chemical properties from its fatty acid composition using genetic programming”. Fuel. Volume 264, 116844.
133. Sandesh SureshK., SureshP.V., Tanaji G. Kudre (2019). Prospective ecofuel feedstocks for sustainable production. Journal of Advances in Eco-Fuels for a Sustainable Environment.

134. Gerhard Knothe, Luis F. Razon. (2017), Biodiesel fuels. Journal of Progress in Energy and Combustion Science. Volume 58, Pages 36-59.
135. OzcanliM., GungorC. & AydinK. (2010) Biodiesel Fuel Specifications: A Review. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. Article link: http://dx.doi.org/10.1080/15567036.2010.503229.
136. BhuiyaM.M.K, RasulM.G., Khan, M.M.K., AshwathN. 2020 Biodiesel production and characterisation of poppy (Papaver somniferous L.) seed oil methyl ester as a source of 2nd generation biodiesel feedstock. Journal of Industrial Crops and Products. Volume 152, 112493
137. Digambar Singh, Dilip Sharma, SoniS.L., Sumit Sharma, Deepika Kumari (2019). Chemical compositions, properties, and standards for different generation biodiesels: A review. Fuel. Volume 253, Pages 60-71.
138. Yuguang Zhou, Zongxi Zhang, Yixiang Zhang, Yungang Wang, Yang Yu, Fang Ji, Riaz Ahmad, Renjie Dong (2016), A comprehensive review on densified solid biofuel industry in China. Journal Renewable and Sustainable Energy Reviews. Volume 16, Issue 1, Pages 143-169.
139. Vinoth Thangarasu, AnandR., (2019) Physicochemical fuel properties and tribological behavior of aeglemarmelos correa biodiesel, Advances in Eco-Fuels for a Sustainable Environment
140. Ivan Pires de Oliveira, Anderson Rodrigues Lima Caires (2019). Molecular arrangement in diesel/biodiesel blends: A Molecular Dynamics simulation analysis. Renewable Energy. Volume 140, September 2019, Pages 203-211
141. Anietie Okon Etim, Chiazor Faustina Jisieike, Eriola Betiku, (2022) Production of Biodiesel from Non-Edible Sources https://doi.org/10.1016/B978-0-12-824295-7.00004-8.