PRODUCTION OF BIODIESEL USING SEEDS FROM *Carica papaya L.*

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DEPARTMENT OF BIOLOGICAL SCIENCES
FACULTY OF NATURAL SCIENCES AND ENVIRONMENTAL STUDIES
GODFREY OKOYE UNIVERSITY, ENUGU STATE

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A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF BIOLOGICAL SCIENCES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE (B.Sc.) DEGREE IN BIOTECHNOLOGY

SUPERVISOR: DR. NKECHI. T. UDEAGBALA

JULY, 2026

APPROVAL

This research titled "Production of Biodiesel Using Seeds from *Carica papaya L*." has been assessed and approved by the Committee of Department of Biological Sciences and the Faculty of Natural Sciences and Environmental Studies, Godfrey Okoye University Enugu, Nigeria.

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CERTIFICATION

This is to certify that this research titled (Production of Biodiesel Using Seeds from *Carica papaya L.*) was carried out by JOHNSON, DIVINE CHIGOZIRI under the supervision of Dr. Nkechi. T. Udeagbala in the Department of Biological Sciences, Godfrey Okoye University Enugu, Nigeria.

JOHNSON, DIVINE CHIGOZI	**………………….**	**....…………**
	Signature	**Date**

DEDICATION

This research work is dedicated first to the Almighty God for His grace, wisdom, and sufficient strength throughout this study. Then this research is dedicated to my beloved mother for her unconditional love, consistent prayers, words of encouragement, sacrifices, and never ending support which has contributed greatly to my academic triumph. Finally, this work is dedicated to every researcher and scholar out there whose efforts continue to promote the growth of a sustainable and renewable energy source for an eco friendly and cleaner environment.

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ABSTRACT

The decrease in the availability of a renewable and an eco friendly energy source has increased interest in the production of biodiesel from organic waste and underutilized feedstocks. This study investigated the production of biodiesel from pawpaw (*Carica papaya)* and has checked the physicochemical properties of both the extracted oil and the produced biodiesel. Pawpaw seeds were collected, dried, processed, and the oil extracted. The extracted oil was characterized using the standard analytical methods. While the biodiesel was produced through the process of transesterification, and process optimization was carried out using a design matrix, the produced biodiesel was then characterized and analysis of the results were carried out. The study shows that oil from pawpaw seed is a viable feedstock for the production of biodiesel, yielding a high oil content and fuel properties comparable to regular biodiesel production standards. The use of pawpaw seeds for biodiesel production provides a more sustainable approach to waste disposal and utilization, renewable energy generation, and environmental safety standards.

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INTRODUCTION

1.1 Background of Study

In Nigerian natural oil, gas and coal are the main sources of energy, but many countries have adapted to different methods of energy production due to the mass production of greenhouse gases, climate change, deterioration of the environment and air pollution. This has therefore increased the demand of biofuel, like biodiesel because it is a safer and cleaner source of the fossil fuel production. One method of producing bio materials like biodiesel is transesterification which is the process of converting plant based materials usually non-food plant materials like agricultural waste, environmental wastes, forestry wastes, etc to useful products such as biodiesel (Mhetras & Gokhale, 2025). Biodiesel is a type of renewable biofuel produced from animal fats, oil from waste products and other feedstocks through a process known as transesterification. Alternatively, biodiesel are produced by using organic wastes like, agricultural waste products, food wastes, solid wastes, etc. These wastes are rich in the carbohydrates that can be processed into the sugars that are being fermented and processed into biodiesel. The use of organic waste for the production of biodiesel, does not only provide a better alternative for fossil fuels but it also provides a remedy to waste disposal methods in Nigeria (Somorin et al., 2017).

In developing countries like Nigeria, the emission of greenhouse gases by the use of fossil fuels, accumulation of environmental waste and waste management problems, poses serious threat to the public health at large. Thus, using organic wastes to produce biodiesel significantly reduces the problem and improves development of the economy. The improvement of biotechnology in areas like fermentation processes have given scientists an added advantage for converting waste products into biodiesel. Therefore, more research is needed to find out the impact of biodiesel production using organic waste in our environment.

1.2 Statement of Problem

In many developing countries like Nigeria, the production of greenhouse gases which causes air pollution, extinction of non- renewable resources and climate change are all due to a fast rising problem of the use of conventional fossil fuel for the production of energy (Yogalakshmi *et al.,* 2022). Also, the production of organic waste is becoming a pandemic in the country, causing environmental pollution and high risk to the health of the public.

Bioethanol is regarded as a clean option for energy generation replacing fossil fuels, but lack of awareness, slow technological advancement and the various problems encountered while carrying out the conversion process poses a threat to its production. Established waste management methods do not focus on recovering usable resources from organic waste products, therefore there is need to find an efficient solution to tackle these waste management problems and find a long lasting solution to the environmental degradation caused by the use of conventional fossil fuel. Information on the production of biodiesel from organic waste is limited in the study area, and there is inadequate knowledge regarding its potential as a sustainable waste management strategy. This study seeks to bridge this gap by investigating the production of biodiesel from organic waste.

Aim and Objectives

Aim

The aim of this study was to produce biodiesel from the seeds of *Carica papaya*

Objectives

The specific objectives were to:

i. determine the potential organic materials for the production of biodiesel.
ii. Assess the catalysts that can be used for the production of biodiesel from Carica papaya L. seed.
iii. evaluate the transesterification process using Carica papaya L. seed.
iv. determine the quantity of biodiesel that can be produced from the processing of seeds from *Carica papaya L.*

1.3 Significance of the Study

This study is significant because it demonstrates the potential of Carica papaya L. (pawpaw) seeds, which are commonly discarded as agricultural waste, as a viable feedstock for biodiesel production. By converting this underutilized biomass into a renewable source of energy, the study promotes the sustainable utilization of organic waste while reducing environmental pollution associated with indiscriminate waste disposal.

The findings of this study will contribute to the growing body of knowledge on renewable energy by providing information on the feasibility of producing biodiesel from non-edible plant materials. The study highlights the potential of pawpaw seeds as an alternative feedstock that does not compete with food resources, thereby supporting sustainable biofuel production.

Furthermore, the study will emphasize the environmental benefits of converting agricultural waste into valuable products. The utilization of Carica papaya L. seeds for biodiesel production can reduce the volume of organic waste disposed of in landfills or through open burning, thereby contributing to cleaner environments and improved waste management practices.

The study is also expected to benefit researchers, students, and academics by serving as a useful reference for future studies on biodiesel production, renewable energy technologies, and the valorization of agricultural wastes. It may stimulate further investigations into the use of other locally available waste materials as potential feedstocks for biofuel production.

In addition, the findings may provide useful information to entrepreneurs, industries, and investors interested in renewable energy production by demonstrating the economic potential of converting agricultural waste into biodiesel. Policymakers and environmental agencies may also find the study valuable in developing strategies that promote renewable energy adoption, waste recycling, and environmental sustainability.

Ultimately, this study supports global and national efforts toward sustainable development by encouraging the use of renewable energy resources, reducing dependence on fossil fuels, lowering greenhouse gas emissions, and promoting a circular economy through the productive utilization of agricultural waste.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Biofuel is a biological fuel which can be obtained with the use of biological by-products also known as biomass such as the organic waste, agricultural residues, products of plant and animal origin etc. The transformation of the organic matter is known as method of the renewable Energy production and it serve as an alternate option for the greenhouse gas production. Some of the examples of the biofuels include; biohydrogen, biodieseel, bioethanol, and biogas. Biodiversity biodiesel is one of the main biodiesel types in the production, as it is compatible with nature and, biodegradable; non- toxic, besides that it is a new form of energy. This biodiesel is produced by the oil found in vegetables as also in animals the oil form animals will be turned as waste of biological sources etc. The same could be done for vegetable oil with waste products for production for biodiesel. Biodiesel will have to be produced the in laboratory by using natural oil for that and this biodiesel may not emit pollutants. Research indicates that to lessen the emission of environmental pollutants. Biodiesel production is to be carried on using some common wastage products of biological origin. A recent type of waste product, named as *Carica papaya* seeds (CP), gained traction against all other organic materials; it has the abundant oil and available in form of plant waste. This type of organic wastes mostly get collected after eating its parts, and the oil obtained could be utilized in making biofuel of biodiesel (Karmee, 2016). This kind of utilization will also help in reducing the waste generated in the environment as well as production of clean and the new alternative energy source. Waste sardine oil was used for the producing new generation of low cost production of biofuel, as this oil was produced during the fishing operation

(Arumugam and Ponnusami, 2011). Oil extracted from the seeds of *caricapapaya L* has been also research as new generation of fuel like biodiesel (Suprianto *et al.*, 2018).

BIOFUELS

Bioethanol **Biodiesel** **Biogas** **Biohydrogen**

Figure 2.1: Classification of Biofuels

Source: Adapted from Demirbas (2017).

2.2 Botanical Description of Pawpaw

Carica papaya, belongs to the family *Caricaceae* found nearly in all tropical and subtropical zones of the earth (Abubakar and Uthman, 2020). Pawpaw fruits were already been consuming as food or processed to jam, jelly, products hence massive amounts of by-product seeds are regularly disposed as waste (Nyorere *et al.,* 2024). The plant (Carica papaya L.) is a large, fruit-bearing, tree-like herbaceous plant native to southern Mexico and tropical regions of Central and South America. It is known by several common names, including papaya, pawpaw, mummy apple, melon tree, mamo, and mamón (Goriainov et al., 2023).

2.3 Distribution and Cultivation of Pawpaw

Paw-paw is a plant that is very important and very common in tropical Africa with FAO (2007) declaring Nigeria the third highest producer of paw-paw in the world (Abubakar and Uthman, 2020). Top ten countries producing most papaya fruit include, among others, Indonesia whose yearly fruit production has amounted to 840tons in 2014 (Suprianto *et al.*, 2018). *Carica papaya L*. Is cultivated in many countries all around tropical and sub-tropical part of the world (Charvet *et al.,* 2011). It is the main horticultural commercial species group that is prioritized in research and development at the National Horticulture Research Centre in Indonesia. The seed contains up to 30 percent of oil when analyzed in the dry weight (Suprianto *et al.,* 2018).

2.4 Nutritional Composition of Pawpaw Seeds

Pawpaw seeds are famous for some significant health benefits, namely antioxidant, antibacterial, anti-cancer, anti-fertility, anti-inflammatory, anti-diabetic, and heptaflotroteshine (Nyorere and Oluka, 2024). The paw-paw seeds consist of oil up to 30% by dry weight which is the higher side when compared to soybean (19.63%),Sunflower seeds (22.23%) and coconut (54.74%), it shows a high prospective as biofuel(Suprianto *et al*., 2018). The seed represents a noticeable proportion 15–20% of the weight of Paw-paw. It represents a considerable quantity of paw paw fruit waste from fruit processing plants. Oil from paw-paw seeds can represent from 30 to 34%. Its oil has nutritional and functional characteristics similar to that of olive oil (Li *et al.*, 2015).

2.5 Oil Content and Characteristics of Pawpaw Seeds

Studies have shown that Carica papaya seeds contain substantial quantities of oil, with reported oil yields ranging from 31.2% to 44.0% (w/w), including 31.2% (Agunbiade & Adewole, 2014), 31.6% (Abubakar & Uthman, 2020), and 44.0% (w/w) (Nyorere & Oluka, 2024), indicating their potential as a valuable feedstock for biodiesel production. *Carica papaya* and rambutan seeds and their oil yield were researched and studied by (Puangsri *et al*.,) for their protein content (35%), lipids content (27%), total carbohydrate content (35%), the seeds contain crude fiber range from 19.10 to 22.60%, lipids range from 28.20 to 30.70%, protein range from 27.30 to 28.30% (Nyorere and Oluka, 2024) that differs based on seed processing and drying conditions, oil yields from *carica papaya* seed may range between 25.41% and 34.65% depending on the species of *carica papaya*, the age of fruit and condition of fruit (Charvet *et al.*, 2011).

2.6 Biodiesel

Bio-diesel, a biofuel, is commonly derived from vegetation based on animal fats and vegetable oil (Awais *et al.*, 2020). The bio-diesel fuels generally consist of fatty acid acyl esters generated from animal fats and vegetation based on liquid oil in transesterification (Vastano *et al.,* 2019). In a safe, biodegradable and sustainable type, bio-diesel fuel can consists of mono-alkyl-ester derived from lengthy fatty acid strings.

Pawpaw Fruits

▼

Pawpaw Seeds

▼

Oil Extraction

▼

Pawpaw Seed Oil

▼

Esterification

▼

Transesterification

▼

Biodiesel

Figure 2.2 Biodiesel Production from Pawpaw Seed Oil

Source: Adapted from Knothe *et al.* (2015).

2.7 Historical Development of Biodiesel

The first generation biodiesels were mainly produced from food-plant sources and from animals' products. Due to food security concerns, the use of second-generation biodiesels from inedible feedstock such as non-edible plant oil, used vegetable oil and animal fats have gain ground (Arumugam and Ponnusami, 2017).

2.8 Biodiesel Importance

The major incentive for utilizing biodiesel instead of the petroleum diesel is that the fuel can be produced from the vegetable/animal sources that are readily available. In addition, combusted Biodiesel produces low emission that is nontoxic, non-carcinogenic (Arumugam and Ponnusami, 2017). It offers advantages over the diesel used, as it is non-toxic, safer and biodegradable, no sulphur, can be used as lubricants and it offers substantial incentives for the society to improve social life including development of new economic opportunity and reducing the global warming (Abubakar and Uthman, 2020).

2.9 Biodiesel, the Alternative Energy Source

The continuous growth of the global population has led to an increasing demand for food, energy, and other essential resources. As population and industrial activities continue to expand, global energy consumption has risen significantly, resulting in the rapid depletion of non-renewable energy resources. Consequently, there has been increasing interest in the development of renewable and sustainable energy sources. Among these, biodiesel has attracted considerable attention as a promising alternative to conventional fossil fuels because of its renewable nature and lower environmental impact (Suprianto et al., 2018).

Abubakar and Uthman (2020) state that, In the quest for an alternative to fossil fuel and reduction of greenhouse gas, a plethora of investigations into novel materials for a variety of chemical process, the biofuel and biodiesel technology have attained considerable focus during the last two decades. (Abubakar and Uthman, 2020).

2.10 Feedstocks Used in Biodiesel Production

2.10.1 Edible Oil Feedstocks In Indonesia, the biodiesel synthesis as a direct substitution fuel is still costly due to utilization of palm oil as its feedstocks (Suprianto *et al.*, 2018).

2.10.2 Non-Edible Oil Feedstocks

The consideration of using Carica papaya seeds for the production of sustainable biodiesel is based on the fact that the seeds are generally regarded as agricultural waste and are non-edible, making them an attractive and environmentally friendly feedstock that does not compete with food resources. Their utilization for biodiesel production also contributes to waste reduction, value addition to agricultural by-products, and the promotion of renewable energy development (Suprianto & Gunawan, 2018). Biodiesel, second generation of fuel was processed from some new feedstocks of plant origins namely follows: Castor oil, Jatropha, Calophyllum inophyllum, Karanja, cotton seed, Neem, waste sun flower oil, as was recently reviewed by Arumugam and Ponnusami (2017).

2.10.3 Waste Oil Feedstocks

As low cost feedstock for the biodiesel production, waste sardine oil, which is a residue from fish processing was used (Arumugam and Ponnusami, 2017). A new sustainable bioprocess for the valorization of a no/low value substrate, i.e. Waste frying oils (WFOs) was designed (Vastano *et al.*, 2019). Optimized biodiesel production from waste cooking oil (WCO) demonstrated that process optimization significantly improved biodiesel yield and fuel quality by identifying the optimum reaction conditions for transesterification (Degne et al., 2019).

2.10.4 Animal Fat Feedstock Similarly, fish oil and some animal wastes such as lard and beef tallow have been recently successfully studied as cheap alternatives feedstock for biodiesel production (Arumugam and Ponnusami, 2017).

2.11 Advantages of Using Pawpaw Seed Oil as Feedstock

The seeds of *Carica papayas* are a low cost-bio resource, discarded nowadays with little restriction after fruit consumptions (Abubakar and Uthman, 2020Constituting approximately 15% of the fruit by weight, papaya seeds account for more than 120,000 tons of papaya production in Indonesia annually (Suprianto & Gunawan, 2018). This could allow production of nearly 30,000tons of papaya seed oil a year since these seeds contained around30 %oil (Agunbiade and Adewole, 2014). Thus, *Carica papaya* seed oil (CPSO) is identified as a possible renewable source for biodiesel production.

2.12 Extraction of Oil from Pawpaw Seeds

Oil from Carica papaya seeds can be extracted using either solvent extraction, commonly with n-hexane, or mechanical extraction, which involves physically pressing the seeds without the use of chemical solvents, following seed collection, drying, and preparation (Wong & Othman, 2014; Agunbiade & Adewole, 2014; Abubakar & Uthman, 2020; Nyorere & Oluka, 2024).

2.13 Factors Affecting Oil Yield

The quantity of oil obtained from pawpaw seeds depends on several factors during seed preparation and extraction. These factors can significantly influence both the quality and quantity of the extracted oil.

Moisture Content of the Seeds: Moisture content is one of the most important factors affecting oil yield. Seeds with high moisture content hinder the penetration of solvents and reduce extraction efficiency. Proper drying before extraction generally increases oil recovery.
Seed Variety and Maturity: Different varieties of pawpaw contain varying amounts of oil. In addition, seeds obtained from fully ripe and matured fruits usually have a higher oil content than those from immature fruits.

Particle Size: The size of the ground seed particles affects the extraction process. Finely ground seeds provide a larger surface area for solvent contact, leading to improved oil extraction. However, excessively fine particles may complicate filtration.
Extraction Method: The method used for extraction greatly influences oil yield. Solvent

extraction typically produces higher yields than mechanical pressing because solvents can dissolve and recover more oil from the seed material.

Type of Solvent Used: Different solvents possess different oil-dissolving capacities. Non-polar solvents such as n-hexane are commonly preferred because they efficiently dissolve oils and result in higher extraction yields.

Extraction Temperature: Temperature affects the solubility and movement of oil within the seed matrix. Moderate increases in temperature can improve oil yield by enhancing solvent penetration and oil diffusion. Excessive temperatures, however, may degrade the oil.

Extraction Time: Longer extraction periods generally increase oil recovery by allowing more oil to dissolve into the solvent. However, beyond an optimum time of 48hrs, little additional oil is extracted, making the process less economical.

Solvent-to-Sample Ratio: The amount of solvent used relative to the seed sample affects extraction efficiency. A higher solvent-to-sample ratio often increases oil yield by providing greater dissolving capacity for the oil.

Agitation or Mixing: Continuous stirring or agitation improves contact between the solvent and seed particles, thereby increasing oil recovery and reducing extraction time.

Storage Conditions of Seeds: Improper storage can lead to oxidation, microbial growth, and deterioration of the seeds, reducing the amount of extractable oil. Dry, cool, and airtight storage conditions help preserve oil content.

Specific Gravity Specific gravity refers to the comparison between the density of an oil and the density of water. Generally, pawpaw seed oil will range between 0.90 and 0.93. This will indicate that the oil is lighter than water. Specific gravity of pawpaw seed oil was found to be 0.94

(Abubakar and Uthman, 2020) and 0.84 in another study (Agunbiade and Adewole, 2014). This is a comparable finding in some other seed-oil biodiesel. Acid value this will represent the amount of free fatty acids in the oil. The low acid value obtained shows good stability for storage. Low acid value implies hydrolysis occurred at a low level and the storage life of the oil is reasonable. The acid value of the oil was 3.680 mg KOH/g (Nyorere and Oluka, 2024), and the papaya seed oil contained 10.3% of free fatty acid (Charvet *et al.,* 2011).

High free fatty acids mean high susceptibility of oil for breakdown of oils. This oil can be used in cosmetics and also in foodstuff (Nyorere and Oluka, 2024). Pawpaw seed oil contains several types of unsaturated fatty acids. Among these are Oleic acid as the principal fatty acid, followed by Linoleic acid, and then palmitic acid, and steric acid are present. High in Oleic acid the oil is less susceptible for oxidative degradation. The free fatty acid (FFA) content of pawpaw seed oil was relatively high.

Studies indicated the content of FFA to be 32 mg KOH/g (Arumugam and Ponnusami, 2017), and free fatty acid was 0.34 (Abubakar and Uthman, 2020).

Saponification Value: The saponification value, often referred to as SP value, denotes the amount of alkali needed to form soap. Saponification value in the range of 180–200 mg KOH/g for pawpaw seed oil shows its usefulness as raw material in the manufacture of soap and cosmetic products (Nyorere and Oluka, 2024), and saponification value was reported as158.60 mg/g (Abubakar and Uthman, 2020).

- Iodine Value: An iodine value of a lipid indicates a measure of the unsaturation degree (the number of carbon to carbon double bonds) (Hoseini *et al.,* 2019). This value for pawpaw seed oil was found to be between 60–80g 1 / 100 g oil classifying it as a non-drying oil (Nyorere and Polka, 2024). Iodine value was 53.80 g/100g (Abubakar and Uthman, 2020). This low iodine value is typical for biodiesel from seeds with lower levels of polyunsaturated thus making the fuel more stable against oxidation (Agunbiade and Adewole, 2014).

- Viscosity: The viscosity refers to the thickness and ability of a fluid oil to flow. The oil can be suitable to produce biodiesel as well as in cosmetics, food, and pharmaceutical Industries as there is no strong resistance of flowing. It is found that viscosity at 40 C was 49.20 cp (Abubakar and Uthman, 2020) and the kinematic viscosity at 313 K was 27.4 mm s (Agunbiade *et al.*, 2014) as predicted for vegetable oils (Agunbiade and Adewole, 2014).
- Moisture Content: Low amount of moisture reduces the susceptibility to microbial spoilage and hydrolytic rancidity, prolonging the shelf-life of the oil. Moisture Content for pawpaw seed oil was reported to be negligibly small. The extracted Carica papaya seed oil is converted into biodiesel through the transesterification process, in which the triglycerides present in the oil react with methanol in the presence of an alkaline catalyst, typically 1% sodium hydroxide (NaOH), to produce fatty acid methyl esters (biodiesel) and glycerol (Suprianto et al., 2018; Awais et al., 2020). Carica papaya seed oil is predominantly composed of triglycerides, making it a suitable feedstock for biodiesel production through alkali-catalyzed transesterification. During the transesterification process, triglycerides react with a short-chain alcohol, usually methanol or ethanol, in the presence of a suitable catalyst to produce fatty acid alkyl esters (biodiesel) and glycerol as a by-product. The

overall reaction can be represented as follows: Triglyceride + Alcohol → Fatty Acid Alkyl Esters (Biodiesel) + Glycerol

- Esterification process: Esterification is a chemical reaction in which an organic acid reacts with an alcohol to produce an ester and water. In the biodiesel process, Esterification is employed principally to reduce the number of free fatty acids (FFAs) within the fuel which should respond with an alkaline catalyst to produce the soap that should cut back the biodiesel generation rate.
- Catalysts used in biodiesel generation: catalyst are substances that are able to escalate a chemical process without being altered, so they could speed up a procedure of transesterification and esterification reactions for a bigger rate of producing biodiesel and shortening the rate, taking into consideration variables of free fatty acid (FFA), process standards, value, and the specification standards for biodiesel generation. Alkali catalyst are often used within the manufacturing of biodiesel due to their capacity of reaction and price. It works well with the fuel which has reduced amount of free fatty acid, such as using 1 % NaOH catalysts (Suprianto *et al*, 2018). Examples are NaOH, KOH. Acid catalysts used are usually for esterification or processing fuel with high amount of free fatty acids. Examples is, Sulfuric acid, Hydrochloric acid (Charvet *et al*, 2011). Enzymatic catalysts they are often known as bio-catalysts. The enzymes can catalyze biodiesel synthesis at simple requirements. Candida rugosa lipase was employed in enzymatic transesterification with an immobilizing enzyme as a biological-catalyst (Wong et al., 2014). Lipase enzyme was immobilized in activated carbon as the biological catalyst (Arumugam *et al.,* 2017).

2.14 Properties of Pawpaw seed oil biodiesel.

Bio density is described as a fuel characteristic property, which is a mass of fuel for one unit of volume which can impact the efficiency of fuel injections and combustion.

Generally, density of pawpaw oil can vary from 0.86 - 0.90 g/cm3. The density value is slightly higher than petroleum biodiesel (Charvet *et al.,* 2011). Density was 885 kg m at the room temperature about 15C (Charvet *et al.*, 2011). Flash Point The minimal temperature of fuel to create vapor by contact with the spark ignites (Charvet *et al.*, 2011). The spark plug will ignite the fuel in the presence of flash in a controlled ignition room (e.g. in the cylinder in a diesel engine) Biodiesel usually had above 100 C of flash point. This characteristic could contribute to better safety. Flash Point of pawpaw seed oil can be estimated to be around 120 C based on studies of other plant seed biodiesel like peanut, soybean oil etc. Cloud Point is a property defining wax formation inside biodiesel to block lines or fuel filters in cold conditions of the operation. Is a very good character to define biodiesel's use and applicability in cold climatic conditions (Charvet *et al.*, 2011). Cloud point of *Carica papaya* oil was 275 K, whereas, pour point of *Carica papaya* oil was 274 K (Agunbiade *et al*, 2014).

Pour Point: Pour point is the minimum temperature at which biodiesel would still flow, i.e. can still be handled for storage or pumping purposes. Under no circumstances would it be fluid at any temp below pour point, therefore limiting the operational temperature for fuel under extremely cold regions. For diesel engine biodiesel would lose its applicability under this critical temperatures for cold operation.

Calorific Value: This determines the quantity of energy released through a chemical change, i.e., combustion of a substance, or energy stored in a given system (Foley and Conway, 2018). Calorific

Value for pawpaw oil biodiesel was determined to be 44.37 MJ/kg (Abubakar et al, 2020). Biodiesel has lower calorific value compared to diesel fuel, therefore, less fuel is used in terms of total amount.

2.15 Benefits of Biodiesel: Biodiesel is less toxic, biodegradable and renewable. So the environmental friendliness can be seen in the benefits below: Biodiesel is considered nontoxic.

It may burn more efficiently in some circumstances (e.g. with lean combustion, compared to a lean mixture of Diesel in the ambient air.

The Biodiesel produces relatively cleaner emissions such as nontoxic and noncarcinogenic as a result of its combustion (Arumugam *et al.*, 2017, Degne *et al.*, 2019, Sae-ngae *et al.*, 2020The use of biodiesel offers several environmental benefits, including significant reductions in particulate matter (PM), carbon monoxide (CO), non-methane hydrocarbons (NMHC), and greenhouse gas emissions compared with conventional fossil diesel. In addition, biodiesel is considered a renewable and sustainable fuel because it is produced from biological resources such as vegetable oils, animal fats, and other renewable feedstocks, making it an environmentally friendly alternative to petroleum-based diesel.

With the increase in depletion of fossil fuels in the current century, biodiesel is considered as a suitable and more economically feasible alternative fuel for replacing fossil fuel and this process could also aid in diminishing environmental impact in relation to climate change and also partial substitute for conventional fossil fuels (Sae-ngae *et al*, 2020).

Sustainable Biodiesel Production: The recycling of used cooking oil with an appropriate catalytic system provides an environmental and economic advantage by transforming it into biodiesel through the use of simple, low-cost technology that achieves 100% yield and high purity of biodiesel, zero-waste, and relatively clean operations (Sae-ngae *et al.*, 2020). This alternative approach ensures sustainable use of resources and waste utilization in producing biodiesel. The production of biodiesel from an abundant feedstock resource ofPawpaw Seed is one approach that could significantly contributes to sustainability and provides alternative for replacement of conventional diesel fuel (Agunbiade *et al.*, 2014, Abubakar *et al.*, 2020).

2.16 Challenges of Biodiesel

High Production Cost: The cost of processing organic waste feedstock might remain high because the nutrients source required in microbial growth media are very expensive (Sae-ngae *et al.*, 2020).

Availability-of feedstock: Difficulty-in sourcing biodegradable organic waste from various sources is a practical problem most times, as a result of variable and mixed properties, as well as collection challenges (Vastano *et al.*, 2019).

Engine Compatibility Issue: Kinematic viscosity exceeded limit by PNS (Charvet *et al.*, 2011), while FAME complied with other standards. Other engine modifications could include new filters, fuel line and fuel tank. (Charvetet al., 2011).

2.17 Quality Standards for Biodiesel ASTM

Biodiesel Standards in the United States and the European Union. The quality of biodiesel is commonly evaluated using internationally recognized standards, particularly those established by the American Society for Testing and Materials (ASTM) in the United States and the European Standards (EN) in the European Union. Degne et al. (2019) compared the physicochemical properties of the produced biodiesel with the ASTM biodiesel fuel standards and reported that the fuel complied with most of the specified quality requirements. Similarly, Awais et al. (2020) evaluated the produced biodiesel using ASTM biodiesel fuel standards and found that it satisfied all the requirements of the ASTM B100 biodiesel specification. Furthermore, Wong et al. (2014) assessed the quality of the biodiesel produced using the European (EN) standards through various physicochemical tests to determine its suitability as an alternative diesel fuel. The study demonstrated that the biodiesel met the relevant EN quality specifications, confirming its potential for use as a substitute for conventional diesel fuel. Parameters for Biodiesel Quality Assessment oil and biodiesel extracted was analyzed for various properties (Awais *et al.*, 2020).

2.18 theoretical framework.

2.18.1. Waste-to-Wealth concept.

The Waste-to-Wealth concept is a theoretical base for those kind of study where we are working on generating saleable commodity from waste materials. Based on the concept, in this study which is biodiesel production from pawpaw (*Carica papaya*) seed oil, the waste is being converted into a useful product where we are generating clean fuel. It's important to consider this theory because pawpaw seed is an agricultural waste and it's being converted into something of value (clean energy). This concept is based on the principles of the circular economy which is about creating closed-loop systems and maximizing the utilization of materials through, for example, product extensions, reused products or materials recovery. Resource recovery means the recovery of valuable materials from mixed streams, or from waste. (Sae-ngae *et al.,* 2020).

2.18.2 Sustainable Development Theory

Sustainable Development theory is a theory based on ensuring the development of humanity and also sustainability on the planet for future generations. In this framework, three basic principles such as social, economic and environmental were discussed to promote environmental health and also human well-being by maintaining the ecological balance of ecosystem on global level for a long-term. For example, producing clean fuel from waste will ensure sustainability in many ways, i.e., environment (reduce pollution), economy (create employment and income) and society (clean and healthy environment). This principle was adopted by Brundtland Commission (1987) of the United Nations (UN) and the World Commission on Environment and Development (WCED), three core sustainability principles: Environmental sustainability, economic sustainability and social sustainability. (Suprianto *et al.,* 2018).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

This research was conducted at Godfrey Okoye University, Thinkers Corner, of Enugu East Local Government Area of Enugu State, Materials required for this work were analytical grade reagents and electronic instruments, Conical flask, beaker, soxhlet extraction apparatus, measuring cylinder, pyrometer, three-neck round bottom flask, reflux condenser, separating funnel, viscometer, petri dish, filter paper, masking tape, spatula, forceps, and masking foil. All glassware used were manufactured by Pyrex. Methanol, ethanol, sodium hydroxide, calcium oxide, magnesium oxide, lithium carbonate, sodium thiosulfate, chloroform, acetic acid, potassium hydroxide, sulfuric acid, hydrochloric acid, phenolphthalein and starch were among the listed analytical grade reagents from May and Baker.

3.1.2 Electronic Instruments: Weighing balance, laboratory hot plate, heating mantle, table top refractometer, gas chromatograph, X-ray diffraction equipment, muffle furnace, hot air oven, and fourier transform infrared spectrometer.

3.2 Methods: Methods adopted here follow a sequence of steps which include collection and preparation of samples, oil extraction and characterization, production of biodiesel from seed oil using sodium hydroxide catalysts, and characterization of optimal yield biodiesel.

3.2.1 Sample Collection and Preparation: Raw paw-paw seeds were obtained from fruits shops in Thinkers Corner and Abakpa market, both in Enugu East Local Government Area. The seeds were sorted to eliminate impurities and washed with distilled water to remove dust and other contaminants. They were then left to air-dry until a constant weight was achieved. Subsequently, the dried seeds were milled using an industrial ball mill to obtain a fine powder and ensure efficient oil extraction. The milled samples were preserved in airtight containers and kept in the laboratory under appropriate conditions until oil extraction.

3.2.2 Oil Extraction (Soxhlet Method): The oil was extracted using a 500g capacity soxhlet extractor. The complete setup consisted of a heating mantle, a round bottom flask, a thimble, and a condenser equipped with a water circulation tube. 100g of the prepared sample was placed in a semi-permeable sample holder and inserted into the thimble. 300ml of n-hexane was measured into the round bottom flask. The flask containing the n-hexane was placed on the heating mantle, the thimble containing the sample was fitted into the flask, and the condenser with water tubes attached was connected to the thimble. Water circulation was set up in the condenser to oppose the flow of vapor, thereby cooling the volatile vapor. This cooled vapor would then condense into n-hexane, which would drip back into the thimble, continuously leaching oil from the paw-paw seed sample within the semi-permeable membrane until very little or no oil remained in the seed sample. The system was cooled, and the mixture of oil and n-hexane in the flask was separated via distillation. The oil was further dried in a water bath at 90°C for 2 hours, then cooled and stored in an airtight container.

Oil Yield (%) = (Weight of oil obtained / Weight of sample used) 100 where: Weight of Oil Extracted (g) = the mass of oil acquired after extraction.

Initial Mass of Sample Used (g) = initial quantity of pawpaw seed utilized for extraction.

3.2.3 Oil characterization: The resultant oil was assessed for: moisture content, free fatty acids, acid value, refractive index, peroxide value, iodine value, saponification value, flash point, fire point, kinematic viscosity, cloud point, pour point, specific gravity, molecular weight, and energy value.

- Moisture content: It was determined using dry oven method (Wick, 1985) to check the amount of water content in oil. This petri dish containing oil was placed in a hot air oven maintained at a temperature of 105 °C. After one hour the petri dish along with the content was removed out of oven, place on a desiccator and cooled down after that; the final weight was obtained using the under listed formula. % Moisture = [(Initial Weight – Final Weight) / (Weight of Sample)] x 100

- Specific Gravity: Measured according to Sivaramakrishnan and Ravikumar, 2012. A dry, cleaned 50ml pycometer (Specific gravity bottle) was weighed. The specific gravity of the oil sample was determined by filling a specific gravity bottle up to the calibration mark with the oil sample and weighing it. The specific gravity was calculated as the ratio of the mass of the oil sample to its corresponding volume using the formula: Specific gravity = Mass of sample / Volume of sample. The refractive index of the oil sample was also determined to evaluate its optical properties and quality characteristics.The reading for the refractive index of the oil were taken with the table top refractometer manufactured by Hanner Instrument. The measurement of kinematic viscosity perform by means of a glass U-tube viscometer. The oil sample's flow time in between upper and lower level of the bulk as measured as flow time of Sample.

Kinematic viscosity=c

Where C= is viscosity constant of 0.48

t= flow time in seconds

- Free fatty: Acid it was determined according to the method specified in ASTM, (2004) 0.5 g of Sample was weight in a 250ml volumetric flask. Then 20 ml of Ethanol was added, 3 drops of Phenolphthalein were added. The entire solution was homogenized and this titrated with 1 M of sodium hydroxide Solution. Free fatty acid was calculated using this formula FFA=Titter value of KOH (56.1) Weight of Sample

- Peroxide Value: It was determined by method of Bowel age and BROEZE, (1990)0.5g of the oil was weight in a Conical flask add 25Ml. Of mixture of glacial acetic and chloroform (in the ratio 2:1) was added. Add 1ml of 10 % potassium Iodide and mix and shake vigorously. Covered and stood for one min in the dark. 35Ml of starch Indicator mixture was titrated against 0.02N sodium thiosuphate Solution until change from pale black colour to white color, titrate also of blank. Peroxide value=100x (V 1 - V 2) x C where C is concentration of titration and, V 1 is titre value of the sample, V 2 is titre value of the blank) Iodine Value It was determine by method of BOERLAGE and BROEZE, 1990 0.5 g of Sample was weighed in to a petri dish and 15ML of Chloroform was added to it. 25ML of the solution was added to the mixture and mixed vigorously, the container was covered and kept for 30 minutes in dark condition. Then 20ml of 10% KI was added, followed by 150ml of distilled Water. 5MLof 5% starch solution was added and was observed to turn from red to blue–black Color and it was titrated against O.1N of sodium thiosuphate solution until color disappeared from white or black precipitation. It was also titrated for blank value and calculated Iodine value according to the below formula: Iodine value=12.69x (V 2 - V 1) x Where C is a concentration of the titre solution is V1 and titre value of the sample, isV2 is Saponification value. It was determine by method of BOERLAGE and BROEZE, 1990 0.5 g of the Sample was weight in to a conical flask, to this added 50MLof 0.5 N ethanolic KOH and mixed well then reflex for saponification. After saponification was completed, excess KOH was back titrated using 0.5N of HCL and using 3 drops of phenolphthale indicator. The Saponification value can be expressed by: Saponification value= 56.1 X (V 2 – V 1) X C / (Sample weight)

Where V 1 = Sample Volume;

V 2 = Blank volume;

C = Sample concentration of titrate

- Molecular Weight: Molecular weight was determine by method of (Zhual *et al.,* 2006). Where AV and SV represents are saponification value of the oil and is molecular weight in mg / mg/moil) Ester Value- was done according to (edmilson *et al*., 2014). Was calculate using the formula (j). The values for ester index (IE) can be Calculated Using the formula; IE= 100 (A − IA)/A Where A is the value is value for fatty acids.

3.2.4 Biodiesel Production (Transesterification)

Following standard method of production of Biodiesel it was performed such that the various production parameters affecting its yield is examined. The apparatus consisted of 500mL three-neck round bottom flask equipped with water cooled condenser (inserted into the neck) fitted on the mid of the flask, fitted through a plastic bong into the mid neck of the3 neck flask, a mercuric glass thermometer through a plastic bong in the middle of the flask and a set up placed on the heating mantel and stirred with capsuled. The quantity of seed oil used was kept constant throughout the experiment. Fifty millilitres (50 mL) of the extracted seed oil were used for each production run. The process parameters were varied one at a time to determine the optimum production conditions. A total of thirty-two (32) production runs were carried out. Thereafter, the physicochemical properties of the extracted oil and the produced biodiesel, including moisture content, saponification value, acid value, free fatty acid, peroxide value, viscosity, specific gravity, refractive index, smoke point, and other relevant parameters, were determined.

3.2.5 Experimental Design for Biodiesel Production

The experimental design utilized for biodiesel production was a two-level, five factor, factorial experiment was employed to examine and ascertain the interaction effect between factors on response of the experiment. In order to satisfy that condition, design expert software (trial version) was employed for experimental design study and also used to optimize the biodiesel production with the usage of heterogeneous catalyst and this provides a program output in terms of 32 experimental runs. The experiments were designed using 5 points (range and level) which can be visualized in the Table 3.1, and they were carried out in a random order. In addition, this point design system was employed to estimate the errors of experiments carried out. The actual (real) value and coded value of the factor are illustrated in Table 3.2 and in coded design, -2 for minimum, 0 for central and +1 for middle maximum and +2 for maximum respectively. There are five study conditions (independent variables, i.e. The catalyst amount, reaction time, reaction temperature, methanol / oil ratio and agitation speed) which were involved to evaluate the optimal conditions of biodiesel yield from transesterification, and the objective function is the biodiesel yield (dependent variable).

Table 3.1: Actual and Coded Levels of the Experimental Factors for Heterogeneous Catalyst Optimization

Factor	Units	Low level	Mid-low level	Mid-level	Mid-high level	High level

Catalyst conc.	Wt%	0.5(-2)	1.0(-1)	1.5(0)	2.0(+1)	2.5(+2)
Methanol : sample ratio	Mol/mol	6(-2)	8(-1)	10(0)	12(+1)	14(+2)
Time,	Minutes	1(-2)	2(-1)	3(0)	4(+1)	5(+2)
Temperature,	°C	30(-2)	40(-1)	50(0)	60(+1)	70(+2)
Agitation speed	Rpm	100(-2)	200(-1)	300(0)	400(+1)	500(+2)

Table 3.2: Experimental design matrix for transesterification studies catalyzed by activated catalysts

Run order	**Catalyst conc. (wt %) A**	**Methanol: sample molal ratio B**	**Time (Hours) C**	**Temperature (^{0}C) D**	**Agitation Speed (rpm) E**

	Coded	Real	Coded	Real	Coded	Real	Coded	Real	Coded	Real
1	-1	1	-1	8	-1	2	-1	40	+1	400
2	+1	2	-1	8	-1	2	-1	40	-1	200
3	-1	1	+1	12	-1	2	-1	40	-1	200
4	+1	2	+1	12	-1	2	-1	40	+1	400
5	-1	1	-1	8	-1	2	+1	60	-1	200
6	+1	2	-1	8	-1	2	+1	60	+1	400
7	-1	1	+1	12	-1	2	+1	60	+1	400
8	+1	2	+1	12	-1	2	+1	60	-1	200
9	-1	1	-1	8	+1	4	-1	40	-1	200
10	+1	2	-1	8	+1	4	-1	40	+2	400
11	-1	1	+1	12	+1	4	-1	40	+1	400
12	+1	2	+1	12	+1	4	-1	40	-1	200
13	-1	1	-1	8	+1	4	+1	60	+1	400
14	+1	2	-1	8	+1	4	+1	60	-1	200
15	-1	1	+1	12	+1	4	+1	60	-1	200
16	+1	2	+1	12	+1	4	+1	60	+1	400
17	-2	0.5	0	10	0	3	0	50	0	300
18	+2	2.5	0	10	0	3	0	50	0	300
19	0	1.5	-2	6	0	3	0	50	0	300

20	0	1.5	+2	14	0	3	0	50	0	300
21	0	1.5	0	10	0	3	-2	30	0	300
22	0	1.5	0	10	0	3	+2	70	0	300
23	0	1.5	0	10	-2	1	0	50	0	300
24	0	1.5	0	10	+2	5	0	50	0	300
25	0	1.5	0	10	0	3	0	50	-2	100
26	0	1.5	0	10	0	3	0	50	+2	500
27	0	1.5	0	10	0	3	0	50	0	300
28	0	1.5	0	10	0	3	0	50	0	300
29	0	1.5	0	10	0	3	0	50	0	300
30	0	1.5	0	10	0	3	0	50	0	300
31	0	1.5	0	10	0	3	0	50	0	300
32	0	1.5	0	10	0	3	0	50	0	300

3.3 Biodiesel Characterization

1. Gross Calorific Value (GCV) gross calorific value is the unit quantity of heat energy is released from the perfect burning of fuel, thus, Gross calorific value = 124 where, the density is 6.

2. The aniline point temperature is lowest of two when equal quantities by volumes, as is indicated in the temperature at which equal volumes of aniline and fuel mix together. This quantity as is measured is the measurement for concentration of aromatic hydrocarbon existing.

3. The API gravity of gasoline, was measured by calculating from measured relative to an arbitrary standard, value of specific gravity of product of each test (Rajarshi et al., 2012).

4. Diesel index is a measure for spark retard of diesel fuel expressed as the arithmetic product of its aniline point in° F and its American petroleum industry gravity in degrees. The more is the diesel index, the higher is ignition quality of diesel fuel. Diesel index =Aniline Point (F).

5. Calorific Value Calorific Value was determined utilizing the formulation beneath that is indicated in (Dawit *et al.,* 2020

CHAPTER FOUR

RESULTS

This chapter presents the results obtained from the physicochemical characterization of the extracted pawpaw seed oil, optimization of biodiesel production using response surface methodology, and characterization of the biodiesel produced from the extracted oil. The results are presented objectively using tables and descriptive narratives. The presentation focuses on the observed values obtained during the experimental investigation without interpretation or comparison with previous studies.

4.1 Physicochemical Characterization of Extracted Pawpaw Seed Oil

The physicochemical properties of the extracted pawpaw seed oil are presented in Table 4.1.

Table 4.1: Physicochemical Characterization of Extracted Oil

Sample	Total 0il yield (%)	Kinematic viscosity @ 40^0c (mm^2s^{-1})	Refractive index @ 33^0c	Acid value (mgKOH/kg)	Free fatty acid value (mgKOH/kg)	Moisture (%)
Paw-paw seed oil	32.75	57.740	1.4627	10.018	5.009	0.846

Sample	Saponification (mgKOH/kg)	Peroxide value (meq/kg)	Specific gravity	Molecular weight (g/mol)	Ester value (%)	Smoke point (^{0}C)
Paw-paw seed oil	299.406	1.864	0.8968	602.427	96.654	96.00

The results presented in Table 4.1 show the physicochemical characteristics of the extracted pawpaw seed oil obtained after the extraction process. The parameters evaluated include oil yield, kinematic viscosity, refractive index, acid value, free fatty acid value, moisture content, saponification value, peroxide value, specific gravity, molecular weight, ester value, and smoke point.

The extraction process produced an oil yield of 32.75%, indicating that approximately one-third of the total weight of the processed pawpaw seeds was recovered as oil. The extracted oil exhibited a kinematic viscosity of 57.740 mm^2/s, while the refractive index was determined to be 1.4627.

The acid value of the extracted oil was 10.018 mgKOH/g, whereas the free fatty acid value was 5.009 mgKOH/g. The moisture content of the oil was found to be 0.846%.

Further analysis showed that the extracted oil possessed a saponification value of 299.406 mgKOH/g and a peroxide value of 1.864 meq/kg. The specific gravity was 0.8968, while the molecular weight was calculated as 602.427 g/mol.

The ester value obtained for the extracted oil was 96.654%, and the smoke point was recorded as 96°C.

The values obtained for each of the measured physicochemical properties are summarized in Table 4.1 and constitute the baseline characteristics of the extracted pawpaw seed oil prior to biodiesel production.

4.2 Process Optimization for Biodiesel Production

The optimization experiments carried out for biodiesel production are presented in Table 4.2. The experimental design consisted of thirty-two (32) experimental runs in which catalyst concentration, methanol-to-oil ratio, reaction time, reaction temperature, and agitation speed were varied to determine their influence on biodiesel yield.

Table 4.2: Process Optimization Using Design Matrix

Run order	Catalyst conc. (wt %) A	Methanol / oil ratio (mol/mol) B	Time (hour) C	Temperature (^0C) D	Agitation Speed (Rpm) E	Biodiesel yield (%, v/v)
1	1	8	2	40	400	70.00
2	2	8	2	40	200	64.90
3	1	12	2	40	200	76.60
4	2	12	2	40	400	80.50
5	1	8	2	60	200	72.60
6	2	8	2	60	400	66.50
7	1	12	2	60	400	83.30
8	2	12	2	60	200	70.00
9	1	8	4	40	200	58.70
10	2	8	4	40	400	65.80
11	1	12	4	40	400	80.40
12	2	12	4	40	200	73.70
13	1	8	4	60	400	70.10
14	2	8	4	60	200	62.40
15	1	12	4	60	200	85.30
16	2	12	4	60	400	96.10
17	0.5	10	3	50	300	50.90
18	2.5	10	3	50	300	79.60
19	1.5	6	3	50	300	63.30
20	1.5	14	3	50	300	73.20
21	1.5	10	3	30	300	77.80
22	1.5	10	3	70	300	76.90

23	1.5	10	1	50	300	78.60
24	1.5	10	5	50	300	82.90
25	1.5	10	3	50	100	74.00
26	1.5	10	3	50	500	60.00
27	1.5	10	3	50	300	66.70
28	1.5	10	3	50	300	66.70
29	1.5	10	3	50	300	66.70
30	1.5	10	3	50	300	66.70
31	1.5	10	3	50	300	66.70
32	1.5	10	3	50	300	66.70

The catalyst concentration investigated during the optimization process ranged from 0.5 wt% **to** 2.5 wt%**,** while the methanol-to-oil ratio varied between 6:1 and 14:1. Reaction time ranged from 1 hour to 5 hours, reaction temperature varied between 30°C and 70°C, and agitation speed ranged from 100 rpm to 500 rpm.

The biodiesel yield obtained from the various experimental runs ranged from 50.90% to 96.10%**.**

Among the thirty-two experimental runs, the highest biodiesel yield of 96.10% was obtained during Run 16, which employed a catalyst concentration of 2 wt%**,** methanol-to-oil ratio of **12:1**, reaction time of 4 hours, reaction temperature of 60°C, and agitation speed of 400 rpm**.**

The lowest biodiesel yield of 50.90**%** was recorded during Run 17, where the operating conditions consisted of 0.5 wt% catalyst concentration**,** 10:1 methanol-to-oil ratio**,** 3-hour reaction time**,** 50°C reaction temperature**,** and 300 rpm agitation speed**.**

The remaining experimental runs produced biodiesel yields within this range under different combinations of the process variables, as presented in Table 4.2.

4.2.1 Effect of Catalyst Concentration on Biodiesel Yield

The biodiesel yields obtained at different catalyst concentrations are presented in Table 4.2. The catalyst concentrations investigated during the optimization study ranged from 0.5 wt% to 2.5 wt%. The experimental design incorporated different combinations of catalyst concentration with methanol-to-oil ratio, reaction time, reaction temperature, and agitation speed to determine their combined influence on biodiesel yield.

The experimental runs conducted using 1 wt% catalyst concentration produced biodiesel yields of 70.00%, 76.60%, 72.60%, 83.30%, 58.70%, 80.40%, 70.10%, and 85.30%**,** depending on the operating conditions employed.

Similarly, the biodiesel yields obtained using 2 wt% catalyst concentration were 64.90%, 80.50%, 66.50%, 70.00%, 65.80%, 73.70%, 62.40%, and 96.10%**.**

Additional experimental runs were carried out at catalyst concentrations of 0.5 wt%, 1.5 wt%, and 2.5 wt%. The corresponding biodiesel yields ranged from 50.90% to 82.90%. The maximum biodiesel yield observed during the study **(**96.10%**)** was obtained using a catalyst concentration of 2 wt%**,** while the minimum biodiesel yield **(**50.90%**)** was obtained using 0.5 wt% catalyst concentration under the specified experimental conditions. These results are summarized in Table 4.2.

4.2.2 Effect of Methanol-to-Oil Ratio on Biodiesel Yield

The biodiesel yields obtained using different methanol-to-oil ratios are presented in Table 4.2. Methanol-to-oil ratios investigated during the optimization process ranged from 6:1 to 14:1.

Experimental runs conducted at a methanol-to-oil ratio of 8:1 produced biodiesel yields ranging from 58.70% to 72.60%, while the biodiesel yields obtained at a ratio of 12:1 ranged from 70.00% to 96.10**%** under different combinations of the remaining process variables.

Additional optimization experiments were performed at methanol-to-oil ratios of 6:1**,** 10:1, and 14:1, with biodiesel yields varying between 50.90% and 82.90%. The highest biodiesel yield recorded during the experimental investigation **(**96.10%**)** was obtained at a methanol-to-oil ratio of 12:1 under the specified process conditions. The results for all experimental runs are presented in Table 4.2.

4.2.3 Effect of Reaction Time on Biodiesel Yield

The influence of reaction time on biodiesel yield is presented in Table 4.2. Reaction times investigated during the optimization study ranged from 1 hour to 5 hours.

Experimental runs carried out at a reaction time of 2 hours produced biodiesel yields ranging from 64.90% to 83.30%, while reaction times of 4 hours resulted in biodiesel yields ranging from 58.70% to 96.10% under different combinations of catalyst concentration, methanol-to-oil ratio, reaction temperature, and agitation speed.

Additional experiments conducted at reaction times of 1 hour**,** 3 hours, and 5 hours produced biodiesel yields ranging from 50.90% to 82.90%. The highest biodiesel yield of 96.10% was obtained at a reaction time of 4 hours, whereas the lowest yield of 50.90% was obtained at a reaction time of 3 hours under the experimental conditions specified in Table 4.2.

4.2.4 Effect of Reaction Temperature on Biodiesel Yield

The biodiesel yields obtained at different reaction temperatures are presented in Table 4.2. Reaction temperatures investigated during the optimization process included 30°C, 40°C, 50°C, 60°C, and 70°C.

The experimental runs conducted at 40°C produced biodiesel yields ranging from 58.70% to 80.50%, while those conducted at 60°C produced biodiesel yields ranging from 62.40% to 96.10%.

Additional experiments carried out at 30°C**,** 50°C, and 70°C produced biodiesel yields within the range of 50.90% to 82.90%. The highest biodiesel yield (96.10%) was obtained at 60°C under the optimum operating conditions identified in the experimental design. The biodiesel yields corresponding to all reaction temperatures investigated are presented in Table 4.2.

4.2.5 Effect of Agitation Speed on Biodiesel Yield

The biodiesel yields obtained at different agitation speeds are presented in Table 4.2. Agitation speeds investigated during the optimization study ranged from 100 rpm to 500 rpm.

Experimental runs carried out at 200 rpm produced biodiesel yields ranging from 58.70% to 85.30%, while those conducted at 400 rpm produced biodiesel yields ranging from 65.80% to 96.10**%**.

Additional experimental runs were performed at agitation speeds of 100 rpm**,** 300 rpm**, and** 500 rpm, resulting in biodiesel yields ranging from 60.00% to 82.90%**.** The highest biodiesel yield **(**96.10%**)** was obtained at an agitation speed of 400 rpm, whereas the lowest biodiesel yield associated with agitation speed was 60.00%, which was recorded at 500 rpm under the specified experimental conditions.

4.3 Optimum Biodiesel Yield

The optimum biodiesel production conditions obtained from the optimization study are presented in Table 4.2. Among the thirty-two experimental runs, the highest biodiesel yield recorded was 96.10%.

The optimum operating conditions corresponding to this maximum yield consisted of 2 wt% catalyst concentration**,** 12:1 methanol-to-oil ratio**,** 4-hour reaction time**,** 60°C reaction temperature**, and** 400 rpm agitation speed**.**

The optimization study also showed that biodiesel yields obtained under the remaining experimental conditions varied between 50.90% and 96.10%, depending on the combination of process variables employed during each experimental run.

4.4 Physicochemical Characterization of Produced Pawpaw Seed Biodiesel

The physicochemical properties of the biodiesel produced from pawpaw seed oil are presented in Table 4.3.

Table 4.3: Biodiesel Characterization

Sample Id.	Moisture (%)	Density (Kg/m^3)	Smoke point (^0c)	Flash point (^0c)	Cloud point (^0c)	Pour point (^0c)
Paw-paw seed biodiesel	0.150	0.8506	76.00	164.00	5.50	1.00

Sample Id.	Viscosity @ 40^0c (mm^2s^{-1})	Aniline Point (^0F)	Diesel index	API Gravity	Cetane Number	Refractive index
Paw-paw seed biodiesel	7.650	189.00	65.87	34.85	62.87	1.4480

The results presented in Table 4.3 show the physicochemical properties of the biodiesel produced from pawpaw seed oil following the transesterification process. The parameters determined include moisture content, density, smoke point, flash point, cloud point, pour point, viscosity, aniline point, diesel index, API gravity, cetane number, and refractive index.

The moisture content of the produced biodiesel was 0.150%, while the density was 850.6 kg/m^3. The smoke point and flash point were recorded as 76°C and 164°C, respectively. The cloud point was 5.5°C, whereas the pour point was 1.0°C.

The viscosity of the biodiesel was 7.650 mm^2/s. The aniline point was 189°F, while the diesel index was 65.87. The API gravity of the biodiesel was 34.85, and the cetane number was 62.87. The refractive index of the produced biodiesel was 1.4480.

The values obtained for all the physicochemical properties measured during the characterization of the biodiesel are presented in Table 4.3 and represent the final fuel properties of the biodiesel produced from pawpaw seed oil.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

5.1 Discussion

Physicochemical Properties of Pawpaw Seed Oil

Pawpaw seeds showed an oil yield of 32.75%. Hence pawpaw seeds are promising alternative sources for the non-edible oil feedstock for biodiesel production, this oil yield value is in a similar range to other values reported in the literature with several workers reporting oil yield between 25%-35% for pawpaw seeds (Fernandez-Rodrguez *et al.*, 2017). This reasonably good oil yield shows the potential of pawpaw seeds, which are commonly treated as a waste in rural agriculture, as source of biodiesel fuel.

The obtained oil yield was higher than other few non-conventional feedstock such as mango kernel and rubber seed, but lower than those for palm kernel oil (Adewale *et al.,* 2015). The kinematic viscosity of the extracted oil was very high and was found to be 57.74 mm/s. This result agrees with the earlier findings of (Meher *et al.,* 2006) that generally; crude vegetable oils has very high viscosity due to long chained triglycerides. High viscosity is very problematic in the direct use in the diesel engines as it reduces the atomization efficiency, incomplete combustion, injector fouling, carbon deposition etc. Therefore it justifies the transesterification process to convert the oil in to biodiesel. Acid value of oil was found to be 10.018 mg KOH/g and free fatty acid content was 5.009 mg KOH/g. These values clearly demonstrate the relatively high concentration of free fatty acids in the pawpaw seed oil, this is in agreement with reports from various scientists that pawpaw seeds contains very high free fatty acids (Bankovic *et al.,* 2015). Oils having more than 2% FFA content must be pre-treated prior to base catalyzed transesterification for the saponification. Thus, the relatively high FFA of the oil clearly warrants the pre-treatment of pawpaw seed oil before biodiesel production. High FFA content might be due to the hydrolytic degradation of triglycerides in storage and handling of seeds. The moisture content of 0.846% found in this study was found to be fairly good, indicates a better oil quality in terms of product stability. As moisture encourages the soap formation during biodiesel preparation, low value found here is favorable for the transesterification process. Similar result obtained in the previous studies on dried pawpaw seeds (Bankovic *et al.,* 2015) on properly dried pawpaw seeds. The peroxide value of the produced oil was found to be 1.864 mq/kg; the low value indicates the low level of oxidation. It is not consistent with the result of (Yogalakshmi *et al*., 2022) that observed very high peroxide values for pawpaw seeds, this value was much lower compared to the reported values for majority of the edible and non-edible vegetable oils particularly exposed to prolonged storage for extended periods. This indicate that the extracted oil was relatively fresh and had not experienced rancidity. Saponification value of pawpaw seed oil found to be 299.406 mg KOH/g. These values reflect that pawpaw seeds contain mainly short and medium-chained fatty acids. High saponification values have been reported for non-conventional seed oils (Ajanaku *et al*., 2018). Higher saponification values in biodiesel feed stocks are beneficial as short/medium chain fatty acids can react easily with methanol for biodiesel production (Ajanaku *et al.*, 2018). Specific gravity of the produced oil was 0.8968. Which was in typical ranges of other vegetable oils (Ajanaku *et al*., 2018).

Effect of Process Variables on Biodiesel Yield

Biodiesel yields ranging from 50.90%-96.10% were obtained and show that catalyst concentration, methanol to oil ratio, reaction time, temperature, agitation speed effect Biodiesel Yield significantly.

Effect of Catalyst Concentration

Biodiesel yield increases as the catalyst concentrations increases from 1 wt % to 2 wt%. Highest biodiesel yield of 96.10% were obtained at 2 wt%. Similar trend observed for the production of biodiesel from jatropha, neem and waste vegetable oil which found that increase in catalyst concentration favors increased Biodiesel yield due to the increase in available catalyst active sites that facilitate transesterification. Increased catalyst amount was found to favor the increase in triglyceride conversion rate (Demirbas, 2009). Increase in catalyst concentration at certain levels increases production rate due to the increase of effective sites of catalyst, but at higher concentrations the soap formation occurs that decreases the biodiesel yield. Therefore yield is expected to decrease with the increase of higher concentrations above optimum level as observed in few cases.

Effect of Methanol to Oil Ratio Results shown that the biodiesel yield was improved at the ratio12:1 compared to the 8:1 oil. According to Le Chatelier's principle, increasing the ratio of alcohol (methanol) to oil will shift equilibrium towards Biodiesel, thus increases the production. This agrees with similar studies carried out with different vegetable oil feedstock such as soybean, palm and jatropha seeds etc. (Knothe *et al.,* 2015). However beyond this ratio, further increase in ratio may lead to the difficulties in separating Glycerol from Biodiesel as it may increase apparent Biodiesel yield but effectively it is not (Knothe *et al.,* 2015). Thus highest methanol ratio doesn't have to produce the maximum yield.

Effect of Reaction

Time it can be observed that with increase of reaction time from 1h to 4h the biodiesel yield gradually increased. Biodiesel yield was more at longer time of reaction. Similar findings have been reported that a satisfactory reaction time is essential for a complete conversion of triglycerides to their corresponding methyl esters (Gui *et al.,* 2008). The yield increased and stabilized after 4 hours; longer reaction times than this generally favour production towards completion but may also lead to increase the production time and cost, also reverse reaction may occur and decrease product.

Effect of Reaction Temperature

In most of the cases, higher biodiesel yield were achieved at 60°C than that at 40°C. Increased temperature results in more molecules having enough energy for collision to undergo reaction and increased the rate of reaction and kinetics. The trend observed is consistent with reported literature which suggests optimum temperature for the transesterification to be within 55-65 °C (Balat *et al.*, 2010). The central composite design showed maximum yield at about 50-60°C. High temperature beyond the boiling point of methanol leads to loss of alcohol and causes low reaction efficiency (Balat *et al.,* 2010).

Effect of Agitation Speed

It can be seen that agitation speed affected biodiesel yield. In general, increase in agitation speed enhanced biodiesel yield through better contact of immiscible phase. However, in some experiments, increase in agitation speed to higher level (above 400rpm) caused decrease in yields (Akinoso *et al.,* 2017). For instance, the decrease of 60% to about 50.9% at higher rpm is clearly indicating the negative effect of high rpm on biodiesel yield perhaps due to excessive mass transfer between two immiscible phases that leads to emulsion formation which hinder biodiesel separation. Similar report on effect of agitation on yield was made for biodiesel produced from other oil source.

Optimum Biodiesel Yield

A yield of 96.10% biodiesel was obtained under the following optimum conditions. Catalyst concentration 2 wt% Methanol to oil ratio 12:1; Reaction time 4h; Temperature 60°C; Agitation speed 400 rpm. Comparison of these yield with reports of production from Jatropha biodiesel (90-95%), soybean biodiesel(92-98%) and waste cooking oil (85-95%) shows that our yields is high and in similar range to be competitive to those sources(Sani *et al*., 2014).

Physicochemical Properties of Pawpaw Seed Biodiesel

Biodiesel moisture content of the produced oil was 0.150%, indicating a very good quality of biodiesel as low moisture content means that the product could be stored for extended periods and has no microbial contamination. This product conforms to standard biodiesel property limit (ASTM D6751 and EN 14214) biodiesel limit [52]. Product density was 850.6 kg/m^3 in the ranges allowable for ASTM D6751 and EN 14214 which has a range of 850 kg/m^3 (ASTM D6751) to 860kg/m^3 (EN14214) Biodiesel density from other vegetable oil sources similar to what we got also in range with reported values (Rashid *et al*., 2008) of soy, palm and Jatropha biodiesel etc. Flash point for the produced oil was found to be 164C. This is a desirable property of the biodiesel fuels because it signifies good storage and transportation safety in terms of flammability. Biodiesel fuels have high flash points (commonly in the range 110-175°C) as compared to petroleum diesel fuel (commonly 52-96°C) (Lam *et al*., 2010). The smoke point of 76°C further confirms the combustion characteristics of the produced biodiesel. The cloud point (5.5°C) and pour point

(1.0°C) indicate acceptable cold-flow properties. These values are comparable to those reported for biodiesel derived from tropical vegetable oils. However, the relatively high cloud point suggests that the biodiesel may experience flow difficulties under very cold conditions (Lam *et al.,* 2010). The viscosity of the biodiesel was 7.65 mm^2/s, representing a substantial reduction from the crude oil viscosity of 57.74 mm^2/s. This dramatic reduction confirms the effectiveness of transesterification. Although the value is slightly higher than some biodiesel standards, it remains much lower than that of the original oil and would significantly improve fuel atomization and combustion. The cetane number of 62.87 is higher than the minimum values required by International Biodiesel Standards. High cetane numbers indicate shorter ignition delays and better combustion efficiency. This result suggests that pawpaw seed biodiesel possesses excellent ignition quality (Lam *et al.*, 2010). The refractive index decreased from 1.4627 in the crude oil to 1.4480 in the biodiesel, confirming the conversion of triglycerides into methyl esters. Similar decreases have been reported during successful biodiesel production from various vegetable oils (Sani *et al.*, 2014). The diesel index of 65.87 and API gravity of 34.85 further indicate favorable fuel characteristics comparable to those of conventional diesel fuel.

The result showed that pawpaw seed oil is a fit feedstock oil for the production of biodiesel due to its physicochemical property. The high percentage biodiesel yield (96.10%) and good fuel properties produced have also compared favorably with biodiesel derived from the known feedstock like soybeans, jatropha, palm, and waste cooking oils. The remarkable decrease in viscosity and increase in cetane number, reasonable density, and high flash point confirm the effectiveness of the transesterification process. The waste valorization, environmental sustainability, and renewable energy development would be improved by using the pawpaw seeds for biodiesel biodiesel production.

Thus, the finding proves that pawpaw seed oil is a potential raw material and source for biodiesel production and adds value to the stock of information available for non-edible and waste generated biofuels.

5.2 Applications of biodiesel used in Power Generation

Biodiesel plays an outstanding role in electricity and power generation worldwide. They serve as power source to generate electricity and power most especially when utilized on diesel generators as alternative fuel. Biodiesel can be used as straight diesel (100% biodiesel; B100), as an additive or can be blended with conventional petroleum-diesel at varying percentages such as (20% biodiesel and 80% conventional diesel: B20). Biodiesel has a vast application on homes, hospitals, industries, as well as communities with no stable public electricity where biodiesel fueled generator sets are often used. The application of biodiesel as fuel to generate power or electricity has many benefits which among other are its non-degradable nature due to its origin from plants, biodiesel combustion contributes in reduction of carbon (II) oxide emission, carbon dioxide (CO2) as well as sulphur oxides and non-burnt hydrocarbons and it is less polluting to the atmosphere thereby reducing impact of harmful gases on the global warming or climate (Agunbiade and Adewole, 2014). Biodiesel fuel offers higher lubricant properties than diesel that helps in wear reduction in generators; a higher flash point and lower volatile due to that fact it reduces the chance of engine explosion and can be safely stored, transported and used at very cold climates as well, it’s ideal for use on small size generators and those operating in rural/off-grid environments. It can also be applied in mini-power plants on homes and rural communities, helping both the energy independence and security. Used in Agricultural machinery Biodiesel is widely applied on agricultural machineries like tractor, combine harvester, irrigation pump, plough machines and threshing machines, because it can serve as a viable substitute in running diesels engine with little or no modifications, biodiesel can be blended with petroleum diesel at 5, 10, 20 and 100 percent blend ratios without significant modifications to equipment designed to run on petroleum diesel, since it is derived from agriculture resources it aids in reducing dependence on petroleum based diesel, boosting renewable energy resources application in agricultural sector (Abubakar and Uthman, 2020). Other benefits includes high fuel economy and superior combustion characteristics, good engine lubricity resulting in reduced engine wears and lower maintenance costs. Because they are eco-friendly, use of biodiesels significantly reduces particulate matter emission, hydrocarbon, carbon (II) oxide, sulfur oxides and even non-burning of particles that are known contributors to air pollution and environmental impact on health and ecosystem. The usage of sustainable agricultural practices is central in developing and managing a food supply which also contributes to climate action through mitigation and adaptation strategies. Agricultural machinery should embrace efficient technologies, efficient usage of fuel and application of renewable energy such as biodiesel in the operation.

Farmers can use Biodiesel fuel in generators to power equipment, irrigation systems, and to provide light for the night work and in tractors, irrigation machines, combines and harvesters used to facilitate fieldwork in rural areas that have no stable electrical supply and a lot of agricultural residue which can be processed to produce biodiesel. Biodiesel production from agricultural waste products can contribute to increasing the income of farmers and supporting rural community.

Biodiesel production process itself promotes agricultural residue as valuable by-products. It has positive impact to the soil and water. Biodiesel has superior lubricating properties, which can increase the lifetime of engines, compared to diesel fuel which typically has poor lubricating properties. Biodiesel combustion in engines emits 70% less emissions of pollutants, Biodiesel has a flash pointofaround150◦ C, compared to conventional diesel fuel's190◦ C; so its flame point is significantly lower.

5.3 Economic Importance of Biodiesel Production from Pawpaw Seeds

Utilization of Agricultural Waste The papaya seed is presently a waste product (Abubakar and Uthman, 2020). Cost effectiveness waste sardine willow cost feedstock (Arumugam and Ponnusami, 2017) employment opportunities. The biodiesel production chain comprises collection of seeds, extraction of oils, processing of crude oil into biodiesels, transportation, and marketing. These activities create employment in rural areas as well as in industrial settings. It supports small and large-scale biodiesel processing businesses and entrepreneurships, as well as generating income for farmers and processor (Abubakar and Uthman, 2020). Industrial applications include the production of biodiesel which encourages the establishment of industries and businesses related to fuel and energy sectors, particularly supporting investments and growth of renewable energy technologies and industry. This provides impetus for local manufacturing, job creation, and entrepreneurship (Degne *et al.*, 2019).

5.4 Conclusion

This research showed that pawpaw (*Carica papaya*) seed oil could be easily converted to biodiesel via esterification and transesterification reactions. It further showed that pawpaw seeds are potential feedstock for biodiesel production and are often wasted resources with good prospective. From the study, the following conclusions were drawn. Pawpaw seeds oil is a suitable alternative feedstock for biodiesel production. Pawpaw seeds oil needed pretreatment via esterification when its free fatty acid content is high. Transesterification of pawpaw seeds oil gave high yield of biodiesel with enhanced fuel properties. The process variables such as alcohol: oil ratio, catalyst concentration, reaction temperature and reaction time are important factor affecting the yield of biodiesel. Biodiesel produced met the standard physiochemical properties required for biodiesel fueling in a diesel engine. It turns pawpaw seeds that are usually wasted to something valuable that generates income and protect the environment.

Therefore, biodiesel from pawpaw seeds is a renewable, environmental friendly and sustainable alternative for use in diesel engine.

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