UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 6(3), September (2026), 3691-3704
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Optimization of Solvent Extraction of African Pea Seed Oil Using Ethanol and Petroleum Ether for Bioaviation Fuel Feedstock

John Jones Ajali *
Department of Chemical Engineering, Nnamdi Azikiwe University, Awka, Anambra State
Joseph Tagbo Nwabanne
Department of Chemical Engineering, Nnamdi Azikiwe University, Awka, Anambra State
Philomena Kanwulia Igbokwe
Department of Chemical Engineering, Nnamdi Azikiwe University, Awka, Anambra State

**Corresponding Author's E-mail: jj.ajali@unizik.edu.ng*

Abstract
Extraction of oil from African pea seeds for jet fuel sustainability is vital in promoting renewable energy. This work focuses on extracting oil from African pea seeds by optimizing the extraction process parameters using response surface methodology (RSM). Solvent extraction method was used with ethanol and petroleum ether as solvents. Three independent extraction parameters; particle sizes (0.15, 0.3, 0.45 mm), temperature (40, 60, 80 °C) and time (30, 60, 90 min) were considered. The highest oil yield was 6% and 18.4% for ethanol petroleum ether respectively. The optimal conditions: particle size, temperature and extraction time, were recorded at 0.3 mm, 60 °C and 123.9 min respectively for ethanol and 0.45 mm, 40 °C and 120 min respectively for petroleum ether. Quadratic model is suggested for both solvents as the best fit with adjusted R^2 of 0.9143 and 0.8571 and predicted R^2 of 0.7452 and 0.7822 respectively, indicating good agreement between the two (predicted and observed). Temperature (B), time (C), and interaction terms (AB, AC, BC) are significant for petroleum ether with temperature and particle size having the most significant effect on oil yield, while Particle size (A), time (C), and squared terms (B^2 and C^2) are significant in affecting ethanol. Time (C) has the most substantial effect (F-value of 27.38), meaning the longer the extraction time, the higher the yield for ethanol as solvent. Consequently, the results showed that Petroleum ether gave a better yield compared to ethanol.
Keywords: Pea seed oil, extraction, optimization, rsm, bio-aviation fuel.

1. Introduction

African pea seed (*Dacryodes edulis*) is emerging as a promising source of oil for biofuel production, particularly in Africa where it is abundant and readily available. The seeds contain a high oil yield, estimated at 18 - 34%, making them an attractive feedstock for biodiesel production. This native tree thrives in various African regions, providing a sustainable resource that can be harvested without depleting the ecosystem (Agbo, 2024, Maestri et al., 2020). Utilizing African pea seeds for oil extraction, not only supports local economies but also contributes to reducing reliance on fossil fuels, aligning with global efforts to transition to renewable energy sources. The oil's favorable fatty acid composition further enhances its potential as a viable alternative fuel, supporting the aviation industry's shift towards sustainable energy solutions.

Adipah, (2018) and Veljković et al., (2018) observed that there are abundant economic prospects in the development of sustainable bio-jet fuel, especially in areas where there are large quantities of agricultural resources like African pea seeds. This will promote rural economies, create employment in agriculture, processing, and manufacturing industries thereby stimulating investment in renewable energy infrastructure. Biofuel development will also enhance economic stability thereby forestalling incessant increase of oil prices and market fluctuations. Optimizing the technologies of fuel conversion, refining and blending are essential for bio-jet fuel production from unusual feedstock as it will enhance production efficiency, fuel quality and cost effectiveness.

Pea seeds, often discarded as agricultural waste, contain oil that can be extracted and processed for biofuel production. This approach not only contributes to waste valorization but also promotes circular economy by utilizing by-products that would have otherwise been wasted. The extraction of oil from pea seeds offers a renewable and potentially abundant source of raw material for energy production, thus reducing reliance on fossil fuels and contributing to environmental sustainability (John et al., 2024; Fu et al., 2021, Onoji et al., 2016). Pea seed, a by-product of the pea fruit industry, though available with environmental benefits, yet little research has been conducted on the extraction efficiency and characterization of pea seed oil. Additionally, optimizing the extraction process to achieve high yields in a cost-effective and energy-efficient manner remains a significant challenge.

This work seeks to address these gaps by employing response surface methodology (RSM) in optimizing the extraction process of pea seed oil, using solvents, while maintaining the oil's quality and properties. It also contributes to global efforts to reduce greenhouse gas emissions by developing a renewable alternative feedstock to fossil-based jet fuel. Biofuels produced from non-edible sources like pea seed oil offer a cleaner, carbon-neutral solution, and helping to mitigate climate change (Baroutaji, et al., 2019, Alalwan et al., 2019).

The major concern with biofuel production which is the competition between food and fuel crops is equally addressed by the non-edible resource feedstock that does not interfere with food supply chain. According to Melillo et al,. (2021) and, jet fuel production from renewable sources is one possible route for the manufacturing of sustainable bio-aviation fuel. This is because of their availability, affordability, and lack of competition with food crops. This agricultural by-product has the potential to be used as feedstock for the production of bio-jet fuel (Obianom et al., 2024), nonetheless, in order to fully exploit their prospects in aviation fuel applications, a few crucial difficulties must be resolved. Firstly, in order to increase fuel yield and quality while reducing energy consumption and environmental impact, the extraction process must produce optimum results in terms of cost and yield (Kassi et al,. 2019). This entails determining which solvent gives the best results after extraction, at what temperature and duration the optimum results can be obtained.

African Pea Seed (APS)

African pea (*Dacryodes edulis*) known as ube among the Igbo speaking people of Southeastern Nigeria is a member of the family Burseraceae. It is an evergreen tropical fruit tree which grows in the humid and subhumid climate of the West African countries (Onwuzuruike et al., 2024, Kassi, et al., 2019). The African pea (*Dacryodes edulis*) fruit pulp is well known for its richness in protein, fat, fibre, minerals and essential amino acids. They are often softened by heating in hot water or ash and eaten as an accompaniment to roasted or boiled maize. However, the seeds are not eaten and are often discarded as waste or sometimes consumed by domestic animals if discovered before they are rotten. Previous research has revealed that the seed contains 18-34% oil, making it comparable with other oil bearing seeds such as palm kernel (40%), cotton seed oil (30%). The high oil content provides a good yield for commercial production of biofuel from this feedstock.

The seed of African pea *Dacryodes edulis* is oval or ellipsoidal in shape, measuring about 2 to 5 cm in length. The seed coat is hard, protecting the kernel, which contains the oil. The oil is rich in lipids,. Inside the seed, the kernel is whitish and contains essential nutrients, including fatty acids, proteins, and minerals (Asanja et al., 2020,).
The physicochemical properties of the oil include specific gravity of 0.89 at 24°C and a refractive index of 1.58. The iodine value ranges from 39.9-46 g/100g, indicating a low degree of unsaturation. The saponification and peroxide values are 192 and 1.73 respectively (Onwuzuruike et al., 2024, Kassi, et al., 2019, Adegbe et al, 2016). The **chemical composition** of African pea seed oil is composed of a mixture of **fatty acids, glycerides, vitamins**, and **trace elements**, which contribute to its **nutritional, cosmetic**, and **industrial** value. Below is a detailed breakdown of its main components (Agwu et al., 2017, Akpan et al., 2024):

Table 1: **Summary of Chemical Composition of African pea seed oil**

Component	Concentration	Applications
Oleic Acid (C18:1)	40-55%	Heart health, stability, oxidation resistance
Linoleic Acid (C18:2)	20-30%	Nutritional value, skincare, anti-inflammatory
Palmitic Acid (C16:0)	15-20%	Biodiesel stability, structural properties
Stearic Acid (C18:0)	3-7%	Cosmetic applications, soaps, emollient
Vitamin E (Tocopherols)	Trace amounts	Antioxidant, skincare, shelf-life enhancement
Phytosterols	Trace amounts	Cholesterol-lowering properties, health benefits
Carotenoids	Trace amounts	Antioxidant, color, health benefits
Squalene	Trace amounts	Skin hydration, cosmetic applications
Mono- and Diglycerides	Trace amounts	Emulsification in cosmetics and food applications
Unsaponifiable Matter	Moderate	Antioxidant, skin protection, pharmaceuticals
Minerals	Trace amounts (Ca, Mg, Fe)	Nutritional value, no significant industrial use

These properties of African pea seed in table 1 above are comparable to those of conventional diesel fuel, making the oil suitable for use as a direct replacement or blend component in biofuel production (Ene-Obong et al., 2019, Durrett et al., 2018). The chemical composition also makes it valuable **multifunctional oil** suitable for a wide range of applications. The high oleic acid content in the oil is particularly advantageous for aviation fuel, as it reduces the tendency for oxidation and improves cold-flow properties (Akpan et al., 2021).

Oils derived from plant seeds and microalgae comprise mainly triacylglycerols (TAG) molecules with very high energy density, low free fatty acid content (3.92-3.97%), which are good characteristics for biofuels production. These renewable energy sources for transportation are increasingly in demand by societies because they do not raise global carbon dioxide levels. The most common biofuel derived from seed oils is biodiesel, which consists of the fatty acid methyl esters (FAME) produced from the TAG molecules. More recently, renewable aviation fuels termed "biojet" have been synthesized from seed oils through hydroprocessing (Aguoma et al., 2023). The economics of production limits the widespread adoption of fuels derived from seed and microalgal oils. For example, the available oil feedstock is not enough for the fuel market size (Durrett et al., 2018), and it often represents the highest cost of production (Veljković et al., 2018). While increasing seed oil production would help offset these problems, it should be done in a sustainable manner that does not destroy existing ecosystems or create food fuel conflict (Onoji et al, 2016).

*1.1.1. **Oil Extraction Methods***

The extraction of oil from seeds presents several challenges and opportunities, and various studies have been carried out on the subject matter. The key methods of oil extraction from African pea seeds, the advantages, challenges, and applications based on existing research are outlined.

a. Traditional Extraction Methods

Traditional oil extraction processes from seed crops available in rural communities of West and Central Africa are **manual pressing** and **boiling** the seeds. In this method, the seeds are boiled, and the oil is manually extracted through pressing or grinding. This method is accessible to rural areas because of its simplicity which does not also require complex apparatus. However, the process produces low yield and efficiency and some of the oil's bioactive components may be degraded by prolonged exposure to heat (Madaminova et al., 2024, Musa et al., 2023). It is a simple, low cost and accessible method. However, it is disadvantaged by low oil yield, time consuming and quality reduction as a result of high temperatures.

b. Mechanical Extraction (Cold Pressing)

Mechanical extraction, particularly **cold pressing**, is one of the most widely researched methods for extracting oil from oil bearing seeds. This method involves the use of **hydraulic presses** or **expellers** to crush the seeds and extract the oil. It does not involve heat thereby preserving the oil's **nutritional** and **bioactive properties**, such as **vitamin E** and **unsaturated fatty acids** (Thilakarathna et al., 2023, Madaminova et al., 2024). Studies have shown that cold pressing can achieve an oil yield of about **35-40%,** depending on the quality of the seeds and the specific pressing conditions. It has the advantage of preserving the oil quality and suitable for high-value oils (cosmetics, food). The challenge is low oil yield in comparison to solvent extraction and the equipment can be expensive for large –scale production.

c. Solvent Extraction

Solvent extraction is a more industrialized method that involves using organic solvents like **hexane** to dissolve the oil from the crushed seeds, followed by solvent evaporation to recover the oil. Studies have shown that solvent extraction can achieve a much higher oil yield (up to **45-50%)** compared to mechanical methods (Ajali and Emembolu, 2024, Saini et al,. 2018). This method is commonly used for large-scale commercial extraction because of its efficiency in extracting the maximum amount of oil from seeds. It has a potential for residual solvent contamination, environmental concerns related to the use of volatile organic solvents like hexane, and the risk of degrading certain heat-sensitive bioactive compounds during the solvent recovery phase (Ajali et al., 2022).

d. Supercritical CO2 Extraction

Supercritical carbon dioxide (CO2) extraction is a more advanced and eco-friendly method of oil extraction that does not allow residual solvent in the oil. It involves the use of supercritical CO_2 as a solvent to dissolve and extract oil from seeds at high pressure and moderate temperatures. The moderate operational temperature enables preservation of the oil's **chemical integrity**, such as its unsaturated fatty acid profile and **antioxidants** like **tocopherols** (Nozari and Kander, 2025). The method equally promotes selective extraction of oil components based on pressure and temperature adjustments. This method also requires high equipment cost, specialized expertise required, and the process may not be economically feasible for small-scale operations (Nozari and Kander, 2025**).**

1.1.2. Factors Affecting Oil Extraction Efficiency

Several factors influence the efficiency and yield of oil extracted from African pea seeds. These include:

a. Seed Maturity and Quality

- The **maturity** of the fruit and the quality of the seeds significantly affect the oil content and quality. Fully mature seeds tend to have a higher **oil content**, while under-ripe or overripe fruits yield less oil. The **moisture content** of the seeds also affects extraction efficiency; lower moisture content improves oil yield in both mechanical and solvent extraction methods (Agwu et al., 2017).

b. Temperature

- In traditional and solvent extraction methods, the application of heat can affect the **quality** of the oil. High temperatures can lead to the degradation of heat-sensitive components such as **unsaturated fatty acids** and **vitamins**. On the other hand, higher temperatures can increase oil yield by reducing viscosity, making the oil easier to extract (Musa et al., 2023, Levenburg et al., 2021).

c. Solvent Type and Ratio

- In solvent extraction, the choice of **solvent** and the **solvent-to-seed ratio** plays a crucial role. Hexane is commonly used due to its **non-polar nature**, which makes it effective for dissolving oils. However, researchers are investigating alternative, **less toxic solvents** like **ethanol** for more sustainable extraction processes (Thilakarathna et al., 2023).

d. Pre-treatment of Seeds

- **Pre-treating seeds** by drying, roasting, or grinding can improve the extraction efficiency. Studies suggest that pre-grinding the seeds into smaller particles enhances the **surface area**, thereby increasing the interaction between the solvent or pressing mechanism and the seed material, which boosts oil yield (Midhun et al., 2023).

1.1.3. Emerging Trends and Research Areas

a. Green Extraction Technologies

- The increasing demand for **environmentally friendly** and **sustainable extraction** methods has led to more research on using **green solvents** like **ethanol** and **supercritical fluids**. These methods aim to reduce the environmental impact of traditional solvent extraction techniques while preserving oil quality (Musa et al., 2023, Agwu et al., 2017).

b. Biorefining and Valorization

- Beyond oil extraction, there is growing interest in the complete **valorization of seeds**, including using the **seed cake** (the byproduct after oil extraction) for animal feed, biofertilizers, and bioenergy. These **biorefining** approaches can help improve the economic viability of oil extraction processes and reduce waste (Okuthe, 2024).

1.1.4. Challenges and Limitations

While research on seed oil extraction has made progress, several challenges remain:

- **High Cost of Advanced Technologies**: Methods like supercritical CO_2 extraction require expensive equipment, limiting their use to **laboratory-scale research** rather than widespread commercial production.
- **Environmental Impact**: Solvent extraction, while efficient, has significant **environmental drawbacks** due to solvent use. More research is needed to develop **green extraction techniques** that are both efficient and sustainable.
- **Lack of Standardization**: There is currently no standardized **extraction protocol** for African pea seed oil, leading to **variations** in oil quality and yield across different regions and research settings.

Solvents for Extraction: Ethanol and Petroleum Ether

Ethanol

Ethanol is a colorless, volatile liquid with the chemical formula C_2H_5OH. It is widely used as a solvent, fuel additive, and in the production of alcoholic beverages (Saini et al,. 2018). It is miscible in water and organic compounds, highly inflammable with flash point of 13^{o}C

Effects of Ethanol on Oil Extraction

- Solvent Efficiency: Ethanol is effective in dissolving a range of polar and non-polar compounds, enhancing the extraction of valuable fatty acids from the seeds
- Reduction of Free Fatty Acids (FFA): Ethanol can help lower the FFA content in the extracted oil, improving its quality and making it suitable for biodiesel production
- Safety and Environmental Impact: Compared to more toxic solvents like n-hexane, ethanol is safer and more environmentally friendly, reducing health risks during extraction
- Yield: The oil yield may vary depending on the extraction conditions, such as temperature and time
- Quality: Ethanol-extracted oil may require further refining to remove impurities and improve stability.

Petroleum Ether

- Petroleum Ether is a volatile, flammable and colorless mixture of liquid hydrocarbons derived from petroleum refining. It consists of low molecular weight aliphatic hydrocarbons, with a boiling point and specific gravity range of 30-60 °C and 0.6 to 0.8 respectively indicating that it is lighter than water. It is commonly used as a nonpolar solvent in laboratories and for extracting compounds in various applications, including oil extraction and fat analysis. Petroleum ether is not an ether in the chemical sense; it lacks the ether functional group (-O-) present in true ethers.

2.0 Materials and methods

The African Pea Seeds (APS) were collected from a farmer at Awka, Anambra State, Nigeria. The endosperm and the skin coats were peeled out and the kernels washed and sun dried. After sun drying to reduce the moisture content to about 13%, the seeds were oven dried for 1 hour at 65°C. The dried seeds were milled with electric grinder and sieved using standard sieve plates into 3 different average standard particle sizes (0.15mm, 0.3mm and 0.45mm). These samples were stored at room temperature (Ajali and Emembolu, 2024). Ethanol was used as solvent in a Soxhlet apparatus for the extraction of the seed oil. A ratio of 10g of the solute (seed samples) to 100ml of the solvent was used for each run. The oil was separated from the solvent and concentrated using a simple distillation apparatus. The process was repeated for different size particles, temperature and extraction time according to the experimental matrix. The same procedure was also followed using petroleum ether as solvent.

$$Oil\ Yield\ (\%) = \frac{weight\ of\ extracted\ oil\ (g)}{weight\ of\ sample}\ x\ 100 \qquad (1)$$

3.0 Result and Discussion

1.1.5. 3.1 Response Surface Methodology

Factor	Name	Units	Minimum	Maximum	Coded Low	Coded High	Mean	Std. Dev.
A	Particle Size	mm	0.1305	0.4695	-1 ↔ 0.15	+1 ↔ 0.45	0.3000	0.1118
B	Temp	^{o}C	37.40	82.60	-1 ↔ 40.00	+1 ↔ 80.00	60.00	14.91
C	Time	min	56.10	123.90	-1 ↔ 60.00	+1 ↔ 120.00	90.00	22.36

Table 3: Experimental results of oil extraction using different solvents

	Factors			Response (%) Yield	
Runs	**Particle size (mm)**	**Temperature (°C)**	**Time (mins)**	**Ethanol**	**Petroleum Ether**
1	0.15	40	60.0	2.0	3.2
2	0.45	40	60.0	1.4	13.2
3	0.15	80	60.0	2.8	8.0
4	0.45	80	60.0	1.4	7.0
5	0.15	40	120.0	4.0	10.0
6	0.45	40	120.0	3.0	18.4
7	0.15	80	120.0	5.0	15.0
8	0.45	80	120.0	2.9	12.0
9	0.13	60	90.0	5.0	10.0
10	0.47	60	90.0	3.8	10.0
11	0.30	37.4	90.0	1.0	11.3
12	0.30	82.6	90.0	1.3	9.0
13	0.30	60	56.1	5.6	13.2
14	0.30	60	123.9	6.0	10.4
15	0.30	60	90.0	3.8	8.0
16	0.30	60	90.0	2.8	7.5
17	0.30	60	90.0	3.8	8.0
18	0.30	60	90.0	2.8	7.5
19	0.30	60	90.0	2.8	7.5
20	0.30	60	90.0	3.8	8.0

1.1.6. Table 4: Fit Summary for Petroleum Ether Yield

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.7759	0.0005	-0.1105	-0.7243	
2FI	0.0958	0.0007	0.1470	-2.1757	
Quadratic	**< 0.0001**	**0.1301**	**0.9143**	**0.7452**	**Suggested**
Cubic	0.2991	0.0824	0.9298	-6.9967	**Aliased**

1.1.7. Table 5: Fit Summary for Ethanol Yield

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.1004	0.0249	0.1871	-0.0275	
2FI	0.9000	0.0147	0.0419	-0.2475	
Quadratic	**< 0.0001**	**0.6474**	**0.8571**	**0.7822**	**Suggested**
Cubic	0.9937	0.1328	0.7698	-20.2244	**Aliased**

1.1.8. Table 6: Sequential Model Sum of Squares for Petroleum Ether Yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	2244.23	1	2244.23			
Linear vs Mean	8.79	3	2.93	0.3697	0.7759	
2FI vs Linear	47.65	3	15.88	2.61	0.0958	
Quadratic vs 2FI	**72.99**	**3**	**24.33**	**39.78**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	3.11	4	0.7783	1.55	0.2991	Aliased
Residual	3.00	6	0.5006			
Total	2379.77	20	118.99			

1.1.9. Table 7: Sequential Model Sum of Squares [Type I] Ethanol Yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	206.79	1	206.79			
Linear vs Mean	10.70	3	3.57	2.46	0.1004	
2FI vs Linear	0.9845	3	0.3282	0.1919	0.9000	
Quadratic vs 2FI	**19.68**	**3**	**6.56**	**25.73**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	0.0845	4	0.0211	0.0514	0.9937	Aliased
Residual	2.47	6	0.4109			
Total	240.71	20	12.04			

1.1.10. *From the results above, the quadratic model is suggested as the best fit based on the sequential p-values are given as <0.0001 for both petroleum ether and ethanol yield. This implies that the p-value falls within the limit of acceptance.*

1.1.11. Table 8: ANOVA for Quadratic model for Petroleum Ether Yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	129.42	9	14.38	23.51	< 0.0001	significant
A-Particle Size	0.0256	1	0.0256	0.0419	0.8419	
B-Temp	3.42	1	3.42	5.59	0.0396	
C-Time	5.34	1	5.34	8.73	0.0144	
AB	24.36	1	24.36	39.83	< 0.0001	
AC	5.35	1	5.35	8.74	0.0144	
BC	17.94	1	17.94	29.33	0.0003	
A^2	4.69	1	4.69	7.66	0.0199	
B^2	23.28	1	23.28	38.05	0.0001	
C^2	4.62	1	4.62	7.55	0.0206	
Residual	6.12	10	0.6117			
Lack of Fit	4.57	5	0.9137	2.95	0.1301	not significant
Pure Error	1.55	5	0.3097			
Cor Total	135.54	19				

1.1.12. Table 9: ANOVA for Quadratic model for Ethanol Yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	31.37	9	3.49	13.67	0.0002	Significant
A-Particle Size	3.46	1	3.46	13.58	0.0042	
B-Temp	0.2514	1	0.2514	0.9860	0.3441	
C-Time	6.98	1	6.98	27.38	0.0004	
AB	0.6670	1	0.6670	2.62	0.1369	
AC	0.2850	1	0.2850	1.12	0.3153	
BC	0.0325	1	0.0325	0.1275	0.7285	
A^2	0.8691	1	0.8691	3.41	0.0946	
B^2	18.55	1	18.55	72.73	< 0.0001	
C^2	5.30	1	5.30	20.79	0.0010	
Residual	2.55	10	0.2550			
Lack of Fit	1.05	5	0.2100	0.7001	0.6474	not significant
Pure Error	1.50	5	0.3000			
Cor Total	33.92	19				

The **F-values** of 23.51 and 13.67 for petroleum ether and ethanol respectively imply that the models are significant. There is only a 0.01% and 0.02% chance that an F-value this large could occur due to noise for petroleum ether and ethanol respectively. **P-values** less than 0.0500 indicate model terms are significant. For petroleum ether B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms while A, C, B^2, C^2 are significant model terms for ethanol. This is in agreement with the observation of Ogwor et al., (2025) and Kadir and Mekonnen, (2025) in their works. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may be appropriate. The **Lack of Fit F-value** of 2.95 and 0.70 for petroleum ether and ethanol respectively implies that the Lack of Fit is not significant relative to the pure error for the both. This result is supported by Genene, (2024) and Ajali et al., (2026). There is a 13.01% and 64.74% chance that a Lack of Fit F-value this large could occur due to noise for petroleum ether and ethanol respectively. Non-significant lack of fit is good -- we want the model to fit.

The predicted and adjusted R^2 values were in reasonable agreement as their difference was less than 2 for both operations. The predicted and adjusted R^2 values are 0.7452 and 0.9143 respectively for petroleum ether and 0.7822 and 0.8571 respectively for ethanol. **Adeq Precision** measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 14.121 and 14.545 for petroleum ether and ethanol respectively indicates adequate signal. This model can be used to navigate the design space. These statistical data show that petroleum ether is more effective than ethanol in the extraction of pea seed oil as also reflected by their yield of oil in table 2.

1.1.13. Final Equation in Terms of Coded Factors for Petroleum Ether

$$Y_{Pet.Ether} = 8.25 + 0.05 * A + -0.57 * B + 0.71 * C + -1.75 * AB + 0.82 * AC + 1.50 * BC + 1.05 * A^2 + 2.34 * B^2 + 1.04 * C^2 \quad (2)$$

Eliminating all insignificant factors, the equation becomes;

$$Y_{Pet.Ether} = 8.25 + -0.57 * B + 0.71 * C \; -1.75 * AB + 0.82 * AC + 1.50 * BC + 1.05 * A^2 + 2.34 * B^2 + 1.04 * C^2 \quad (3)$$

1.1.14. Final Equation in Terms of Coded Factors for Ethanol Yield

$$Y_{Ethanol} = 3.49 + -0.57 * A + 0.15 * B + 0.81 * C + -0.29 * AB + -0.19 * AC + 0.06 * BC + 0.45 * A^2 + -2.09 * B^2 + 1.12 * C^2 \quad (4)$$

For the final equation, eliminating all insignificant factors, we have:

$$Y_{Ethanol} = 3.49 + -0.57 * A + 0.81 * C -2.09 * B^2 + 1.12 * C^2 \quad (5)$$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

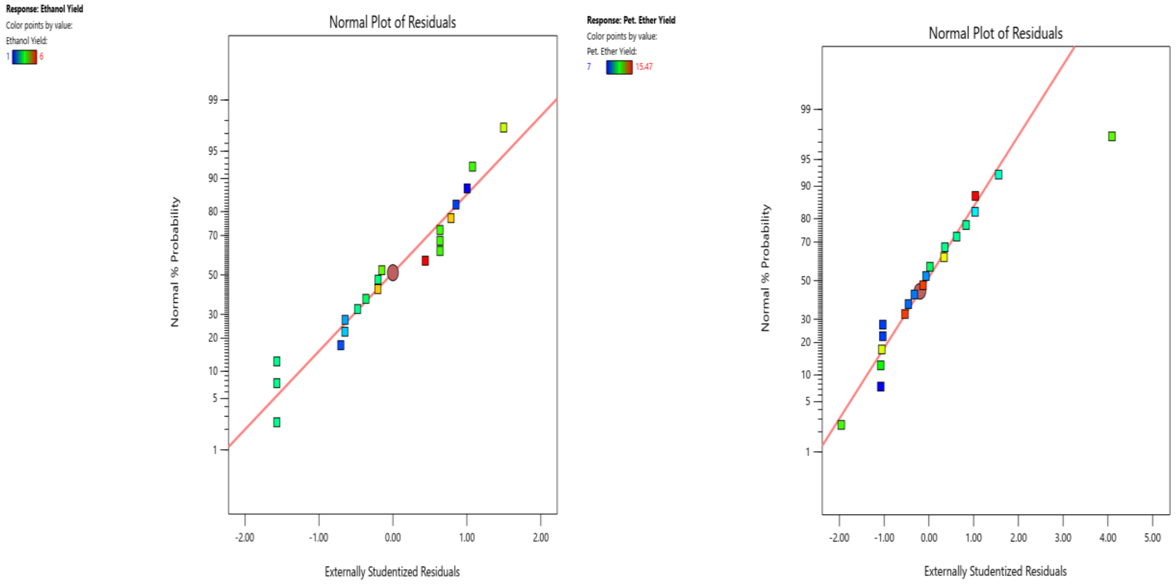

Fig 1: Normal plot of Residual for ethanol and petroleum ether

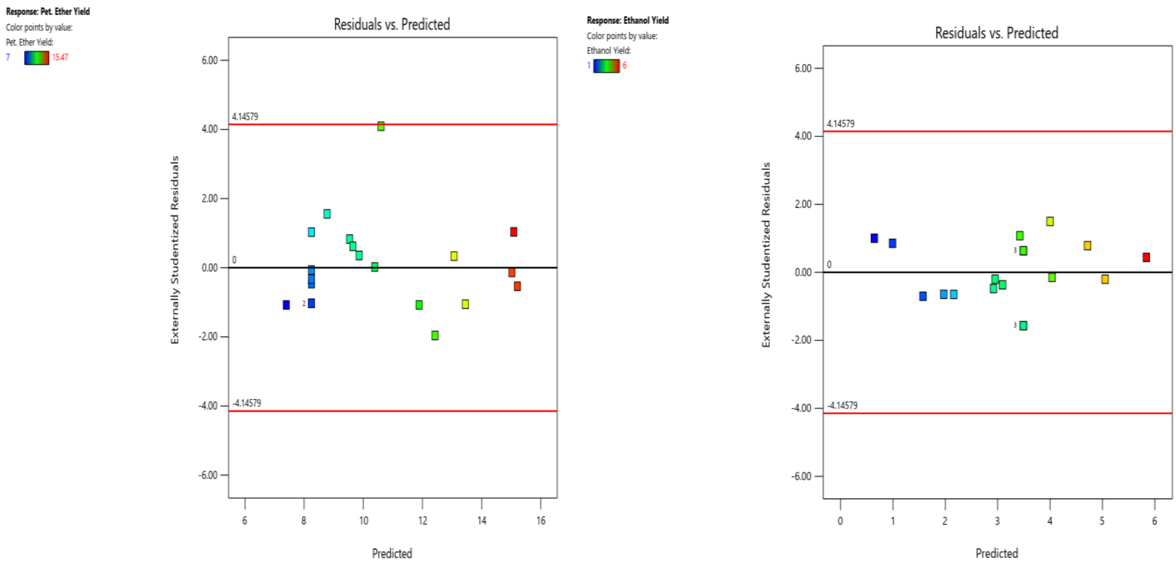

Fig 2: Residuals vs Predicted values for petroleum ether and ethanol

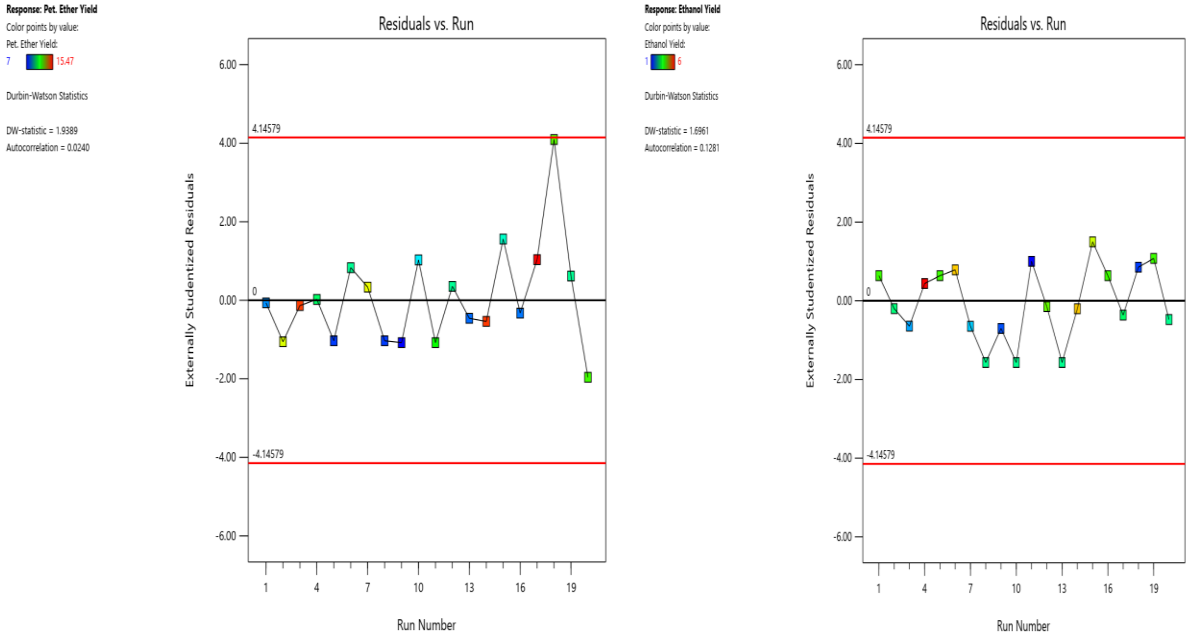

Fig 3: Residuals vs Number of Runs for petroleum ether and ethanol

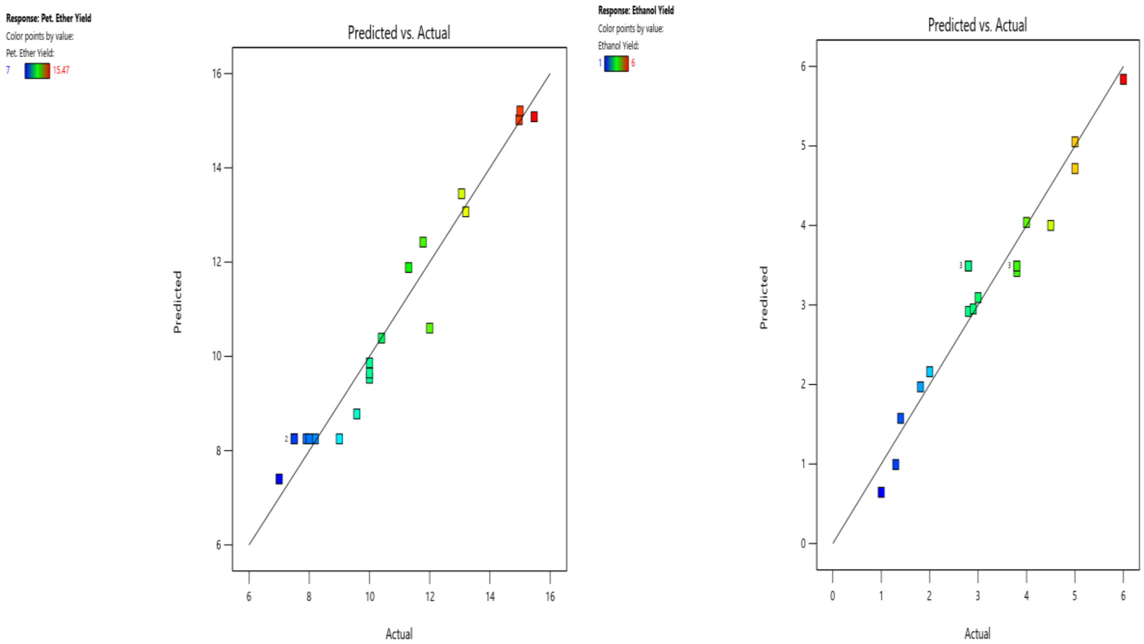

Fig 4: Predicted vs Actual for petroleum ether and ethanol

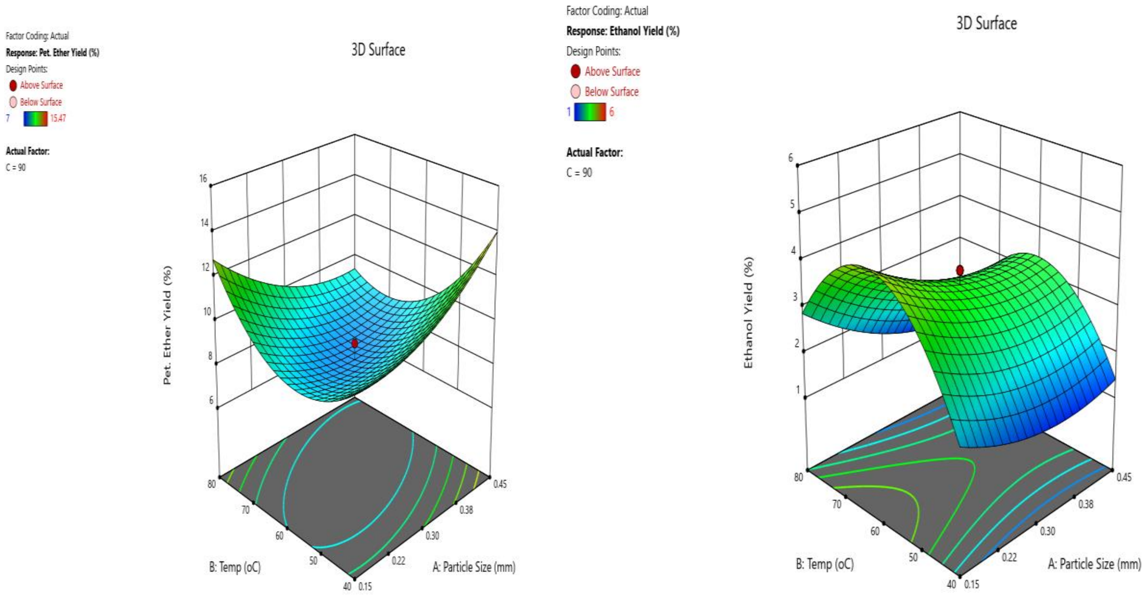

Fig 5: 3D surface diagram petroleum ether and Ethanol when Time is the actual factor

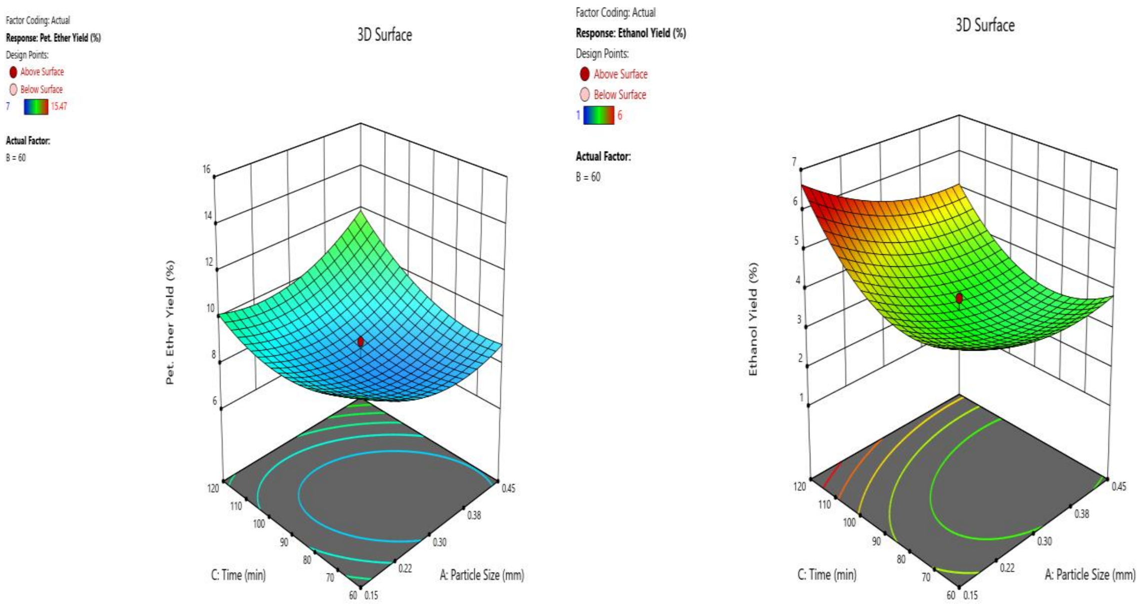

Fig 6: 3D surface diagram petroleum ether and Ethanol when Temperature is the actual factor

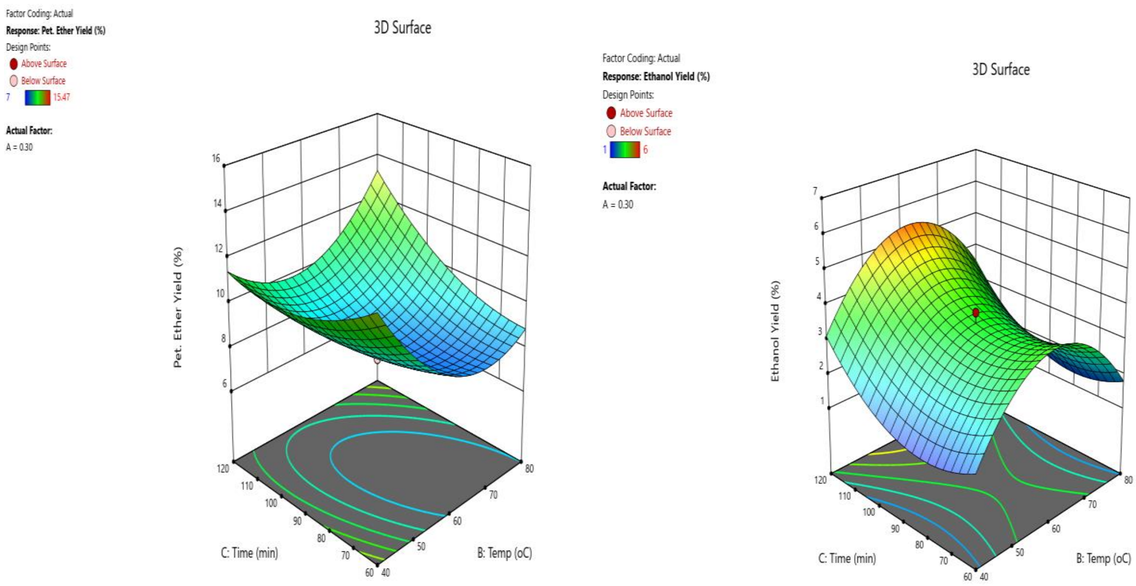

Fig 7: 3D surface diagram petroleum ether and Ethanol when actual factor is Particle Size

3.2 Discussion of the response surface methodology results

Factors and responses**:** The experiment investigated the impact of three factors: particle size (A), temperature (B), and time (C) on oil yield for each solvent used— Ethanol, and Petroleum ether. These factors were varied across minimum and maximum ranges.

- Model Summary: Quadratic model is suggested for both petroleum ether and ethanol with adjusted R^2 of 0.9143 and 0.8571 and predicted R^2 of 0.7452 and 0.7822 respectively. These values indicate good agreement between the predicted and observed values. Ogwor et al., (2025) and Chen et al., (2022) in their works confirmed this result.
- Significant Terms: Temperature (B), time (C), and interaction terms (AB, AC, BC) are significant for petroleum ether extraction. The interactions between factors have a pronounced effect, particularly the AB interaction, which suggests that particle size and temperature together significantly affect the yield. However, Particle size (A), time (C), and squared terms (B^2 and C^2) are significant in affecting ethanol extraction yield. Time (C) has the most substantial effect (F-value of 27.38), meaning the longer the extraction time, the higher the yield for ethanol as solvent (figures 5-7). Similar result has been demonstrated by Kedir and Mekonnen, (2025), Ogwor et al., (2025) and Ajali et al., (2026).
- Interpretation of ANOVA: The models for petroleum ether and ethanol have F-values of 23.51 and 13.67 respectively, indicating highly significant for petroleum ether and significant for ethanol in predicting oil yield. This result is in line with the report of Kumar et al., (2025). Their Lack of Fit is not significant with ($p = 0.1301$ and 0.6474 respectively), which again suggests a good model fit for the both. This is in agreement with the works of Kedir and Mekonnen, (2025) and Genene, (2024).
- Conclusion**:** Petroleum ether shows good extraction performance, especially with a longer extraction time and high temperature, making it a better and more viable option for oil extraction than ethanol under similar conditions.
- Ethanol is effective in extracting oil, especially when the extraction time is extended. However, it shows a lower yield predictability compared to petroleum ether due to its lower R^2 values.

4.0. Conclusion

The extraction variables for APSO using ethanol and petroleum ether were optimized using response surface methodology. Prominent variables to determine the response values were the effects of particle size, temperature, extraction time and solvent used on the value of oil yield. The optimal conditions: particle size, temperature and extraction time, were recorded at 0.3 mm, 60 oC and 123.9 min respectively for ethanol and 0.45 mm, 40 oC and 120 min respectively for petroleum ether. The highest oil yield was 6% for ethanol and 18.4% for petroleum ether.

Based on the RSM results, petroleum ether is the more effective solvent for oil extraction from pea seeds using Soxhlet extraction. It has the high predictability and yield when the extraction is carried out at high temperatures and longer times. Petroleum ether was consistent and efficient. Petroleum ether extracted both non-polar and polar compounds, with possible enhanced solubility for certain esters and alcohols, making the solvent suitable for a specific applications.

The extraction of oil from African pea seeds (Dacryodes edulis) with its inherent characteristics present a significant opportunity for developing sustainable biofuels feedstock, particularly in the context of the global energy crisis faced by the aviation industry, and this cannot be overemphasized. This work therefore offers opportunity for industrial production of APSO having determined the optimal conditions of extraction and recommend for further research on other possible non-edible seed oils as bio-aviation feedstock.

References

Adegbe, A. A., Larayetan, R. A., & Omojuwa, T. J. 2016. Proximate analysis, physicochemical properties and chemical constituents characterisation of *Moringa oleifera* (Moringaceae) seed oil using GC-MS analysis. *American Journal of Chemistry*, *6*(2), 23–28. https://doi.org/10.5923/j.chemistry.20160602.01

Adipah, S. 2018. Introduction of biodiesel as a sustainable resource. *Journal of Environmental Science and Public Health*, *3*(1), 99–103.

Agbo, N. J. 2024. Comparative nutritional and mineral analysis of fermented *Pentaclethra macrophylla* (African oil bean) seeds. *FUDMA Journal of Sciences*. https://doi.org/10.33003/fjs-2024-0803-2351

Aguoma, C. C., Egbulefu, A. V. I., O., Chudi, O. P. A., Christian, I. O. and Obiora, A. I. 2023. A comparative study of transesterification of hydnocapus weightiana seed oil using calcined and acid activated natural heterogeneous catalyst and its kinetic study. American Journal of AnalyticalChemistry. 14(4), 202-227. https://doi.org/10.4236/ajac.2023.144012.

Agwu, O. P., Akinyele, A. O., and Aduradola, A. M. 2017. Agroforestry potential of decryodes edulis (G. Don) HJ Lam: A tool for agro industry innovation in South West Nigeria. Journal of Agricultural Science and Food Research, 8(4) 190

Ajali, J. J., Nwabanne,J. T., Igbokwe, P. K. 2026. Statistical analysis of African pea seed oil extraction using N-hexane. Sustainable Development Research, 8(1), 36. https://doi.org/10.30560/sdr.v8n1p36

Ajali, J. J., & Emembolu, L. N. 2024. Comparative analysis of solvent extraction of rice brain oil from various sources. *European Journal of Sustainable Development Research*, *8*(1), em0243. https://doi.org/10.29333/ejosdr/13891

Ajali, J. J. O., Ikezue, E. N., & Ezeugo, J. N. O. 2022. Kinetic modelling of biopreservation of mango fruit juice using *Murraya koenigii* Sprenge. *World Scientific News*, (*170*), 46–68.

Akpan, U. E., and Achugasim, O. 2024. Pour point depression of waxy crude oil using unmodified African pear (Dacryodes edulis) seed oil. Asian Journal of Applied Chemistry Research, 15(4), 250-259.

Akpan, U. I., Akpabio, U. D., Owhoeke, E., and Ekpo, I. E. 2021. Biodiesel synthesis from African pear (Dacryodes edulis) oil using catalyst assisted transesterification process. World Journal of Applied Chemistry, 5(4).

Alalwan, H.A.,Alminshid, AH, and Aljaafari, H.A.S.2019. Promising evolution of biofuel generations. Subject review. Renew Energy Focus 28, 127139doi:10.1016/j.ref2018.12006.

Asanja, J. A., Simon, N., and Akpan, S. E. 2023. Physicochemical and nutritional characterization of seed oil from Dacryodes edulis (African Pear). BIMA Journal of Science and Technology, 7(2), 136-142.

Baroutaji, A., Wilberforce, T., Ramadan, N., & Olabi, A. G. 2019. Comprehensive investigation on hydrogen and fuel cell technology in the aviation and aerospace sectors. *Renewable and Sustainable Energy Reviews*, *106*, 31–40. https://doi.org/10.1016/j.rser.2019.02.022

Chen, X., Li, Z., Smith, S. A., Chen, M., Liu, H., Zhang, J., Tang, L., Li, J., Liu, Q., & Wu, X. 2022. Optimization of supercritical CO2 extraction of *Moringa oleifera* seed oil using response surface methodological approach and its antioxidant activity. *Frontiers in Nutrition*, *8*, 829146. https://doi.org/10.3389/fnut.2021.829146

Durrett, T. P., Benning, C., and Ohlrogge, J. 2018. Plant Triacylglycerols as Feedstocks for the Production of Biofuels. Plant J. 54, 593–607. Doi:10.1111/j.1365-313x.2008.03442.x.

Ene-Obong, H., Igile, G., Ekpo, A., Egbung, E., Agbo, M. 2019. Variations in the nutrients and bioactive compounds of different accessions of the West African pear (Dacryodes edulis): Implications for dietary intake assessment and health. Journal of Food Composition and Analysis, 79, 80-86. https://doi.org/10.1016/j.jfca.2019.03.005

Fu, J., Summers, S., Morgan, T. J., Turn, S. Q., & Kusch, W. 2021. Fuel properties of Pongamia (*Millettia pinnata*) seeds and pods grown in Hawaii. *ACS Omega*, *6*(13), 9222–9233. https://doi.org/10.1021/acsomega.1c00511

Genene, D. 2024. Extraction of oil from *Azadirachta indica* and *Moringa stenopetala* seeds and evaluation of its physicochemical properties. *Manas Journal of Engineering*, *12*(2), 163–176. https://doi.org/10.51354/mjen.1377816

John, S. U., Ezechukwu, M. C., Onyenanu, C. N., Ejiofor, C. C., John, M. C., & Ajali, J. J. 2024. Catalytic processes for sustainable aviation fuel production in biorefineries. *International Multidisciplinary Research Journal Reviews*, *1*(4), 38–50. https://doi.org/10.17148/IMRJR.2024.010404

Kassi ABB, Soro Y, Koffi NE, Sorho S. 2019. Physicochemical study of kernel oils from ten varieties of Mangifera indica (Anacardiaceae) cultivated in Cote d'Ivoire. African Journal of Food Science, 13(7): 135142.

Kedir, H. J., & Mekonnen, K. T. 2025. Experimental optimization of oil extraction from Moringa seed by using application of response surface methodology (RSM). *Discover Chemistry*, *2*, 358. https://doi.org/10.1007/s44371-025-00410-w

Kumar, S., Rai, A., & Prasad, K. 2025. Optimization and multifactor assessments of supercritical *Moringa oleifera* seed oil extraction. *Journal of Food Measurement and Characterization*, *19*(3), 1586–1602. https://doi.org/10.1007/s11694-024-03045-0

Lavenburg, V.M., Rosentrater, K. A., and Jung, S. 2021. Extraction Methods of oils and Phytochemicals from seeds and their Environmental and Economic Impacts. Processes, 9 (10), 1893.

Madaminova, Z., Khamdamov, A., and Xudayberdiyev, A. 2024. Preparing peach seed for oil extraction and improving oil extraction through pressing. Scientific and Technical Journal of Namangan Institute of Engineering and Technology, 9(4), 154–161.

Maestri, D., Cittadini, M. C., Bodoira, R., Martínez, M., 2020. Tree nut oils: chemical profiles, extraction, stability, and quality concerns. European Journal of Lipid Science and Technology. 122: 1-14.

Melillo, J., Reilly, J., Kickligher, D., Gurgel, A., Cronin, T., Paltsev, S., Felzer, B., Wang, X., Sokolov, A., and Schlosser. C. A. 2021. "Indirect Emissions from Biofuels: How Important?" Science, 326 (5958): 1397-1399.

Midhun, J., Stephi, D., Muthamil Selvi, Kameshwari, Y. Swatika, S. K., and Sunil, C. K. 2023. Effect of emerging pretreatment methods on extraction and quality of edible oils: A review. Food and Humanity, 1, 1511-1522.

Musa, S. H., Alhassan, A. S., Ahmed, U. A., Magami, S. M., and Ahmad, Y. M. 2023. Recent advances in seed oil extraction science: A review. Journal of Applied Chemical Science International, 14(2), 28–34.

Nozari, B., and Kander, R. 2025. Upercritical CO_2 technology for biomass extraction: Review. Industrial Crops and Products, 233,121348. https://doi.org/10.1016/j.indcrop.2025.121348

Obianom, A. O., Odibo, F. J. C., & Iheukwumere, I. H. 2024. Nutritive and phytate contents of raw and fermented African oil bean seeds. *International Journal of Research and Innovation in Applied Science, 9*(5), 410–420. https://doi.org/10.51584/IJRIAS.2024.905036.

Ogwor, O. E., Onukwuli, O. D., Ude, C. N., Elvis, E., & Ochuko, U. G. 2025. African oil bean seed oil biodiesel optimization production via the technique of response surface methodology-genetic algorithm (RSM-GA) and RSM. *Applied Science and Engineering Journal for Advanced Research*, *4*(3), 39–49. https://doi.org/10.5281/zenodo.150

Okuthe, G. 2024. Valorizing fruit and vegetable waste: The untapped potential for entrepreneurship in Sub-Sahara Africa- A systematic review. Recycling, 9(3), 40. https://doi.org/10.3390/recycling9030040.

Onoji, S. E., EIyuke, S., Igbafe, A. I., and Nkazi, D. B. 2016. Rubber seed oil: a potential renewable source of biodiesel for sustainable development in sub Saharan Africa. Energy Convers. Manag.110, 125-134. doi:10.1016/j.enconman.2015.12.002.

Onwuzuruike, U. A., Inyang, U. E., Edima-Nyah, A. P., Victoria, O. A., & Ugochi, E. A. 2024. Oil yield, physicochemical properties, fatty acid profile and nutritional value of oils from different varieties of African oil bean (*Pentaclethra macrophylla*) seeds. *Journal of Food Technology and Preservation*, *6*(2), 160.

Saini, R. K., & Keum, Y. S. (2018). Carotenoid extraction methods: A review of recent developments. *Food Chemistry*, *240*, 90–103. https://doi.org/10.1016/j.foodchem.2017.07.099

Thilakarathna, R. C. N., Siow, L. F., Tang, T. K., and Lee, Y. Y. 2023. A review on application of ultrasound and ultrasound assisted technology for seed oil extraction. Journal of Food Science and Technology, 60, 1222–1236.

Veljković, V. B., Biberdžić, M. O., Banković-Ilić, I. B., Djalović, I. G., Tasić, M. B., Nježić, Z. B., et al. 2018. Biodiesel Production from Corn Oil: a Review. Renew. Sustain. Energ. Rev. 91, 531–548. Doi:10.1016/j.rser.2018.04.02