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Extraction and Characterization of Palm Kernel Oil from African oil palm (*Elaeis guineensis*) as a Biodiesel Feedstock in Sudan

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Abstract

This study aims to identify a sustainable source of energy from natural and environmentally friendly resources. Crude palm kernel oil (CPKO) was extracted from kernel of African oil palm (*Elais Guineensis*) by two chemical extraction methods; soxhlet extraction and cold solvent extraction; yields % were found 40.98% and 34% respectively. The physiochemical properties of extracted oil were evaluated and results showed that its color (Golden Yellow), refractive index was 1.477, density at 15 ºC was 0.80343g/cm^3, Kinematic viscosity at 40 ºC was 25.13 cSt, cloud point was 31 ºC, pour point was 21 ºC, free fatty acid was 2.60%, acid value was 5.20 mg KOH g^{-1}, peroxide value was 7.30 mEq kg^{-1}, iodine value was 18.23 mg g-^{1}, saponification value was 216.11mg/KOH g^{-1}and water content was 0.0329%. The fatty Acid compositions were determined using GC-MS. The results showed the dominant fatty acids were lauric acid, myristic acid and Oleic acid in which represent of 39.18%, 20.24%, and 18.82% respectively.

Keywords: Sustainable Source, Environmentally Friendly, Palm Kernel Oil, Chemical Extraction, Physiochemical Properties, Fatty Acid Composition.

INTRODUCTION

The palm family (Arecaceae) is the third most economically important plant family (Le W *et al*., 2022). The African oil palm (*Elaeis guineensis*) is one of the most significant palm species (Denis J *et al*., 2021). It's believed to have originated in Africa in the tropical rainforest region of West Africa (Farhatun M *et al*., 2020). Now cultivated extensively in Southeast Asia especially in Malaysia and Indonesia (Ardha A *et al*., 2022) and expanded worldwide due to its multipurpose tree (Panugalla R *et al*., 2022) such as food and feed production and biotechnological applications (Philipp G *et al*., 2021).

African oil palm fruits contain two types of oil, namely palm oil; extracted from the mesocarp, and palm kernel oil; extracted from the kernel (Melvia S *et al*., 2022). The fatty acid composition for two oils are different; the major fatty acids of the crude palm oil are palmitic acid, oleic acid and linoleic acid. lauric acid is among fatty acids in crude palm kernel oil (Philipp G *et al*., 2021). This difference in fatty acid composition means they are used for different industrial applications. Crude palm oil, with its high saturated fat content, is suitable for edible uses (Denis J *et al*., 2021) and also contains significant amounts of carotenoids, tocopherols, and tocotrienols (Niamketchi G *et al*., 2021). It's represented as one of the richest dietary sources of provitamin A and is thus used in programmes to prevent deficiency of vitamin A (Fabienne M *et al*., 2021). Palm kernel oil is a less dense product that is mostly used for non-edible applications (Denis J *et al*., 2021). It's used as a lubricant or biodiesel, food processing industries, cosmetics, pharmaceutical industries and traditional medicine (Charity A and George C, 2021).

The physiochemical properties of vegetable oils and their applications (edible or nonedible) are evaluated by their fatty acid composition. Vegetable oils are renewable resources to produce environment-friendly industrial products (Nair K, 2021). Palm oil and kernel oil have become major feedstocks for biodiesel production due to their favorable properties, including high energy content, low volatility, and excellent lubricity (Anetokhe M *et al*., 2023).

The present study aimed to evaluate the physiochemical properties and fatty acid composition of crude palm kernel oil to verify its suitability as a good source of environmentally friendly fuel which is biodiesel.

MATERIALS AND METHODS

Materials

African oil palm fruits were sourced from Khartoum State, Sudan. mesocarp and shells were removed, then the palm kernel nuts crashed into fine particles using electric mill. All chemicals used were analytical grade, GS-MS-QP2010SE (SHIMADZU, Japan).

Methods

Oil Extraction

The extraction of palm kernel oil was done with two chemical extraction methods were Soxhlet extraction and cold solvent extraction. In Soxhlet extraction system; crashed sample were kept in sample paper thimble. N-Hexane was kept in the soxhlet round bottom flask. The condenser was fitted and connected to the cooling system, heated to 60 °C for 8 hours; n-hexane was removed from oil using rotary evaporator. The yield% of extracted oil was calculated (AOAC, 2000). In cold solvent extraction method; crashed sample were placed in 1liter beaker, n-hexane was added, and then kept for 24 hours at room temperature under steering at1000 rpm, after which the resulting solution was filtered using filter paper, n-hexane was removed from filtrate using rotary evaporator. The yield % of extracted oil was calculated (Abiodun A *et al*., 2014).

Fatty Acids Profile of Crude Palm Kernel Oil

Fatty acids composition of crude palm kernel oil was determined using a (GC/ MSQP2010SE, Shimadzu Japan), equipped with capillary colum (Rtx-5MS-30m×0. 25mmI.D×0.25µm). The sample was injected by using split mode, helium was used as carrier gas with flow rate (1.6 mL/ min). The oven temperature was programmed from 60° C to300° C at 10° C/ min. The sample was analyzed using the scan mode in the range of m/z 40-500; the total run time was 24 minutes. The identification of the peaks characteristic and composition of crude palm kernel oil achieved by retention times by means of comparing them database of spectrum of known components stored in the GC-MS library (Aiman A *et al*., 2017).

Determination of Physiochemical Properties of Crude Palm Kernel Oil

The physiochemical properties of extracted oil include free fatty acid, acid value, peroxide value, iodine value, moisture content, saponification value were determined according to (AOAC, 2000) methods. Refractive index, density at 15ºC, Kinematic viscosity at 40 ºC, color, cloud point and pour point were determined according to ASTM methods and results shown in Table 3.

RESULTS AND DISCUSSION

Oil Extraction

Table 1 shows the comparison between extraction methods which proving that Soxhlet solvent extraction method having the higher efficiency of oil extraction than cold solvent extraction method.

Table 1: Yields % of extracted oil using two chemicals extraction methods

No.	Extraction method	Oil yield %
1	Soxhlet extraction	40.98
2	Cold solvent extraction	34.00

The oil content plays a crucial role in determining the suitability of plant seeds as potential feedstock for biodiesel production (Akuzuo *et al*., 2019). This high oil content of palm kernel oil, indicates its suitability as feedstock in oleochemical industries such as biodiesel.

Fatty Acid Profile of Crude Palm Kernel Oil

Table 2 shows the Fatty acids composition of crude palm kernel oil. CPKO is composed of three major acids, lauric acid, myristic acid and Oleic acid in which represent of 39.18%, 20.24%, and 18.82% respectively of the total fatty acids. The percentage of saturated fatty acids (SFA) according to these results corresponds to higher than the unsaturated fatty acids.

Table 2: Fatty acids composition of crude palm kernel oil

Fatty Acids	Molecular Formula	Area %
Caproic acid (C6, n=0)	$C_6H_{12}O_2$	0.24
Caprylic acid (C8, n = 0)	$C_8H_{16}O_2$	2.45
Capric acid (C10, n = 0)	$C_{10}H_{20}O_2$	2.58
Lauric acid (C12, n = 0)	$C_{12}H_{24}O_2$	39.18
Myristic acid (C14, n = 0)	$C_{14}H_{28}O_2$	20.24
Palmitic acid (C16, n = 0)	$C_{16}H_{32}O_2$	11.96
Linoleic acid (C18, n = 2)	$C_{18}H_{30}O_2$	1.36
Oleic acid (C18, n = 1)	$C_{18}H_{34}O_2$	18.82
Stearic acid (C18, n = 0)	$C_{18}H_{36}O_2$	2.43

cis11Eicosenoic acid (C20, n =1)	$C_{20}H_{38}O_2$	0.21
others		0.52

C = No of Carbon Present, n = no of Double Bonds

The high amount of SFA in CPKO makes it suitable in industry, such as soap, lubricants and cosmetics. In contrast the low amount of unsaturated fatty acids in CPKO makes it less sensitive to oxidation (Niamketchi *et a*l., 2021). Biodiesel derived from feedstock oil with a high saturated fatty acid content tends to have a higher cetane number. The cetane number measures a fuel's ability to ignite quickly after injection, with higher values leading to better emissions. This parameter is crucial when selecting fatty acid alkyl esters for use as biodiesel (Chanida L *et al*., 2015).

Physiochemical Properties of Crude Palm Kernel Oil

The physiochemical properties of feedstock oil are influence on the biodiesel production process and important factor for quality of biodiesel produced (R. Sakthivela *et al*., 2018). The physiochemical properties of CPKO were determined and the results are shown in Table 3. The CPKO appears as a golden yellow, semi solid at room temperature. The refractive index of oil reflects the possible occurrence of rancidity development. It is mostly used as a quality control measure to assess the purity of the oil. A higher refractive index indicates an increased probability of spoilage due to oxidation (Osahon K *et al*., 2022). Refractive index of CPKO was found 1.477 which is close to 1.409 of palm kernel oil in another study reported by (Charity and George, 2023). Density is an important parameter for oil used in diesel fuel injection systems, as high density can result in incomplete combustion (ketema B *et al*., 2022). The density of CPKO at 15 ºC was 0.8034 g/cm^3 less than of *jatropha* oil and neem oil which were founded 0.9133g/cm^3 and 0.875g/cm^3 respectively (Amiera H *et al*., 2022), (ketema B *et al*., 2022).

Table 3: Physiochemical properties of (CPKO) in comparison with other oils

Parameters	CPKO (This Study)	Palm kernel oil	Jatropha oil	Neem oil
Color	Golden yellow	-	-	-
Refractive index	1.477	1.409	-	-
Density at 15 ºC, g/cm3	0.8034	-	0.9133	0.875
Kinematic viscosity at 40 ºC, cSt	25.13	29.3	34.94	33.5
Cloud point, ºC	31	-	-	-
Pour point, ºC	21	-	-	-
Free fatty acids, %	2.60	2.555	-	-
Acid value, mg KOH g-1	5.20	5.11	36.5	1.81
Peroxide value, m Eq kg-1	7.30	5.988	-	-
Iodine Value, mg g-1	18.23	13.106	106.3	122.5
Saponification value, mg/KOH g-1	216.11	240.43	-	206.7
Moisture content, %	0.0329	0.91	0.30	4.61

Kinematic viscosity at 40 ºC of CPKO was found 25.13 cSt which is lower than 29.3 cSt of palm kernel oil reported by (Charity and George., 2023), *jatropha* oil and neem oil were found 34.94 cSt and 33.5 cSt respectively (Amiera H *et al*., 2022), (ketema B *et al*., 2022). However, high viscosity is a significant challenge that prevents the direct use of vegetable oils and animal fats in diesel engines, as it adversely affects fuel flow and spray characteristics (Johnson O *et al*., 2018).

The cold flow properties of biodiesel are influenced by chain length and saturation level, with long-chain saturated fatty acid esters performing poorly in low-temperature conditions (E. I. Bello *et al*., 2015). The cloud point is the temperature at which wax crystals start to form, making the oil appear cloudy, while the pour point is the lowest temperature at which the oil can still flow (Stella and Athanasios, 2013). Cloud point and pour point of studied sample were found 31 ºC and 20 ºC respectively.

In biodiesel production, feedstock oils with high levels of free fatty acids (FFAs) are not suitable for the alkaline transesterification process. This is because the alkaline catalyst reacts with FFAs, forming soap, which reduces biodiesel yield (Abdul Haq *et al*., 2023). The free fatty acids (FFAs%) value indicates the degree of oil degradation and its quality. Storage conditions and seed storage duration are key factors influencing FFAs levels (Abd Al-Wali J *et al*., 2017). Oils with low FFAs% are suitable for edible use, as they can be stored for extended periods without spoilage due to oxidative rancidity (Niamketchi G *et al*., 2017). FFAs% obtained of CPKO was 2.6% which is close to 2.555% of palm kernel oil determined by (Charity and George, 2023). The acid value of oil reflects the extent of spoilage in an oil sample, generally indicated by the presence of free fatty acids formed due to enzymatic hydrolysis (Osahon K *et al*., 2022). The acid value observed for the CPKO was 5.20 mg KOH g^{-1} which is close to 5.11 mg KOH g^{-1} of Palm kernel oil determined by (Charity and George, 2023).

The peroxide value represents the degree of oxidation and quality degradation of the oil (Niamketchi *et al*., 2021). Peroxide value of CPKO was found 7.3 meq/ kg^{-1}which is higher than of palm kernel oil determined by (Charity and George, 2023) which was founded 5.988 meq/ kg^{-1}. This value corresponded to normal Codex Alimentarius value which recommend a maximum peroxide value of 15 meq / kg^{-1} of fat. The iodine value is a measure of the presence of unsaturation in oils or in the fat (Osahon K *et al*., 2022). The value determined for the CPKO was 18.23 mg g^{-1}; this is a very low value which shows that the percentage of unsaturated and polyunsaturated fatty acids is low; hence the biodiesel produced would be having high oxidative resistance; thus, suitable for use as alternative fuel for diesel engines.

The saponification value (SV) estimates the degree of decomposition and oxidation of oils during storage (Abd Al-Wali J *et al*., 2017). The saponification value of CPKO (216.11 mg $KOHg^{-1}$) which is lower than of palm kernel oil studied by (Charity and George, 2023) which was founded 240.43 mg $KOHg^{-1}$.

The water content of CPKO was obtained 0.0329% less than of palm kernel oil reported by (Charity and George, 2023), *jatropha* oil and neem oil which were founded 0.91% and 0.30% and 4.61% respectively (Amiera H *et al*., 2022), (ketema B *et al*., 2022). In a diesel engine, high water content can cause corrosion and accelerate the hydrolysis of biodiesel, leading to the formation of fatty acids, which may contribute to the deterioration of engine components (Alexandre C *et al*., 2022). In contrast, low water content ensures storage stability and reduces engine corrosion (Amiera H *et al*., 2022).

CONCLUSION

From this study; the following conclusions can be drawn:

- Higher yield of extracted oil was gained from soxhlet solvent extraction and its higher efficiency than the cold extraction method.
- The results showed the dominant fatty acid was lauric acid (39.18%).
- The percentage of saturated fatty acids according to the results corresponds to higher than the unsaturated fatty acids.
- The physiochemical properties indicate the prospect of using of palm kernel oil as a promising raw material in various industrial fields, including biodiesel production, food industries and cosmetics.

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