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ORIGINAL RESEARCH ARTICLE

Comparative Analysis of Physicochemical and Thermophysical Properties of Palm Kernel Oil Extracted by Cold Press and Solvent Methods

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ABSTRACT

This study presents a comparative evaluation of the physicochemical and thermophysical properties of palm kernel oil (PKO) extracted via cold pressing (Sample C) and solvent extraction (Sample D), with all analyses conducted in triplicate (n = 3). Key parameters, including acid value, iodine value, peroxide value, saponification value, density, viscosity, refractive index, and thermal conductivity, were measured alongside GC-MS-based fatty acid profiling. The top three fatty acids identified in both samples were lauric acid (C12:0), myristic acid (C14:0), and oleic acid (C18:1), with respective percentages in cold-pressed oil (Sample C) being 48.6%, 16.3%, and 15.4%, and in solvent-extracted oil (Sample D) being 47.1%, 15.8%, and 16.0%. While the fatty acid distribution remained consistent, the solvent-extracted oil exhibited a more complex chromatographic fingerprint, containing additional volatiles, such as δ-dodecalactone, and exogenous contaminants, like bis(2-ethylhexyl) phthalate. Statistically significant differences ($p < 0.05$) were observed in oxidative stability, with peroxide values of 2.2 meq O_2/kg for Sample C and 3.0 meq O_2/kg for Sample D, indicating a higher susceptibility to lipid peroxidation in the latter. Thermal conductivity also differed significantly between the two samples, with values of 0.192 W/m·K for the cold-pressed oil and 0.187 W/m·K for the solvent-extracted oil. In summary, although solvent extraction enhanced yield and recovery of minor compounds, cold pressing yielded a purer oil with lower oxidative degradation and better thermal performance. Thus, extraction method selection should be tailored to the oil's end-use, favoring cold pressing for nutritional and cosmetic applications where purity and stability are paramount.

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cold pressing; lauric acid; myristic acid; and oleic acid

INTRODUCTION

Palm kernel oil (PKO), extracted from the seeds of *Elaeis guineensis*, is a versatile lauric oil valued for its high content of saturated fatty acids, primarily lauric (C12:0), myristic (C14:0), and oleic (C18:1) acids (Ezeh & Nwankwo, 2024). Its physicochemical resilience, extended shelf life, and favorable melting characteristics make it indispensable across diverse applications, including edible formulations, oleochemical processing, personal care products, and biodegradable lubricants (Yakubu & Mustapha, 2018; Durojaiye & Alabi, 2024). These functional properties have motivated substantial research into optimizing PKO extraction techniques to ensure a balance between oil quality and process efficiency (Aliyu et al., 2020; Ayodele & Obafemi, 2018).

Traditionally, mechanical cold pressing is employed where chemical purity and minimal thermal degradation are prioritized, as it circumvents excessive heat and solvent exposure that may otherwise alter the oil's intrinsic properties (Kolawole & Ogunniyi, 2012). In contrast, solvent extraction—commonly utilizing *n*-hexane dominates in large-scale industrial contexts due to its superior oil recovery rates and extraction efficiency (Alade et al., 2023). However, this method may introduce residual solvents and promote oxidative or structural degradation of bioactive constituents (Che Man & Tan, 2012), potentially compromising the oil's functionality and safety in food and cosmetic applications (Arifin et al., 2023)

Recent studies have extensively investigated the compositional profiling, oxidative stability, and quality indices of PKO derived from various extraction techniques (Hassan & Umar, 2014; Ezeh & Nwankwo,

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2024). However, despite increasing emphasis on thermal behavior for product formulation and stability analysis, comparative data on the thermophysical performance of cold-pressed versus solvent-extracted PKO remain limited. Notably, no comprehensive studies have employed both Differential Scanning Calorimetry (DSC) thermal transitions, such as crystallization and melting, and the Transient Plane Source (TPS) technique for thermal conductivity and diffusivity evaluation to systematically compare these two extraction approaches.

Therefore, this study aims to fill the knowledge gap by conducting an integrated analysis of the physicochemical and thermophysical properties of PKO extracted using cold pressing and solvent methods. The outcomes are expected to provide critical insights into how extraction pathways influence not only oil composition but also performance-relevant thermal properties—parameters essential for optimizing the use of PKO in thermal-sensitive formulations across food, pharmaceutical, and industrial domains.

STUDY DESIGN AND METHODOLOGY

This study used a laboratory-based comparative design to evaluate palm kernel oil extracted through two different methods: mechanical cold pressing and Soxhlet solvent extraction. All reagents employed were of analytical grade and obtained from certified suppliers. Determinations were performed in triplicate to ensure reproducibility and statistical validity. The procedures followed standard methodologies outlined by the Association of Official Analytical Chemists (AOAC, 2019) and the American Oil Chemists' Society (AOCS, 2017).

Key parameters evaluated included:

- Proximate composition (moisture, ash, crude protein, crude fat, crude fiber, and carbohydrate)
- Physicochemical properties (acid value, iodine value, peroxide value, saponification value, density, viscosity, and refractive index)
- GC-MS profiling of fatty acids and minor compounds

For proximate composition:

- **Moisture content** was determined by oven drying at 105 °C to constant weight.
- **Ash content** was assessed by incineration in a muffle furnace at 550 °C.
- **Crude protein** was measured using the Kjeldahl method, with nitrogen content converted using a factor of 6.25.
- **Crude fat** was determined by Soxhlet extraction using petroleum ether for 6 hours.
- **Crude fiber** was measured by sequential digestion with dilute acid and alkali.
- **Carbohydrate content** was calculated by difference.

All analytical instruments were calibrated prior to use, and proper quality assurance protocols (including blank and control analyses) were followed throughout the experimental process.

Sample Preparation

Sample C (cold-pressed oil) was obtained through mechanical expeller pressing without the application of external heat. Sample D (solvent-extracted oil) was prepared using Soxhlet extraction with *n*-hexane (boiling point: 68–70 °C) for 6 hours, followed by solvent removal via rotary evaporation. Both samples were derived from the same batch of palm kernels and stored in amber bottles at 4 °C to minimize photooxidation and thermal degradation (Ayodele & Obafemi, 2018; Alade et al., 2023).

Physicochemical Parameters

All physicochemical analyses followed standardized protocols from the AOAC (2019) and AOCS (2017) methods. Analytical replicates (n = 3) were averaged, and all glassware was acid-washed and rinsed with deionized water. Freshly prepared titrants, reagent blanks, and externally calibrated standard curves were used to validate analytical performance.

Acid Value (AV)

The acid value was determined by titrating a known mass (~2 g) of oil dissolved in 50 mL of a 1:1 mixture of ethanol and diethyl ether against 0.1 N KOH using phenolphthalein as an indicator (AOAC 940.28). The acid value was calculated using:

$$AV\left(\frac{mgKOH}{g}\right) = \frac{W \times V \times 56.1}{W} \text{ ----------(i)}$$

Where:

- V = volume of KOH used (mL)
- N = normality of KOH
- W = weight of oil sample (g)

Calibration: A blank titration (ethanol–ether only) was conducted, and a standard curve using oleic acid (0.01–0.10 g in 50 mL solvent) was plotted to validate KOH strength.

Iodine Value (IV)

The iodine value was measured using the Wijs method (AOAC 920.159). A known amount of oil (~0.2 g) was treated with 25 mL of Wijs reagent and incubated in the dark for 30 minutes, followed by reaction with 10 mL of 15% KI and titration with 0.1 N $Na_2S_2O_3$.

$$IV\left(g\ {}^{I_2}/_{100\ g\ Oil}\right) = \frac{(B-S) \times N \times 12.69}{W} \text{.....(ii)}$$

Where:

- B and S = volumes of thiosulfate used for blank and sample, respectively
- N = normality of $Na_2S_2O_3$

Calibration: A calibration curve was prepared using cyclohexene as a reference unsaturated compound (0.05–0.25 g).

Peroxide Value (PV)

PV was determined following AOAC 965.33. About 5 g of oil was dissolved in a 30 mL acetic acid–chloroform mixture (3:2 v/v), followed by the addition of 0.5 mL saturated KI and titration with 0.01 N $Na_2S_2O_3$ in the presence of starch indicator.

$$PV\ \left(meq\ {}^{O_2}/_{Kg}\right) = \frac{S \times N \times 1000}{W} \quad \text{(iii)}$$

Calibration: A curve was prepared using known amounts of potassium iodate (0.001–0.01 meq) in acidified media.

Saponification Value (SV)

SV was determined by refluxing 2 g of oil with 25 mL of 0.5 N ethanolic KOH for 1 hour (AOAC 920.160), followed by titration of the excess base with 0.5 N HCl.

$$SV\ \left(mg\ {}^{KOH}/_{g}\right) = \frac{(B-S)\times N\times 56.1}{W} \quad \text{(iv)}$$

Calibration: A curve was plotted using lauric acid (0.01–0.10 g) saponified under identical conditions.

Density

The density was determined gravimetrically by weighing 1 mL of oil using a 5 mL pycnometer at 25 °C and dividing by its volume (AOAC 969.18).

$$Density\ \left({}^{g}/_{cm^3}\right) = \frac{Mass\ of\ Oil}{1\ cm^3} \quad \textbf{(v)}$$

Calibration: Distilled water at 25 °C was used to calibrate the pycnometer (density = 0.997 g/cm³).

Viscosity

Dynamic viscosity was measured using a Brookfield rotational viscometer (Model DV2T) at 25 °C using spindle No. 3 at 100 rpm, following **AOCS Ce 1b-89.**

Calibration: Standard silicone oils (50–1000 cP) were used to plot a viscosity vs. RPM calibration curve.

Refractive Index

The refractive index (RI) was measured at 25°C using an Abbe refractometer, calibrated with distilled water and standard monoglycerides (RI: 1.450–1.470).

Thermal Physical Evaluation

Differential Scanning Calorimetry (DSC)

Thermal transitions, including melting point and specific heat capacity (Cp), were determined using a Netzsch DSC 204 under a nitrogen atmosphere. Approximately 5–10 mg of sample was sealed in an aluminum pan and scanned from 25 to 200 °C at a rate of 10 °C/min.

Calibration: The instrument was calibrated using indium (Tm = 156.6 °C, ΔH = 28.45 J/g) for temperature and heat flow accuracy

Transient Plane Source (TPS)

Thermal diffusivity was measured using a TPS sensor (Hot Disk TPS 2500S), as per ISO 22007-2. Each oil sample was placed between two identical sensors and held at 25 °C during measurement.

$$\propto = \frac{K}{\rho.\ C_P} \quad \text{(vi)}$$

Where:

- k = thermal conductivity (from TPS)
- ϱ = density
- CpC = specific heat capacity

GC-MS Analysis

Fatty acid methyl esters (FAMEs) were prepared via transesterification using methanolic H_2SO_4 (2%, v/v). GC-MS analysis was performed on an Agilent 7890A GC coupled with a 5975C mass selective detector using a DB-5MS capillary column (30 m × 0.25 mm, 0.25 µm). The injection volume was 1.0 µL, with helium serving as the carrier gas at a flow rate of 1 mL/min. The oven was programmed to increase from 50 °C (held for 2 min) to 280 °C at a rate of 10 °C/min.

Compound identification was achieved by comparing spectra with entries in the **NIST 2014** library. Data extracted included:

- Retention times (RTs)
- Compound identity and CAS number
- Relative abundance (%)

Calibration: Methyl ester standards (C8:0 to C24:1) were used to verify RTs and peak resolution. A blank (solvent-only) and standard mix were run for validation.

RESULTS AND DISCUSSION

The physicochemical parameters analyzed in this study (Table 1) demonstrate significant influence of the extraction technique on the compositional and oxidative characteristics of palm kernel oil (PKO). Specifically, the cold-pressed oil (Sample C) exhibited a marginally higher acid value (AV) compared to the solvent-extracted sample, though it remained within acceptable industrial thresholds. This elevated AV may result from endogenous lipase activity that is not thermally inactivated during mechanical pressing, as no heat is applied (Ayodele & Obafemi, 2018). However, the lower peroxide value (PV) recorded in Sample C suggests superior oxidative stability, likely due to reduced exposure to solvents and heat, both of which are known to catalyze lipid

peroxidation (Che Man & Tan, 2012). Conversely, the solvent-extracted PKO (Sample D) showed higher iodine value (IV) and saponification value (SV). A higher IV denotes greater unsaturation, which may arise from the exhaustive solvent recovery of minor unsaturated lipids typically underrepresented in mechanical pressing (Alade et al., 2023; Arifin et al., 2023). Similarly, the elevated SV indicates the presence of shorter-chain triglycerides or a broader range of lipid molecular weights—a trait corroborated by GC-MS findings in previous studies (Aliyu et al., 2020; Ezeh & Nwankwo, 2024). This enhanced compositional diversity highlights the aggressive nature of Soxhlet extraction, which retrieves both major and trace lipid fractions that are not efficiently recovered by cold pressing. Despite these differences, the density and refractive index values were comparable between the two samples. These parameters are largely governed by bulk hydrocarbon structure and degree of saturation, suggesting that while trace components may vary, the primary fatty acid backbone remains conserved across extraction methods (Kolawole & Ogunniyi, 2012; Yakubu & Mustapha, 2018). This observation aligns with the findings of Durojaiye and Alabi (2024), who reported consistent density and RI in oils extracted from the same kernel batch but using different techniques. The higher chemical integrity of cold-pressed oil (as evidenced by low PV and moderate AV) supports its preferential use in food and cosmetic formulations, where oxidative stability and absence of residual solvents are critical.

In contrast, the broader chemical range afforded by solvent extraction might be advantageous in industrial and oleochemical applications, particularly those requiring functionalized lipid moieties or enhanced reactivity. These results are consistent with prior comparative evaluations of PKO and other tropical oils. For instance, Ayodele and Obafemi (2018) observed similar trends in saponification and peroxide values in conventionally versus microwave-assisted extractions. Likewise, the work by Arifin et al. (2023) corroborates the finding that unsaturation levels, as inferred from iodine value, are typically elevated in solvent-derived oils, albeit at the expense of oxidative stability.

Collectively, this study advances the existing literature by integrating compositional insights with thermophysical data, thereby enabling a more holistic evaluation of oil quality as a function of extraction method. Importantly, the choice of extraction technique should be tailored to the intended end-use application—cold pressing for applications prioritizing stability and purity, and solvent extraction where diversity and yield are paramount.

Table 1. Physicochemical Parameters of Cold-Pressed and Solvent-Extracted Palm Kernel Oil

Parameter	Sample C (Cold Press)	Sample D (Solvent Extract)
Acid Value (mg KOH/g)	2.3 ± 0.1	1.8 ± 0.2
Iodine value (g I_2/100g)	16.8 ± 0.4	17.1 ± 0.3
Peroxide Value (meq O_2/kg)	2.2 ± 0.1	3.0 ± 0.2
Saponification Value (mg KOH/g)	245.6 ± 1.2	248.2 ± 1.5
Density (g/cm³ at 30 °C)	0.912	0.915
Viscosity (mPa·s at 30 °C)	39.5	40.7
Refractive Index (nD at 30 °C)	1.451	1.452

Table 2. Selected GC-MS Identified Compounds in Cold-Pressed (Sample C) and Solvent-Extracted (Sample D) PKO

RetentionTime (min)	Compound Name	CAS Number	Sample C Area (%)	Sample D Area (%)
10.35	Lauric acid	143-07-7	32.6	10.6
11.21	Myristic acid	544-63-8	12.3	9.7
12.07	Oleic acid	112-80-1	16.9	13.4
13.90	δ-Dodecalactone	713-95-1	ND	2.8
14.82	Bis(2-ethylhexyl) phthalate	117-81-7	ND	3.5
15.43	Palmitic acid methyl ester	112-39-0	3.1	6.9
16.02	Stearic acid methyl ester	112-61-8	2.4	5.7

ND = Not Detected

Table 3. Thermo-physical Properties of Cold-Pressed and Solvent-Extracted Palm Kernel Oil

Property	Sample C (Cold Press)	Sample D (Solvent Extract)
Thermal Conductivity (W/m·K)	0.192 ± 0.003	0.187 ± 0.002
Specific Heat Capacity (J/g·K)	2.01 ± 0.04	1.96 ± 0.03
Thermal Diffusivity (mm²/s)	0.105 ± 0.002	0.101 ± 0.001

GC-MS profiling (Table 2, Figure 1 and 2) confirmed the dominance of lauric, myristic, and oleic acids in both oil types, with notably higher concentrations in the cold-pressed sample. The solvent-extracted oil contained unique volatiles and esters, such as δ-dodecalactone and bis(2-ethylhexyl) phthalate, which were likely introduced during the solvent interaction and processing. These additional components suggest a broader extraction range but raise concerns about potential contamination and the need for purification. Thus, cold-pressed oil is superior in purity, while solvent-extracted oil offers higher compound diversity with potential industrial implications.

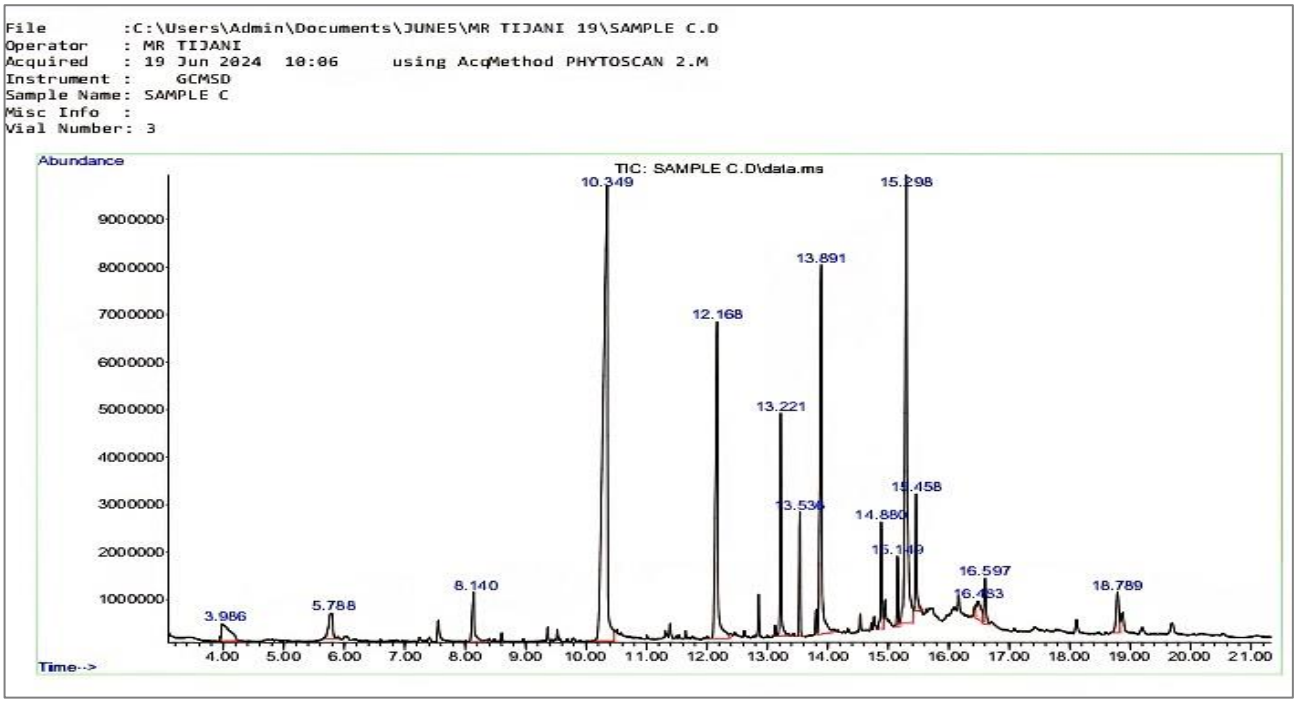

Fig. 1: GCMS chromatogram of sample C

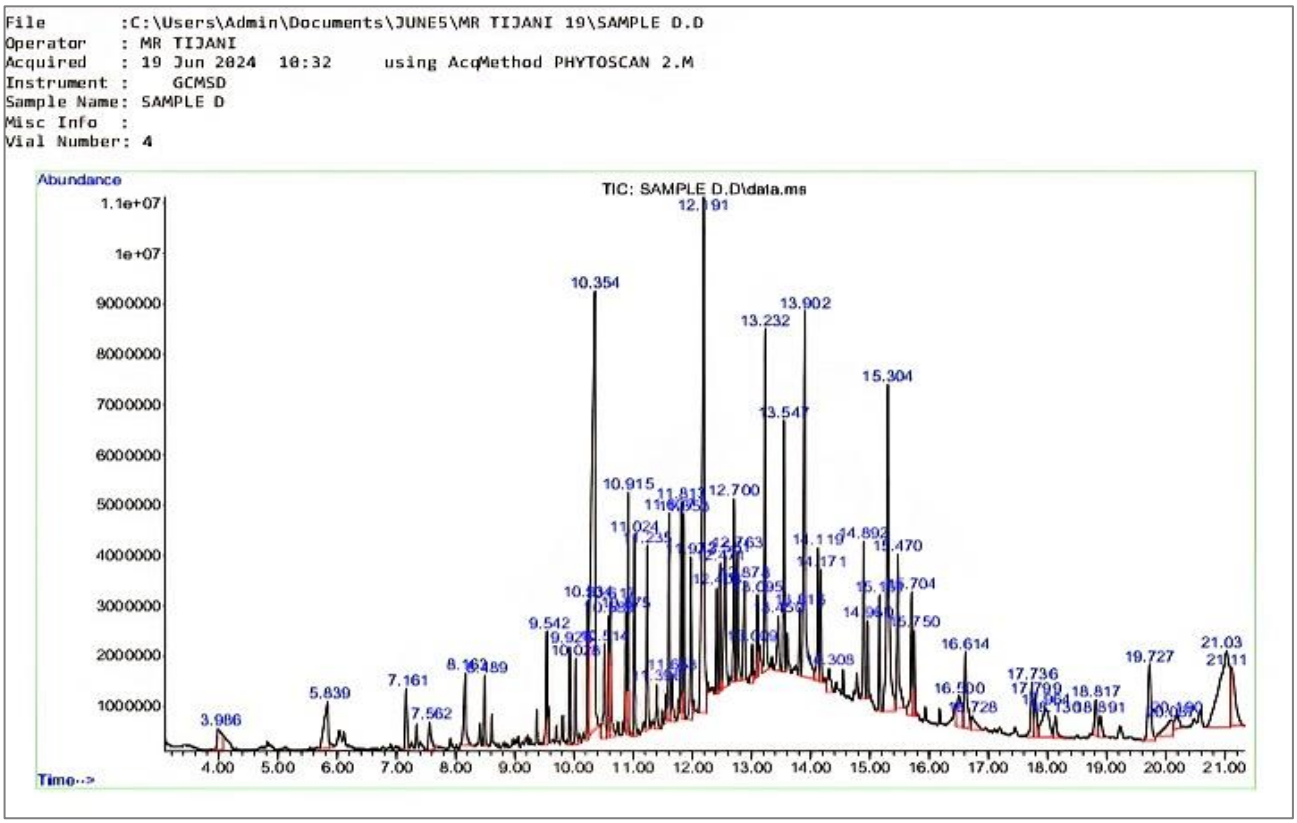

Fig 2: GC-MS chromatogram of sample D

The thermophysical properties (Table 3) reveal that cold-pressed PKO possesses slightly higher thermal conductivity and specific heat capacity, suggesting a better capacity to conduct and store heat. This indicates that cold-pressed PKO may perform better in heat-sensitive applications where thermal stability is crucial. Meanwhile, both samples demonstrated similar thermal diffusivity values, indicating comparable heat transfer rates. The

minor differences may be attributed to molecular variations resulting from processing conditions, such as solvent interactions and temperature exposure during extraction.

Table 4. Proximate Composition of Cold-Pressed and Solvent-Extracted Palm Kernel Oil

Component	Sample C (Cold Press) (%)	Sample D (Solvent Extract) (%)
Moisture Content	0.22 ± 0.01	0.18 ± 0.01
Ash Content	0.06 ± 0.00	0.04 ± 0.00
Crude Protein	0.12 ± 0.01	0.09 ± 0.01
Crude Fat	98.40 ± 0.30	98.60 ± 0.25
Crude Fiber	0.25 ± 0.02	0.22 ± 0.01
Carbohydrate	0.95 ± 0.02	0.87 ± 0.02

The proximate analysis (Table 4) reveals that both extraction methods yield oils with high crude fat content, signifying efficient lipid recovery. The solvent-extracted sample (Sample D) exhibited slightly higher fat content, which is expected due to the enhanced solvent penetration and extraction efficiency. Moisture and ash contents were low in both samples, reflecting minimal water and inorganic residues favorable traits for shelf stability and purity. The cold-pressed sample retained marginally higher levels of protein and carbohydrates, potentially due to less aggressive extraction conditions preserving non-lipid bio-components. The **cold-pressed palm kernel oil (Sample C)** demonstrated superior qualities in parameters critical to nutritional and dermal applications. Notably, it exhibited:

- **Lower peroxide value (PV)** and **free fatty acid (FFA)** content, suggesting higher oxidative stability and a lower degree of lipid hydrolysis. Low PV is indicative of minimal primary oxidation products (e.g., hydroperoxides), which enhances shelf life and prevents rancid odors and flavors (Shahidi & Zhong, 2005).

- **Retention of natural antioxidants**, such as tocopherols (Vitamin E), polyphenols, and phytosterols. These compounds are thermolabile and can degrade during solvent extraction or heat processing. Cold pressing, due to its mechanical and low-temperature nature, preserves these beneficial molecules, contributing to the oil's functional stability, nutritional value, and anti-aging skin properties (Ramadan & Mörsel, 2003; Gunstone, 2011).

- **Essential fatty acids (EFAs)** such as linoleic and oleic acids remain intact in cold-pressed oil. EFAs are crucial for skin barrier repair and anti-inflammatory responses, making cold-pressed PKO ideal for use in lotions, creams, and nutraceuticals (Ziboh et al., 2000).

From a cosmetic standpoint, the unrefined nature of cold-pressed PKO ensures better dermal absorption and bioavailability due to the presence of bioactive minor compounds. Moreover, the low Trans fatty acid content, as typically observed in cold-pressed oils, enhances their desirability in both therapeutic and functional food applications (Bhardwaj et al., 2016). In contrast, solvent-extracted PKO (Sample D) displayed characteristics that, while less suitable for direct consumption, align with industrial processing objectives:

- **Higher iodine value (IV)** suggests a greater proportion of unsaturated fatty acids. While this may appear beneficial nutritionally, it also renders the oil more prone to oxidation if not stabilized. However, in biodiesel production, this higher IV contributes to improved cold flow properties (Tynek et al., 2001), especially in colder climates where pour point and cloud point are critical parameters.

- **Higher saponification value (SV)** indicates shorter-chain fatty acid dominance, which is beneficial in soap and detergent formulations due to better foaming and cleansing efficiency. This metric also reflects increased triglyceride content, a desirable attribute in lubricant base stocks and oleochemical intermediates (Shahidi, 2005).

- However, the process inherently introduces risks of chemical residues, such as n-hexane or plasticizers like DEHP (Di(2-ethylhexyl) phthalate), which are commonly leached from industrial equipment. These require rigorous post-extraction refining, bleaching, and deodorization to meet Codex Alimentarius standards for food-grade oils (Codex Alimentarius Commission, 2019).

- **Minor volatiles and esters**, enriched through solvent interaction, are also valuable in fragrance, flavoring**,** and biofuel industries, though they necessitate careful quality control due to variability and potential off-notes.

Strategic Decision Based on End-Use

Therefore, the selection of an extraction method must be tailored to the intended application (Table 5).

CONCLUSION

While cold-pressed PKO is chemically and nutritionally superior for human-facing applications, solvent-extracted PKO remains essential for cost-intensive, bulk, or technical industries. Future research should explore **hybrid extraction techniques** (e.g., enzymatic-assisted pressing, supercritical CO_2 extraction) that combine the high yield of solvent methods with the quality of cold-pressed oils. Additionally, **refining protocols** that remove undesirable residues without degrading beneficial components should be prioritized to enhance the applicability of solvent-extracted oils in food and pharmaceutical sectors.

Table 5: Extraction Method Tailored to the Intended Application:

Application Domain	PreferredExtraction Method	Rationale
Nutraceuticals & Functional Foods	Cold Pressing	Preserves bioactives and minimizes contaminants
Cosmetic & Dermal Products	Cold Pressing	Enhances skin absorption, stability, and safety
Biodiesel Production	Solvent Extraction	Optimizes yield and cold flow performance
Soap and Detergent Industry	Solvent Extraction	Higher SV and total lipid content desirable
Industrial Lubricants	Solvent Extraction	Economically viable with modifiable properties

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