

Valorization of Underutilized Seed Oils as Bio-Based Feedstocks for Oilfield Chemical Development

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ARTICLE INFO	ABSTRACT
Article History: Received: Revised: Accepted: Published: Article type: Research Keywords: <i>Bio-based, oilfield chemicals, Fatty-acid profile, Gas chromatography–flame ionization detection (GC–FID), Sustainable drilling fluids.</i>	The growing dependence of the oil and gas industry on petroleum-derived chemicals has intensified the search for renewable and environmentally sustainable feedstocks. This study investigated the valorization potential of oils extracted from <i>Mangifera indica</i>, <i>Citrus sinensis</i>, <i>Jatropha curcas</i>, <i>Carica papaya</i>, and <i>Citrullus lanatus</i> seeds as bio-based feedstocks for oilfield chemical development. The extracted oils were characterized using standard physicochemical analyses, while their fatty-acid compositions were determined by gas chromatography–flame ionization detection (GC–FID). Oil yields ranged from 12.0% for <i>M. indica</i> to 58.6% for <i>C. lanatus</i>, with <i>J. curcas</i> (56.5%) and <i>C. lanatus</i> producing yields comparable to the soybean oil reference. The oils exhibited favourable iodine and saponification values, indicating the presence of chemically reactive lipid components suitable for oleochemical conversion. GC–FID analysis showed that <i>C. lanatus</i> (86.0%), <i>C. papaya</i> (78.46%), and <i>C. sinensis</i> (73.71%) possessed high proportions of unsaturated fatty acids, predominantly oleic and linoleic acids, while <i>M. indica</i> contained the highest phenolic content (3022.73 mg/kg). These compositional characteristics provide reactive molecular platforms for functionalization through epoxidation, esterification, amidation, polymerization, and related reactions to produce bio-based lubricants, drilling-fluid additives, emulsifiers, demulsifiers, corrosion inhibitors, and wax-control agents. The findings demonstrate that these underutilized seed oils are promising renewable oleochemical feedstocks whose valorization could reduce dependence on petroleum-derived chemicals, promote agricultural resource utilization, and support the development of sustainable oilfield chemical technologies.

Introduction

The oil and gas industry relies extensively on specialty chemicals during drilling, well completion, production, stimulation, enhanced oil recovery, and transportation operations. These chemicals include drilling-fluid additives, lubricants, emulsifiers, demulsifiers, corrosion inhibitors, shale stabilizers, pour-point depressants, wax inhibitors, and production chemicals that are essential for maintaining operational efficiency and equipment integrity [1,2]. Traditionally, most of these products are manufactured from petroleum-derived feedstocks, which are non-renewable and may contribute to environmental pollution, greenhouse gas emissions, and ecological degradation. Increasing environmental regulations and the global transition towards sustainable industrial practices have therefore stimulated considerable interest in developing renewable, biodegradable, and environmentally benign alternatives [3].

Vegetable oils have emerged as attractive renewable feedstocks for the synthesis of bio-based oilfield chemicals because of their abundance, biodegradability, low toxicity, and structural versatility. Their triglyceride molecules contain ester linkages together with saturated and unsaturated fatty-acid chains that provide numerous reactive sites for chemical modification.

Depending on the degree of unsaturation and the functional groups present, these oils can be transformed through reactions such as epoxidation, transesterification, esterification, amidation, sulphonation, polymerization, graft copolymerization, and metathesis to produce a wide range of functional materials suitable for oilfield applications. Consequently, vegetable oils have attracted increasing attention as sustainable precursors for drilling-fluid additives, lubricants, corrosion inhibitors, surfactants, demulsifiers, and other specialty chemicals [2,6].

Africa possesses abundant agricultural resources that generate substantial quantities of seed residues from fruit processing and food industries. Many of these residues are treated as waste despite containing appreciable quantities of extractable oils with valuable chemical functionalities. The valorization of these underutilized biomass resources represents an important component of the circular economy by converting agricultural waste into value-added industrial products while simultaneously reducing environmental burdens associated with waste disposal. Furthermore, the utilization of locally available non-edible or underutilized seed oils could reduce dependence on imported petrochemical feedstocks, stimulate indigenous oleochemical industries, and promote sustainable economic development [4-7].

Among the numerous underutilized oil-bearing materials available in tropical regions, the seeds of *Mangifera indica* (mango), *Citrus sinensis* (orange), *Jatropha curcas* (physic nut), *Carica papaya* (pawpaw), and *Citrullus lanatus* (watermelon) are particularly attractive because they are widely available yet remain largely underexploited for high-value industrial applications. Previous studies have demonstrated that these seed oils contain varying proportions of saturated and unsaturated fatty acids, together with naturally occurring phenolic compounds and other oxygen-containing constituents that influence their chemical reactivity, oxidative stability, and functional performance [16,17]. However, most previous investigations have focused primarily on biodiesel production, food applications, cosmetics, or general physicochemical characterization, with comparatively limited attention given to their potential as renewable feedstocks for oilfield chemical development [9].

The suitability of vegetable oils for oleochemical synthesis depends largely on their physicochemical characteristics and fatty-acid composition [16]. Parameters such as oil yield, iodine value, peroxide value, saponification value, free fatty-acid content, total phenolic content, and fatty-acid profile collectively determine the availability of chemically reactive functional groups and influence the efficiency of subsequent modification reactions. Oils containing high proportions of unsaturated fatty acids provide abundant carbon-carbon double bonds for epoxidation, polymerization, hydroxylation, and other functionalization processes, whereas phenolic compounds may enhance antioxidant activity and contribute to corrosion inhibition. Comprehensive characterization of these properties therefore provides an essential scientific basis for selecting appropriate renewable feedstocks for specific oilfield chemical applications [19-23].

In the present study, the physicochemical properties and fatty-acid compositions of oils extracted from *Mangifera indica*, *Citrus sinensis*, *Jatropha curcas*, *Carica papaya*, and *Citrullus lanatus* seeds were systematically evaluated using standard analytical techniques and gas chromatography-flame ionization detection (GC-FID). The objective was to assess their suitability as renewable molecular platforms for the development of environmentally sustainable oilfield chemicals. The findings provide valuable information for the design and production of bio-based lubricants, emulsifiers, demulsifiers, corrosion inhibitors, wax inhibitors, drilling-fluid additives, and related oleochemical products, while promoting the valorization of agricultural waste and supporting the transition towards a sustainable circular bioeconomy.

Materials and Methods

Materials

The seed samples used in this study were obtained from five underutilized plant species, namely *Mangifera indica* (mango), *Citrus sinensis* (orange), *Jatropha curcas* (physic nut), *Carica papaya* (pawpaw), and *Citrullus lanatus* (watermelon). All analytical-grade reagents and solvents employed during the study were used without further purification. *n*-Hexane was used as the extraction solvent, while carbon tetrachloride, Wijs solution, potassium iodide, sodium thiosulfate, potassium hydroxide, hydrochloric acid, ethanol, diethyl ether, acetic acid, chloroform, phenolphthalein, and starch indicator were used for the physicochemical analyses.

Sample Collection and Preparation

The seed samples were collected from fruits obtained within the Ibadan North Local Government Area of Oyo State, Nigeria. The seeds were manually separated from the fruits and thoroughly washed with distilled water to remove adhering pulp, dust, and other foreign materials. The cleaned seeds were mechanically dried in a thermostatically controlled laboratory drying oven at 40 °C for 6 h to reduce their moisture content and minimize microbial deterioration. The dried seeds were pulverized using an electric stainless-steel laboratory grinder to obtain a homogeneous powder suitable for solvent extraction. The pulverized samples were stored in clean airtight polyethylene containers until required for oil extraction [19].

Extraction of Oil from the Seed Samples

Oil extraction was carried out using a Soxhlet extraction apparatus with *n*-hexane as the extraction solvent. A known mass of each pulverized seed sample was placed in a cellulose extraction thimble and introduced into the Soxhlet extractor connected to a reflux condenser and a 2-L round-bottom flask containing *n*-hexane. Extraction was performed at 60 °C for 6 h using a thermostatically controlled water bath to ensure continuous solvent reflux and efficient oil recovery. Following extraction, the solvent was removed using rotary evaporation, and the extracted oils were transferred into clean amber glass bottles fitted with airtight screw caps. The oils were stored at 4 °C prior to analysis to minimize oxidation and photo-oxidative degradation. The extracted oils varied in colour from pale yellow to light brown depending on the seed source [19].

Oil Yield Determination

The percentage oil yield was determined gravimetrically after complete removal of the extraction solvent using Equation (1).

The oil yield was calculated according to Equation (1):

$$\text{Oil yield (\%)} = \frac{P - Q}{R} \times 100 \quad (1)$$

where *P* is the mass of the extraction vessel containing the extracted oil (g), *Q* is the mass of the empty extraction vessel (g), and *R* is the mass of the seed sample used for extraction (g).

Physicochemical Characterization of the Seed Oils

The extracted oils were characterized by determining their iodine value, peroxide value, saponification value, free fatty acid content, and total phenolic content using standard analytical procedures.

Determination of Iodine Value

The iodine value was determined using the Wijs method [2]. 1.0 g of seed oil was accurately weighed into a 250-mL iodine flask, after which 20 mL of carbon tetrachloride, previously dried over anhydrous calcium chloride, was added to dissolve the oil completely. Subsequently, 10 mL of standardized Wijs solution, consisting of approximately 0.1 mol L⁻¹ iodine monochloride (ICl) dissolved in glacial acetic acid, was added using a dry pipette. The flask was immediately stoppered, gently shaken, and allowed to stand in the dark for 30 min to permit complete reaction between iodine monochloride and the carbon-carbon double bonds present in the oil.

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After the reaction period, 5 mL of 1% potassium iodide solution followed by 5 mL of distilled water was added. The liberated iodine was titrated against standardized 0.1 mol L⁻¹ sodium thiosulfate solution using freshly prepared 1% (w/v) starch solution as the indicator. A reagent blank was analysed simultaneously under identical conditions.

The iodine value was calculated using Equation (2):

$$\text{Iodine value} = \frac{(W - X) \times 1.25}{S} \quad (2)$$

where W is the volume of sodium thiosulfate solution used for the blank titration (mL), X is the volume of sodium thiosulfate solution used for the sample titration (mL), and S is the mass of oil sample used (g). The factor 1.25 applies to a 0.1 N sodium thiosulfate solution under the specified analytical conditions [16].

Determination of Saponification Value

1.5 g of each seed oil sample was transferred into a 250-mL conical flask. Thereafter, 10 mL of 0.1 mol L⁻¹ alcoholic potassium hydroxide solution and 1 mL distilled water were added. The mixture was refluxed gently for 4 min to ensure complete hydrolysis of the triglycerides. Following cooling to room temperature, phenolphthalein indicator was added and the excess potassium hydroxide was titrated with standardized 0.05 mol L⁻¹ hydrochloric acid until the pink colour disappeared. A blank determination was performed under identical conditions [19].

The saponification value was calculated using Equation (3):

$$\text{Saponification value} = \frac{0.1 N (V_1 - V_2)}{R} \quad (3)$$

where V_1 is the volume of hydrochloric acid used for the blank titration (mL), V_2 is the volume of hydrochloric acid used for the oil sample titration (mL), N is the normality of the hydrochloric acid, and R is the mass of the oil sample (g).

Determination of Peroxide Value

Peroxide value was determined using iodometric titration method [7]. 1.5 g of each seed oil was dissolved in a freshly prepared acetic acid–chloroform (3:2, v/v) solvent mixture. Saturated potassium iodide solution was added, and the mixture was allowed to react under dark conditions to liberate iodine from lipid hydroperoxides. The liberated iodine was titrated with standardized sodium thiosulfate solution using 1% starch indicator near the endpoint. A reagent blank was analysed concurrently. The peroxide value was calculated from the relation:

$$\text{PV (meq O}_2 \text{ kg}^{-1}) = \frac{(V_s - V_b) \times M \times 1000}{m}$$

Where:

V_s = volume of sodium thiosulfate solution used for the sample titration (mL)

V_b = volume of sodium thiosulfate solution used for the blank titration (mL)

M = molarity of the sodium thiosulfate solution (mol L⁻¹)

m = mass of the oil sample (g)

Determination of Free Fatty Acids

Diethyl ether and ethanol were mixed in the ratio of 1:1 (v/v). 1.5 g of each oil sample was dissolved in the solvent mixture and gently warmed for approximately 10 min to ensure complete dissolution. The solution was titrated with standardized 0.1 mol L⁻¹ potassium

hydroxide solution under continuous agitation until a faint pink colour persisted for approximately 10 s, indicating the phenolphthalein endpoint. The free fatty acid content, expressed as percentage oleic acid, was calculated using Equation (5).

FFA as oleic acid (%)

$$\text{FFA (\% as oleic acid)} = \frac{V \times N \times 28.2}{W}$$

Where:

V = volume of KOH or NaOH used for titration (mL)

N = normality of the KOH or NaOH solution

W = mass of oil sample (g)

28.2 = equivalent weight of oleic acid $\times$ 100 conversion factor

Determination of Total Phenolic Content

The total phenolic content of the extracted oils was determined using the appropriate standard spectrophotometric method [12] and the results were expressed as milligrams of phenolic compounds per kilogram of oil (mg kg⁻¹).

Gas Chromatography–Flame Ionization Detection (GC-FID)

The fatty-acid composition of the extracted seed oils was determined using a PerkinElmer Clarus 800 Gas Chromatograph equipped with a flame ionization detector (FID). Separation was achieved on an Elite-Wax capillary column (10 m $\times$ 0.25 mm i.d.; 0.25 μ m film thickness). The chromatographic conditions were as follows: injection volume 1.0 μ L; splitless injection with a 0.5-min hold; injector temperature 210 $^{\circ}$ C; detector temperature 260 $^{\circ}$ C; helium carrier gas operated at constant pressure with a linear velocity of 1.1 cm s⁻¹ at 100 $^{\circ}$ C; oven temperature initially maintained at 100 $^{\circ}$ C for 0.5 min, followed by programmed heating to 200 $^{\circ}$ C at 10 $^{\circ}$ C min⁻¹. Individual fatty acids were identified by comparing their retention times with those of authenticated reference standards and quantified from their corresponding peak areas. The resulting chromatograms were used to determine the relative composition of saturated and unsaturated fatty acids present in each seed oil.

Results and Discussion

Physicochemical Properties of the Seed Oils

Samples	% oil yields	Iodine value (gI/100g)	Peroxide value meq/kg	Saponification value (mgKOH/g)	Free fatty acids (%)	Phenolic content (mg/kg)
<i>Mangifera indica</i>	12.01	82.00 $\pm$ 0.13	10.13 $\pm$ 2.42	192.06 $\pm$ 0.08	4.90 $\pm$ 0.01	30.72, 73 $\pm$ 4.22
<i>Citrus sinensis</i>	36.00	108.11 $\pm$ 1.32	8.90 $\pm$ 0.11	196.20 $\pm$ 0.74	8.23 $\pm$ 0.00	128.0, 23 $\pm$ 0.18
<i>Jatropha curcas</i>	06.00	108.33 $\pm$ 1.78	0.32 $\pm$ 0.00	198.30 $\pm$ 0.77	9.33 $\pm$ 0.02	2391, 30 $\pm$ 0.11
<i>Carica papaya</i>	34.21	102.00 $\pm$ 0.38	10.06 $\pm$ 0.01	188.39 $\pm$ 0.42	7.06 $\pm$ 0.07	2763, 00 $\pm$ 3.27
<i>Citrullus lanatus</i>	08.68	196.13 $\pm$ 0.72	1.01 $\pm$ 0.28	189.34 $\pm$ 0.82	7.26 $\pm$ 0.02	2644, 16 $\pm$ 1.71
<i>Soyabean oil (control)</i>	00%	120.00	7.83	196.40	8.31	

Note: Values represent mean $\pm$ standard deviation where applicable. Soybean oil was used as the commercial control/reference oil for comparative evaluation.

Physicochemical Properties of Seed Oils

The physicochemical properties of the extracted seed oils are presented in Table 1. Commercial soybean oil was used as the control/reference sample for comparative evaluation. Significant differences ($p < 0.05$) were observed among the investigated oils for the measured physicochemical parameters, indicating variations in their chemical composition and functional characteristics. The oil yields ranged from 12.01% for *Mangifera indica* to 58.68% for *Citrullus lanatus*. The yields obtained for *Citrus sinensis* (36.50%), *Jatropha curcas* (56.50%), *Carica papaya* (34.21%), and *Citrullus lanatus* (58.68%) demonstrate that these underutilized seeds contain appreciable quantities of extractable oil. The oil yields of *J. curcas* and *C. lanatus* were comparable to that of the soybean oil control (55.00%), suggesting their potential as alternative lipid feedstocks for oleochemical applications. In contrast, the relatively low oil yield obtained from *M. indica* (12.01%) indicates that its economic viability as a standalone industrial oil source may be limited. However, its oil may still provide value as a supplementary feedstock or as a component in blended formulations where specific chemical functionalities are required. The oil yield obtained for *M. indica* is consistent with previously reported values for mango seed oils, where yields between approximately 10–12% have been documented for different mango varieties [12]. The comparable yields observed for *J. curcas* and *C. lanatus* relative to soybean oil indicate that these non-conventional seed oils may serve as promising renewable alternatives (Table 1). However, oil yield alone does not determine industrial suitability; factors such as fatty-acid composition, oxidation stability, chemical reactivity, availability, and processing requirements must also be considered. Therefore, the physicochemical properties of the extracted oils were further evaluated to assess their potential as renewable precursors for oilfield chemical development. The iodine values of the oils ranged from 82.00 ± 0.13 g I₂/100 g for *M. indica* to 196.13 ± 0.62 g I₂/100 g for *C. lanatus*, compared with 125.00 g I₂/100 g for the soybean oil control.

The iodine values obtained for *C. sinensis* (108.11 ± 1.32 g I₂/100 g), *J. curcas* (108.33 ± 1.78 g I₂/100 g), and *C. papaya* (102.55 ± 0.38 g I₂/100 g) indicate considerable levels of unsaturation, although slightly lower than the soybean reference. The lower iodine value of *M. indica* suggests a comparatively higher proportion of saturated fatty acids, whereas the value obtained for *C. lanatus* indicates an exceptionally high degree of unsaturation. The degree of unsaturation is an important parameter for evaluating seed oils as chemical feedstocks because carbon–carbon double bonds provide reactive sites for functionalization reactions such as epoxidation, oxidation, polymerization, addition, and metathesis. Therefore, the observed iodine values suggest that these oils possess different levels of chemical reactivity that can be exploited in the synthesis of value-added oleochemicals and oilfield chemical additives [13, 14]. However, highly unsaturated oils may exhibit increased susceptibility to oxidation, and therefore their chemical reactivity must be balanced against oxidative stability during processing and storage. The unusually high iodine value observed for *C. lanatus* should be further verified through fatty-acid profiling because it is higher than values commonly reported for most vegetable seed oils [15]. The degree of unsaturation is an important parameter for evaluating seed oils as chemical feedstocks because carbon–carbon double bonds provide reactive sites for functionalization reactions such as epoxidation, oxidation, polymerization, addition, and metathesis. Therefore, the observed iodine values suggest that these oils possess different levels of chemical reactivity that can be exploited in the synthesis of value-added oleochemicals and oilfield chemical additives [13, 14]. However, highly unsaturated oils may exhibit increased susceptibility to oxidation and therefore their chemical reactivity must be balanced against oxidative stability during processing and storage [16–18].

The saponification values ranged from 188.39 ± 0.42 mg KOH/g for *C. papaya* to 198.30 ± 0.77 mg KOH/g for *J. curcas*. The values obtained for *M. indica* (192.06 ± 0.08 mg KOH/g), *C. sinensis* (196.20 ± 0.74 mg KOH/g), and *C. lanatus* (189.34 ± 0.82 mg KOH/g) were comparable with the soybean oil control (196.40 mg KOH/g). These results indicate similarities in the average molecular weight of fatty acids present in the oils [20]. The relatively high saponification values suggest that the oils contain substantial quantities of triglycerides and other saponifiable lipid components, supporting their suitability as raw materials for oleochemical transformations. The free fatty acid (FFA) contents ranged from $4.90 \pm 0.01\%$ in *M. indica* to $9.33 \pm 0.02\%$ in *J. curcas*. The FFA values of *C. sinensis* ($8.23 \pm 0.05\%$), *C. papaya* ($7.06 \pm 0.07\%$), and *C. lanatus* ($7.26 \pm 0.02\%$) were comparable with the soybean oil control (8.31%). The relatively high FFA levels indicate the presence of significant quantities of free fatty acids, which may arise from hydrolytic degradation during seed maturation, storage, or extraction. Although elevated FFA content may require pretreatment for certain processing routes, free fatty acids also represent valuable reactive substrates for esterification, amidation, and other chemical modification reactions relevant to oleochemical synthesis [22-24]. The peroxide values ranged from 0.22 ± 0.00 meq/kg for *J. curcas* to 10.06 ± 0.01 meq/kg for *C. papaya*, compared with 9.83 meq/kg for the soybean oil control. The low peroxide values observed for *J. curcas* and *C. lanatus* (1.01 ± 0.28 meq/kg) indicate lower levels of primary oxidation products, suggesting improved oxidative stability. Conversely, the higher peroxide values observed for *M. indica*, *C. sinensis*, and *C. papaya* indicate comparatively greater oxidation susceptibility. These variations may be attributed to differences in fatty-acid composition, phenolic content, extraction conditions, and storage history. For oilfield chemical applications, maintaining an appropriate balance between chemical reactivity and oxidative stability is essential because the oils may undergo further processing, transportation, storage, and formulation. The total phenolic contents varied considerably among the investigated oils, ranging from 1280.23 ± 0.08 mg/kg for *C. sinensis* to 2072.73 ± 4.22 mg/kg for *M. indica*. The highest phenolic content was recorded for *M. indica*, followed by *C. papaya* (2763.00 ± 2.27 mg/kg), *C. lanatus* (2644.16 ± 1.71 mg/kg), and *J. curcas* (2391.30 ± 0.11 mg/kg). The high phenolic concentration of *M. indica* oil suggests potential antioxidant properties and indicates the presence of functional groups capable of interacting with metal surfaces [25-27]. These characteristics may be beneficial in the future development of bio-based corrosion inhibitors; however, corrosion performance evaluation remains outside the scope of this study and requires dedicated investigation. Overall, the physicochemical results demonstrate that the investigated seed oils possess distinct combinations of oil yield, unsaturation level, saponifiable content, free fatty acid concentration, oxidation stability, and phenolic composition. Compared with soybean oil used as the reference control, *J. curcas* and *C. lanatus* showed competitive oil yields, while *M. indica* exhibited superior phenolic content. The variations among the oils provide different chemical platforms for downstream functionalization. Therefore, these underutilized seed oils may serve as complementary renewable feedstocks for the development of oilfield chemical additives, either as individual precursors or through controlled blending and chemical modification strategies.

Gas Chromatography–Flame Ionization Detection (GC-FID) Analysis of Seed Oils

Gas chromatography–flame ionization detection (GC-FID) analysis was conducted to complement the physicochemical characterization of the extracted seed oils and to determine their fatty-acid compositions. The analysis provided detailed information on the distribution of saturated and unsaturated fatty acids, thereby offering a more comprehensive understanding of the structural characteristics and chemical reactivity of the oils. While iodine value provides an overall estimation of the degree of unsaturation, GC-FID analysis identifies the specific fatty acids responsible for this unsaturation and provides a stronger basis for evaluating their suitability as renewable oleochemical feedstocks. The degree and position of unsaturation within fatty-acid chains are important because carbon–carbon double bonds serve as reactive sites for chemical modification. These functionalities can facilitate reactions such as

epoxidation, oxidation, hydrogenation, polymerization, esterification, and metathesis, allowing the conversion of natural oils into value-added derivatives. The total unsaturated fatty-acid contents determined from the GC-FID profiles were 86.00%, 78.46%, 50.26%, 49.01%, and 73.71% for *Citrullus lanatus*, *Carica papaya*, *Mangifera indica*, *Jatropha curcas*, and *Citrus sinensis*, respectively. These variations demonstrate differences in fatty-acid composition and provide insight into the relative chemical versatility of the oils for downstream modification.

Fatty-Acid Profile of *Citrullus lanatus* Seed Oil

The GC-FID chromatogram of *Citrullus lanatus* seed oil is presented in Figure 1, while the corresponding fatty-acid composition is summarized in Table 2. The chromatographic profile revealed two dominant peaks accompanied by several minor peaks, indicating that the oil composition was mainly characterized by a limited number of major fatty acids. The dominant peaks corresponded to unsaturated C¹⁸ fatty acids, which accounted for the majority of the total fatty-acid composition. Linoleic acid (C¹⁸:2) was the predominant fatty acid, representing 60.04% of the total fatty acids, followed by oleic acid (C¹⁸:1) at 20.96%. Together, these two unsaturated fatty acids accounted for 86.00% of the oil composition, confirming that *C. lanatus* seed oil is highly enriched in unsaturated fatty acids. The saturated fatty acids identified included palmitic acid (16:0), stearic acid (18:0), caprylic acid (8:0), myristic acid (14:0), and lauric acid (12:0), giving a total saturated fatty-acid content of approximately 14.03%.

The predominance of linoleic and oleic acids explains the high iodine value observed for *C. lanatus* seed oil (196.13 ± 0.62 g I₂/100 g) and confirms its highly unsaturated nature. The abundance of C¹⁸ unsaturated fatty acids provides multiple reactive sites for chemical functionalization, including epoxidation, hydroxylation, oxidation, esterification, and polymerization. These transformations may enable the production of modified oleochemical derivatives with tailored physicochemical properties suitable for applications such as lubricity enhancers, surfactants, emulsifiers, and other specialty oilfield chemical additives [16].

However, the high degree of unsaturation that enhances chemical reactivity may also increase susceptibility to oxidative deterioration during storage and processing. Therefore, practical utilization of *C. lanatus* oil as an industrial feedstock requires consideration of oxidative stabilization strategies, including antioxidant incorporation, controlled storage conditions, or selective modification of reactive double bonds. The relatively high phenolic content observed for *C. lanatus* oil (2644.16 ± 1.71 mg/kg) may provide some natural antioxidant protection by reducing free-radical-mediated oxidation. The fatty-acid profile obtained in this study agrees with previous reports on watermelon seed oil, where linoleic acid is generally identified as the dominant fatty acid, followed by oleic acid, with palmitic and stearic acids representing the major saturated components. The predominance of these unsaturated fatty acids highlights the suitability of *C. lanatus* seed oil as a renewable precursor for the synthesis of functional oleochemical materials [23].

Table 2: Fatty acid profile of *Citrullus lanatus* oil

Name	Bond	Time of elution (mins)	Area (%)
Caprylic acid	C _{8:0}	20.40	0.36
Palmitic acid	C _{16:0}	40.22	10.71
Stearic acid	C _{18:0}	43.90	2.37
Oleic acid	C _{18:1}	44.70	20.96
Linoleic acid	C _{18:2}	46.12	60.04
Lauric acid	C _{12:0}	31.29	0.29
Myristic acid	C _{14:0}	47.82	0.30

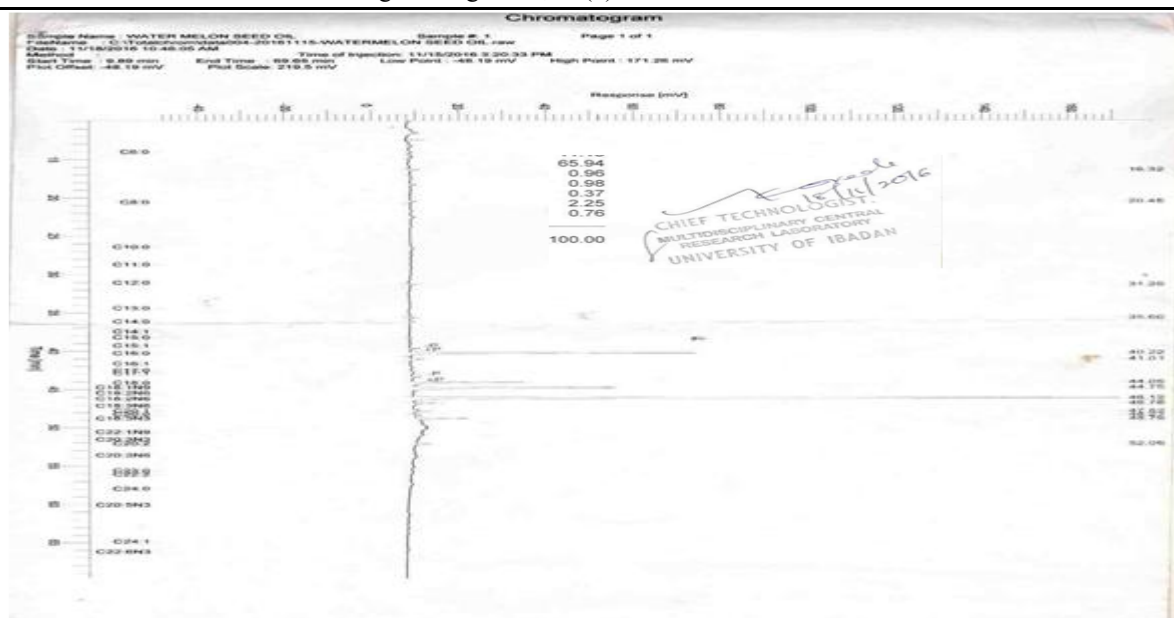


Figure ١: GC-FID chromatogram of *Citrullus lanatus* seed oil

Fatty-Acid Profile of *Carica papaya* Seed Oil

The GC-FID chromatogram of *Carica papaya* seed oil is presented in Figure ٢, while the corresponding fatty-acid composition is summarized in Table ٢. The chromatographic profile exhibited a dominant peak at approximately ٤٥,١٦ min, accompanied by several smaller peaks distributed within the retention time range of ٤٠–٥٥ min. This pattern indicates that the oil composition is largely dominated by one major fatty acid, with other saturated and unsaturated fatty acids occurring as minor constituents. The fatty-acid composition revealed that oleic acid (C١٨:١) was the predominant fatty acid, accounting for ٧٣,٥٣% of the total fatty acids. Other major components included palmitic acid (C١٦:٠) at ١٦,٢١%, stearic acid (C١٨:٠) at ٣,٩٢%, and linoleic acid (C١٨:٢ n-٦) at ٣,٣٧%. Minor fatty acids detected included caproic acid (١,٠٥%), palmitic acid (C١٦:٠), ١,٠٧%, palmitoleic acid (١,٢١%), arachidic acid (٠,١٩%), α-linolenic acid (٠,١٦%), behenic acid (٠,١٦%), and erucic acid (٠,١٢%).

Overall, *C. papaya* seed oil contained approximately ٧٨,٤٦% unsaturated fatty acids and ٢١,٥٣% saturated fatty acids, demonstrating a clear predominance of unsaturated lipid components. The exceptionally high oleic acid content explains the intense chromatographic peak observed at approximately ٤٥ min and confirms the monounsaturated nature of the oil. The relatively simple fatty-acid profile, dominated by a single C١٨ monounsaturated fatty acid, suggests a consistent lipid composition that may be advantageous for controlled chemical modification. The high oleic acid concentration provides reactive carbon-carbon double bonds that can serve as functionalization sites for oleochemical transformations, including epoxidation, hydroxylation, esterification, amidation, and polymerization. These reactions can modify the physicochemical properties of the oil and facilitate the production of functional derivatives with potential applications as bio-based lubricants, surfactants, emulsifiers, and other specialty oilfield chemical precursors [٢٣]. The fatty-acid composition of *C. papaya* seed oil also suggests a favourable balance between chemical reactivity and oxidative stability. Unlike oils dominated by polyunsaturated fatty acids, the high proportion of oleic acid and the relatively low content of polyunsaturated fatty acids (٣,٥٣%) reduce susceptibility to oxidative degradation because monounsaturated fatty acids are generally more resistant to autoxidation than linoleic and linolenic acids [١٧]. This characteristic may improve storage stability while maintaining sufficient chemical functionality for downstream modification. The predominance of oleic acid observed in this study is consistent with previous reports on *C. papaya* seed oil, where oleic acid has been identified as the major fatty-acid component, followed by palmitic, stearic, and linoleic acids. The combination of high oleic acid content, moderate unsaturation,

and favourable oxidative stability indicates that *C. papaya* seed oil represents a promising renewable feedstock for the development of tailored oleochemical derivatives[18].

Table 3 Fatty acid profile of *Carica papaya* seed oil

Name	Bond	Elution time (mins.)	Area (%)
Caproic acid	C _{6:0}	14.73	1.05
Palmitic acid	C _{16:0}	40.39	16.21
Palmitoleic acid	C _{16:1}	41.11	0.21
Stearic acid	C _{18:0}	44.39	3.92
Oleic acid	C _{18:1}	45.16	73.03
Linoleic acid	C _{18:2}	46.29	3.37
Paulinic acid	C _{20:1}	48.03	1.07
Arachidic acid	C _{20:0}	48.83	0.19
α- linoleic acid	C _{18:3}	49.73	0.16
Behenic acid	C _{22:0}	51.20	0.16
Erucic acid	C _{22:1}	52.74	0.12

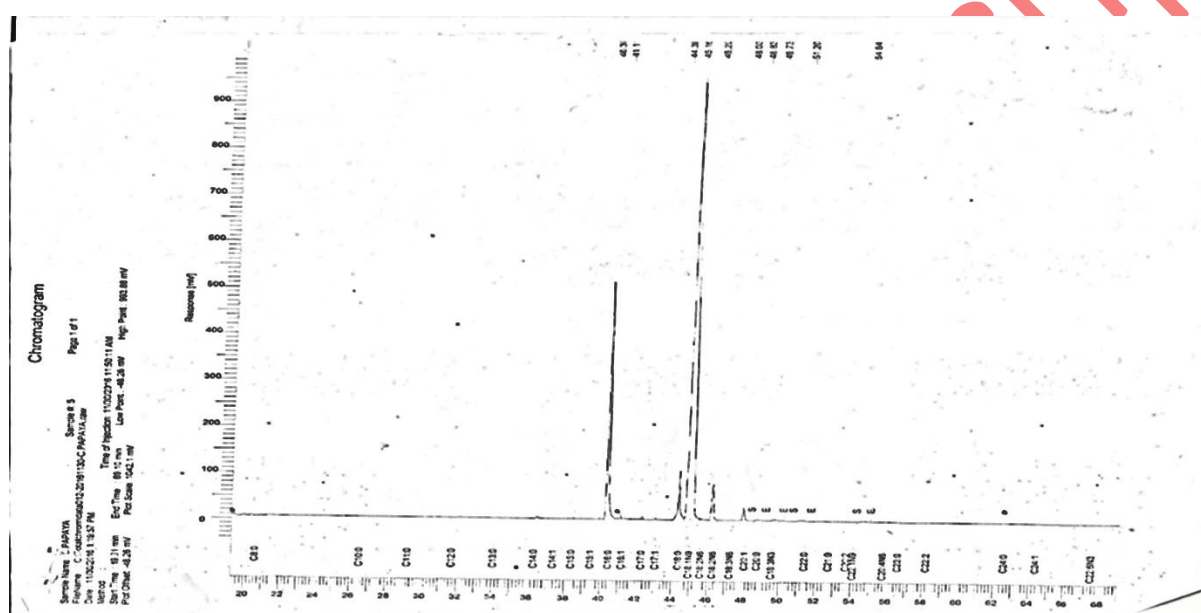


Figure 2: GC-FID chromatogram of *Carica Papaya* oil (CPO)

Fatty-Acid Profile of *Mangifera indica* Seed Oil

The GC-FID chromatogram of *Mangifera indica* seed oil is presented in Figure 3, while the corresponding fatty-acid composition is summarized in Table 4. The chromatographic profile exhibited numerous well-resolved peaks distributed across a broad retention time range, indicating a complex lipid composition comprising diverse saturated and unsaturated fatty acids. Unlike the chromatograms of *Citrullus lanatus* and *Carica papaya* seed oils, which were dominated by one or two major fatty-acid constituents, the profile of *M. indica* seed oil showed several peaks with comparable intensities, suggesting the absence of a single dominant fatty-acid component. The GC-FID analysis identified twenty fatty-acid components consisting of both saturated and unsaturated fatty acids. The predominant fatty acids were gondoic acid (C_{20:1}) and arachidic acid (C_{20:0}), representing 16.02% and 16.28% of the total fatty-acid composition, respectively. Other notable constituents included butyric acid (9.87%), α-linolenic acid (9.26%), tridecanoic acid (3.88%), myristoleic acid (3.82%), stearic acid (3.78%), palmitic acid (3.71%), linoleic acid (3.61%), arachidonic acid (3.50%), behenic acid (3.49%), nervonic acid (3.49%), erucic acid (3.43%), lignoceric acid (3.38%), docosahexaenoic acid (3.31%), trichosanoic acid (3.27%), brassidic acid (3.22%), γ-linolenic acid (1.02%), and palmitoleic acid (1.02%).

Overall, the oil contained approximately 50.26% unsaturated fatty acids and 49.74% saturated fatty acids, indicating a relatively balanced distribution between unsaturated and saturated lipid components. This compositional balance was reflected in the chromatographic profile, where multiple peaks of moderate intensity were observed rather than one or two dominant peaks [Figure 3]. The diverse fatty-acid composition suggests that *M. indica* seed oil possesses a broad range of structural characteristics that may influence its chemical reactivity, oxidative behaviour, and functional performance. The presence of appreciable amounts of unsaturated fatty acids, including gondoic acid, α -linolenic acid, linoleic acid, and other unsaturated constituents, provides reactive carbon-carbon double bonds that can serve as sites for chemical modification. These functional groups may facilitate reactions such as epoxidation, oxidation, esterification, polymerization, and other oleochemical transformation processes [19,20]. Consequently, *M. indica* seed oil may serve as a renewable precursor for producing modified lipid-based materials, including bio-based lubricants, surfactants, emulsifiers, and other specialty chemical intermediates. However, specific formulation and performance evaluations are required to establish its suitability for particular oilfield chemical applications.

In addition to its unsaturated components, the presence of long-chain saturated fatty acids, including arachidic acid, behenic acid, and lignoceric acid, may contribute to improved structural stability, viscosity characteristics, and resistance to oxidative degradation. This combination of saturated and unsaturated fatty acids provides a balance between chemical versatility and stability, which may be advantageous in the development of functional oleochemical derivatives. The fatty-acid composition of *M. indica* seed oil should also be considered alongside its physicochemical characteristics. The oil exhibited the highest total phenolic content among the investigated samples ($3.22, 73 \pm 4.22$ mg/kg), suggesting a potentially enhanced antioxidant capacity due to the presence of phenolic compounds. These antioxidant constituents may contribute to improved oxidative stability by reducing free-radical-induced lipid degradation, which is particularly important for oils containing significant proportions of unsaturated fatty acids. The complex fatty-acid profile observed for *M. indica* seed oil demonstrates its potential as a versatile renewable feedstock. Rather than serving as a direct replacement for conventional vegetable oils, its diverse chemical composition may provide opportunities for selective modification, blending, and formulation strategies aimed at producing tailored bio-based materials for industrial applications.

Table 4. Fatty acid profile of *Mangifera indica* oil

Name	Bond	Elution time (mins)	Area (%)
Butyric acid	C _{4:0}	3.24	9.87
Tridecanoic acid	C _{13:0}	16.87	3.88
Myristoleic acid	C _{14:1}	21.83	3.82
Palmitic acid	C _{16:0}	26.79	3.71
Palmitoleic acid	C _{16:1}	28.26	1.02
Stearic acid	C _{18:0}	31.76	3.78
Linoleic acid	C _{18:2}	36.72	3.61
α -linolenic acid	C _{18:3n-3}	38.34	0.26
Gondoic acid	C _{20:1}	40.70	16.02
Arachidic acid	C _{20:0}	41.70	16.28
γ -linolenic acid	C _{18:3n-7}	46.66	1.02
Erucic acid	C _{22:1n-7}	51.63	3.43
Behenic acid	C _{22:0}	55.09	3.49
Arachidonic acid	C _{20:4n-6}	61.00	3.00
Trichosanoic acid	C _{23:0}	66.02	3.27
Brassicic acid	C _{22:2}	71.48	3.22
Eicosapentaenoic acid	C _{20:5n-3}	76.44	3.04
Lignoceric acid	C _{24:0}	81.41	3.38
Nervonic acid	C _{24:1}	86.67	3.49
Docosahexaenoic acid	C _{22:6n-3}	91.33	3.31

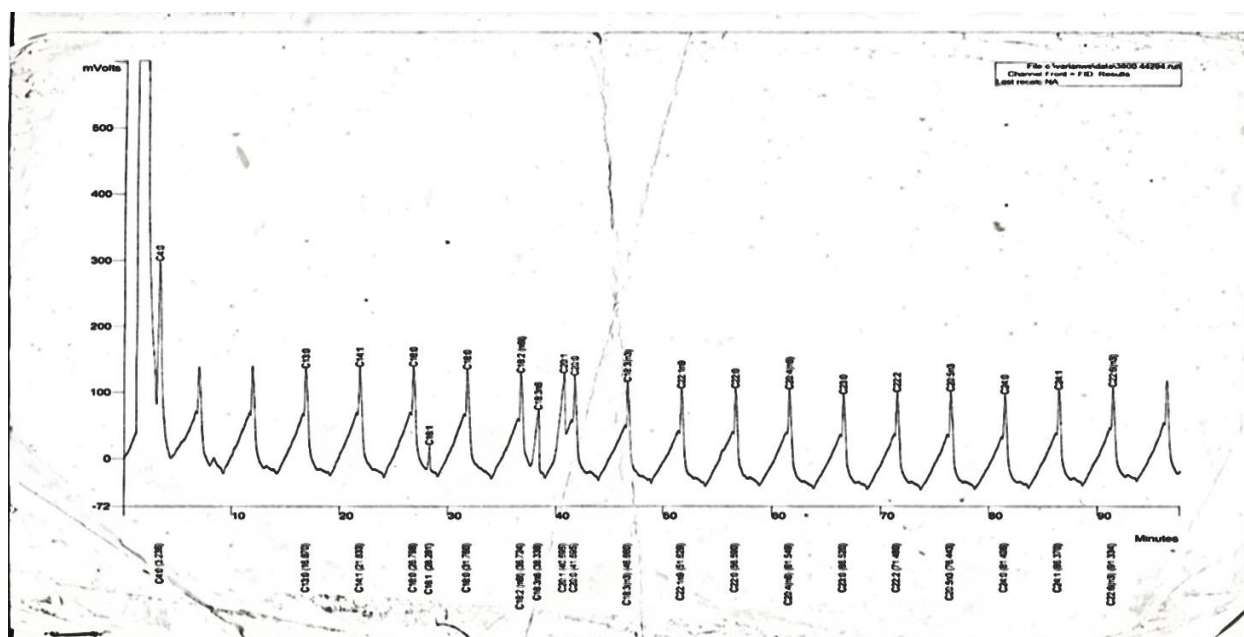


Figure ٣. GCFID chromatogram of *Mangifera Indica* oil (MIO)

Fatty-Acid Profile of *Jatropha curcas* Seed Oil

The GC-FID chromatogram of *Jatropha curcas* seed oil is presented in Figure ٤, while the corresponding fatty-acid composition is summarized in Table ٥. The chromatographic profile exhibited three prominent peaks within the retention time range of approximately ٤٠–٤٦ min, accompanied by several minor peaks of lower intensity. This pattern indicates that the oil composition is dominated by a limited number of major fatty acids, while other constituents occur in relatively smaller proportions. The fatty-acid analysis revealed that palmitic acid (C١٦:٠) was the predominant component, accounting for ٤٠,٩٤% of the total fatty-acid composition. The other major constituents were elaidic acid (C١٨:١) and linoleic acid (C١٨:٢), with concentrations of ٢٧,٤١% and ١٧,٨٥%, respectively. Collectively, these three fatty acids represented approximately ٨٦,٢٠% of the total fatty acids, confirming that *J. curcas* seed oil is primarily composed of C١٦ and C١٨ fatty-acid chains. Minor fatty-acid components identified included stearic acid (٦,٣٦%), palmitoleic acid (٣,١٨%), caprylic acid (١,٤١%), gondoic acid (٠,٩٢%), arachidic acid (٠,٤٥%), lauric acid (٠,٤٤%), myristic acid (٠,٢٥%), margaric acid (٠,٢٢%), tridecanoic acid (٠,١٦%), myristoleic acid (٠,١٥%), undecanoic acid (٠,١٥%), and pentadecanoic acid (٠,١٢%).

Overall, *J. curcas* seed oil contained approximately ٥٠,١٠% saturated fatty acids and ٤٩,٥١% unsaturated fatty acids, indicating an almost balanced distribution between saturated and unsaturated lipid components. This balanced fatty-acid composition distinguishes *J. curcas* oil from the highly unsaturated oils such as *Citrullus lanatus* and the highly oleic *Carica papaya* oil. The chromatographic profile supports this observation, as the oil displayed a few dominant peaks corresponding mainly to palmitic, elaidic, and linoleic acids. The presence of unsaturated fatty acids, particularly elaidic acid and linoleic acid, provides reactive carbon–carbon double bonds that may serve as functionalization sites for chemical modification reactions, including epoxidation, oxidation, esterification, polymerization, and other oleochemical transformations. These modifications may enable the development of renewable lipid-based intermediates for applications such as bio-based lubricants, surfactants, emulsifiers, and other specialty chemical products. However, further formulation and performance evaluation are required to establish their suitability for specific oilfield applications [٢٠–٢٣].

The relatively high concentration of saturated fatty acids, particularly palmitic and stearic acids, may contribute to improved oxidative stability, thermal resistance, and viscosity characteristics. This combination of saturated and unsaturated fatty acids provides a balance between chemical reactivity and structural stability, which is desirable for industrial feedstocks requiring both functionalization potential and storage stability.

The fatty-acid composition observed for *J. curcas* seed oil is consistent with its reported characteristics as a non-edible oil rich in palmitic, oleic, and linoleic acids. Compared with more highly unsaturated oils, the relatively balanced fatty-acid distribution may reduce oxidation susceptibility while maintaining sufficient reactive sites for chemical modification. Therefore, *J. curcas* seed oil represents a promising renewable feedstock for the production of modified oleochemical derivatives and bio-based functional materials.

Table 2 Fatty acid of *Jatropha curcas* seed oil (Appendix 2)

Name	Bond	Elution time (mins)	Area (%)
Caprylic acid	C ₈ : ₁	20.08	1.41
Undecylic acid	C ₁₁ : ₁	29.98	0.10
Lauric acid	C ₁₂ : ₁	30.03	0.54
Tridecanoic acid	C ₁₃ : ₁	34.04	0.16
Myristic Acid	C ₁₄ : ₁	36.10	0.20
Myristoleic acid	C ₁₄ : ₁	37.37	0.10
Pentadecanoic acid	C ₁₅ : ₁	38.71	0.12
Palmitic acid	C ₁₆ : ₁	40.22	40.94
Palmitoleic acid	C ₁₆ : ₁	41.09	3.18
Margaric acid	C ₁₇ : ₁	42.14	0.22
Stearic acid	C ₁₈ : ₁	43.96	6.36
Elaidic acid	C ₁₈ : ₁	44.68	27.41
Linoleic acid	C ₁₈ : ₂	46.02	17.80
Gondoic acid	C ₁₉ : ₁	47.74	0.92
Arachidic acid	C ₂₀ : ₁	48.36	0.40

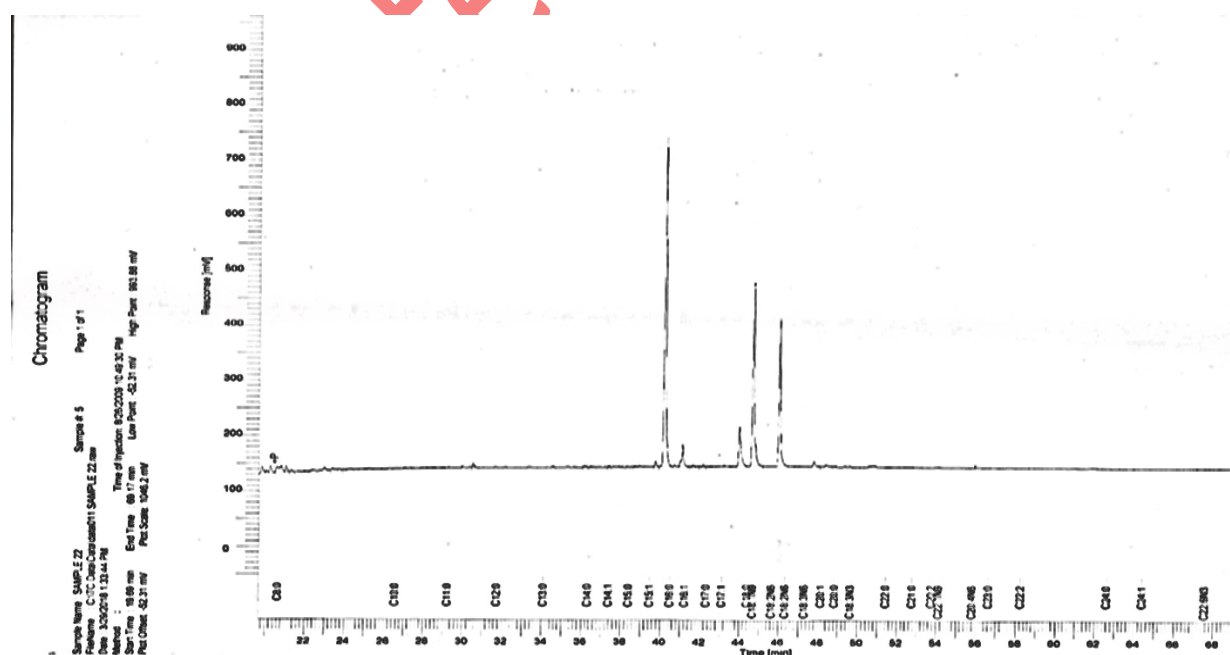


Figure 2: GC/FID chromatogram of *Jatropha curcas* oil (JCO)

GC/FID Analysis of *Citrus sinensis* seed oil

Fatty-Acid Profile of *Citrus sinensis* Seed Oil

The GC-FID chromatogram of *Citrus sinensis* seed oil is presented in Figure 9, while the corresponding fatty-acid composition is summarized in Table 6. The chromatographic profile exhibited three prominent peaks within the retention time range of approximately 30–45 min, accompanied by several minor peaks of lower intensity. This pattern indicates that the oil composition is mainly dominated by a few major fatty acids, with other lipid constituents occurring in relatively smaller proportions. The fatty-acid analysis revealed that oleic acid (C18:1) was the predominant component, accounting for 40.42% of the total fatty acids, followed by linoleic acid (C18:2) at 27.30% and palmitic acid (C16:0) at 18.67%. These three major fatty acids collectively accounted for approximately 86.49% of the total fatty-acid composition, confirming that *C. sinensis* seed oil is primarily composed of C16 and C18 fatty-acid chains. Minor fatty-acid constituents identified included stearic acid (0.77%), caprylic acid (1.24%), palmitoleic acid (0.81%), lauric acid (0.40%), myristic acid (0.21%), and gondoic acid (0.18%). Each of these components contributed less than 2% of the total fatty-acid composition. Overall, *C. sinensis* seed oil contained approximately 73.71% unsaturated fatty acids and 26.29% saturated fatty acids, demonstrating a clear predominance of unsaturated lipid components. The chromatographic profile supports this observation, as the largest peaks corresponded to oleic and linoleic acids, whereas saturated fatty acids appeared as comparatively smaller peaks. The high proportion of oleic and linoleic acids indicates that *C. sinensis* seed oil possesses a considerable degree of unsaturation, providing carbon–carbon double bonds that can serve as reactive sites for chemical modification. These structural features may facilitate oleochemical transformations such as epoxidation, hydroxylation, esterification, oxidation, polymerization, and other functionalization reactions [2–9]. Through such modifications, the oil may serve as a renewable precursor for the development of bio-based materials, including lubricants, surfactants, emulsifiers, and other specialty chemical intermediates. However, application-specific formulation and performance studies are necessary to establish its suitability for particular oilfield chemical applications. The relatively high unsaturated fatty-acid content enhances the chemical versatility of *C. sinensis* seed oil but may also increase its susceptibility to oxidative degradation, particularly because of the presence of linoleic acid. Nevertheless, the predominance of oleic acid, a monounsaturated fatty acid with greater oxidative stability than polyunsaturated fatty acids, provides a favourable balance between reactivity and stability. This characteristic may improve the storage and processing performance of the oil compared with highly polyunsaturated seed oils. Furthermore, the moderate peroxide value observed for *C. sinensis* oil suggests that oxidative deterioration was limited at the time of analysis. Additional stabilization approaches, such as antioxidant incorporation, controlled storage conditions, or selective chemical modification of unsaturated bonds, may further enhance its suitability for industrial applications. The fatty-acid profile of *C. sinensis* seed oil demonstrates that the oil possesses a favourable combination of high unsaturation, significant oleic acid content, and moderate oxidative stability. These characteristics support its potential as a sustainable renewable feedstock for the development of functional oleochemical derivatives and bio-based chemical products.

Table 6. Fatty acid of *Citrus sinensis* seed oil

Names	Bond	Elution time (mins)	Area (%)
Caprylic acid	C ₈ :0	20.81	1.24
Lauric acid	C ₁₂ :0	30.09	0.40
Myristic acid	C ₁₄ :0	36.20	0.21
Palmitic acid	C ₁₆ :0	40.10	18.67
Palmitoleic acid	C ₁₆ :1	40.93	0.81
Stearic acid	C ₁₈ :0	43.92	0.77
Oleic acid	C ₁₈ :1	44.66	40.42
Linoleic acid	C ₁₈ :2	40.98	27.30
Gondoic acid	C ₂₂ :1	47.70	0.18

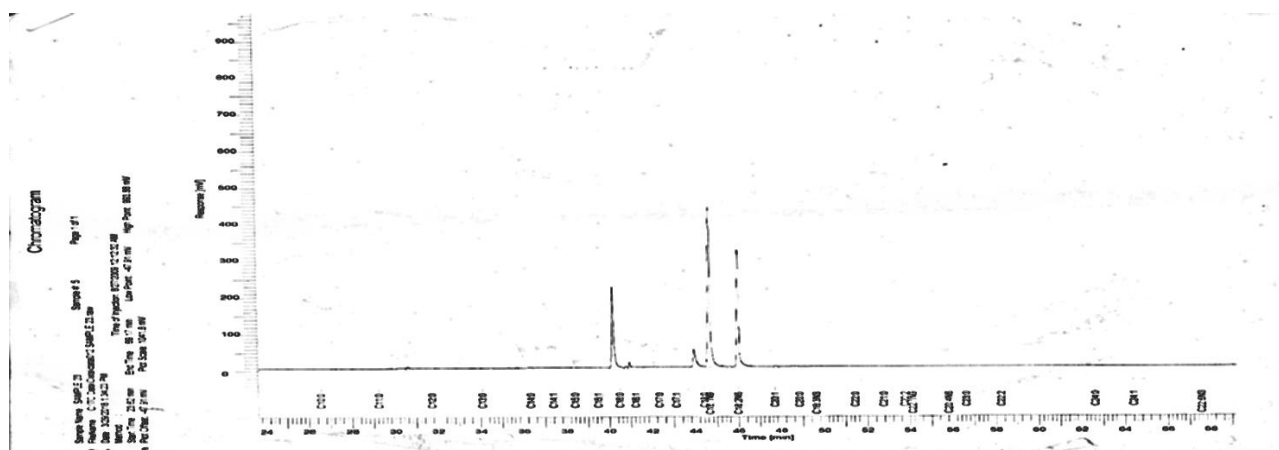


Figure 0: GC-FID chromatogram of *Citrus sinensis* oil (CSO)

Comparative Significance of the Fatty-Acid Profiles

The GC-FID results revealed substantial differences in the fatty-acid composition of the five investigated seed oils, demonstrating that each oil possesses distinct chemical characteristics relevant to oleochemical development. The total unsaturated fatty-acid contents followed the order: *Citrullus lanatus* (86.0%) > *Carica papaya* (78.4%) > *Citrus sinensis* (73.7%) > *Mangifera indica* (50.2%) > *Jatropha curcas* (49.0%). This trend was generally consistent with the iodine-value results, although the two parameters describe different aspects of unsaturation. The iodine value provides an overall measure of the degree of unsaturation based on the amount of iodine consumed by carbon-carbon double bonds, while the total unsaturated fatty-acid content represents the combined proportion of fatty acids containing one or more double bonds. Therefore, oils containing highly unsaturated fatty acids, particularly polyunsaturated fatty acids, may exhibit higher iodine values because each molecule contributes multiple reactive double bonds. Among the investigated oils, *C. lanatus* exhibited the highest proportion of unsaturated fatty acids, primarily due to its high linoleic acid (60.4%) and oleic acid (20.9%) contents. This composition provides a high density of reactive double bonds, making the oil a promising candidate for chemical transformations involving unsaturation, including epoxidation, hydroxylation, oxidation, polymerization, and other functionalization reactions. However, the high degree of unsaturation may also increase susceptibility to oxidative degradation, requiring appropriate stabilization strategies during storage and processing. Similarly, *C. papaya* seed oil exhibited a high unsaturated fatty-acid content, dominated by oleic acid (73.0%). Unlike highly polyunsaturated oils, the predominance of monounsaturated oleic acid provides a favourable balance between chemical reactivity and oxidative stability. This characteristic may make *C. papaya* oil suitable for applications where both functionalization potential and improved storage stability are required. *Citrus sinensis* seed oil also showed considerable unsaturation (73.7%), mainly contributed by oleic acid (40.4%) and linoleic acid (27.3%). The combination of monounsaturated and polyunsaturated fatty acids suggests that this oil possesses useful chemical versatility while maintaining moderate oxidative stability.

In contrast, *Jatropha curcas* seed oil exhibited a nearly balanced saturated and unsaturated fatty-acid composition, containing approximately 49.0% unsaturated and 50.9% saturated fatty acids. The relatively high proportions of palmitic acid (40.9%) and stearic acid (6.3%) may contribute to improved oxidative resistance, thermal stability, and viscosity characteristics. This balanced composition may be advantageous for applications requiring greater structural stability rather than maximum chemical reactivity. Although *Mangifera indica* seed oil showed the lowest unsaturated fatty-acid content among the investigated oils, it still contained a substantial proportion of unsaturated components (50.2%). The presence of gondoic acid, α -linolenic acid, linoleic acid, and other unsaturated constituents provides potential reactive sites

for chemical modification. Furthermore, the relatively higher saturated fatty-acid fraction and high phenolic content observed for this oil may contribute to improved oxidative stability and make it a valuable candidate for blending or applications where enhanced stability is required.

Overall, the GC-FID results demonstrate that these underutilized seed oils should not be evaluated solely based on their degree of unsaturation. Instead, their suitability as renewable feedstocks depend on the relationship between fatty-acid composition, oxidative stability, oil availability, and the specific chemical transformation required. The combined physicochemical and fatty-acid characterization confirms that these oils provide diverse renewable platforms for the development of tailored bio-based oleochemicals and potential oilfield chemical additives through appropriate modification and formulation strategies.

Conclusion

The potential of five underutilized seed oils (*Mangifera indica*, *Citrus sinensis*, *Citrullus lanatus*, *Carica papaya*, and *Jatropha curcas*) as renewable feedstocks for the development of bio-based oilfield chemical precursors was evaluated through physicochemical characterization and gas chromatography–flame ionization detection (GC-FID) analysis. The investigated oils, demonstrated diverse chemical characteristics that provide opportunities for their valorization into value-added oleochemical products. The physicochemical results revealed considerable variations in oil yield and quality parameters among the investigated samples. The highest oil yields were obtained from *Citrullus lanatus* (٥٨,٦٨%) and *Jatropha curcas* (٥٦,٥٠%), which were comparable with the soybean oil reference, whereas *Mangifera indica* exhibited the lowest yield (١٢,٠١%). Despite the lower yield, *M. indica* showed valuable chemical characteristics, including the highest phenolic content, which may contribute to improved oxidative stability and potential functional advantages in modified oleochemical systems.

The GC-FID results demonstrated significant differences in fatty-acid composition among the oils, with total unsaturated fatty-acid contents following the order: *Citrullus lanatus* (٨٦,٠٠%) > *Carica papaya* (٧٨,٤٦%) > *Citrus sinensis* (٧٢,٧١%) > *Mangifera indica* (٥٥,٢٦%) > *Jatropha curcas* (٤٩,٥١%). The high unsaturation observed in *C. lanatus*, *C. papaya*, and *C. sinensis* was mainly associated with their oleic and linoleic acid contents, providing reactive carbon–carbon double bonds suitable for chemical functionalization. In contrast, the relatively balanced saturated and unsaturated fatty-acid composition of *J. curcas* and the higher saturated fatty-acid fraction of *M. indica* may provide improved oxidative stability and structural characteristics. The presence of chemically reactive fatty acids and ester functionalities indicates that these oils possess suitable molecular platforms for modification reactions, including epoxidation, oxidation, esterification, transesterification, polymerization, copolymerization, and metathesis. Such transformations may enable the production of tailored bio-based oleochemical derivatives with potential applications as lubricants, emulsifiers, demulsifiers, corrosion-inhibiting materials, drilling-fluid additives, and other specialty chemical intermediates. Overall, the findings demonstrate that these underutilized seed oils should not be considered direct substitutes for petroleum-derived chemicals but rather as renewable carbon sources that can be chemically engineered into functional materials with application-specific properties. Their valorization provides an opportunity to reduce dependence on conventional petrochemical feedstocks, improve agricultural resource utilization, and support the development of sustainable oleochemical production pathways.

Future studies should focus on the chemical modification of the most promising oils identified in this work, followed by detailed structural characterization, toxicity assessment, environmental evaluation, and performance testing of the resulting bio-based oilfield chemical formulations under relevant operational conditions.

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Declaration of Generative AI Use

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) solely to improve the readability and clarity of the text. The authors critically reviewed and revised the AI-assisted text and take full responsibility for the accuracy, integrity, and final content of the manuscript.

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