

PHYSICOCHEMICAL AND QUALITY ASSESSMENT OF EGYPTIAN-GROWN PALM OIL FOR ADVANCING SUSTAINABLE DEVELOPMENT IN EGYPT

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ABSTRACT

Palm oil is a globally substantial vegetable oil, traditionally produced in Southeast Asia. However, expanding cultivation of oil palm in new regions provides prospects for diversification, sustainability, and regional economic development. Therefore, this pioneering study aimed to present physicochemical and quality assessment of palm oil produced from the Egyptian-grown palm trees. This is the first reported extraction of crude palm oil (CPO) and crude palm kernel oil (CPKO), utilising fresh fruit bunches (FFBs) from six-year-old *Elaeis guineensis* (Nigerian tenera hybrid) palm trees. Results revealed high oil yields ($30.64 \pm 0.74\%$ mesocarp; $25.23 \pm 0.33\%$ whole fruit), with both oils showing excellent quality parameters manifested in low acidity (CPO: 1.42 ± 0.01 ; CPKO: 0.14 ± 0.01), peroxide values (PV) within standards, and favorable fatty acid profiles, dominated by oleic acid ($39.94\% \pm 0.04$) in CPO and lauric acid ($44.83\% \pm 0.24$) in CPKO. Storage stability assessments indicated shelf lives exceeding 16 months for CPO and 40 months for CPKO, reflecting robust oxidative stability. These findings confirm the potential of Egyptian-grown oil palms as a sustainable, high-quality source of palm oil, supporting regional diversification and industrial applications aligned with the Sustainable Development Goals (SDGs).

Keywords: crude palm kernel oil and crude palm oil, Egypt, *Elaeis guineensis*, physicochemical and quality assessment, *Tenera* variety.

Received: 29 October 2025; **Accepted:** 29 July 2026; **Published online:** 16 October 2026.

INTRODUCTION

About 35% of all vegetable oil produced worldwide comes from palm oil, making it a vital component of both industrial supply chains and agricultural economies. With 25.8% of global production, Malaysia is a key player among the top producers (Goh et al., 2025). In the early 1870s, African oil

palm (*Elaeis guineensis*) was brought to Malaya from West Africa primarily as an ornamental plant (Zainal et al., 2024). The tropical rainforest climate of Malaysia is well-suited for oil palm cultivation, which has expanded to cover over 5.6 million hectares (Parveez et al., 2025).

The *E. guineensis* is a member of the *Arecaceae* family, producing oil palm fruit (OPF) in clustered bunches. Each fruit features an outer skin, fleshy pulp, protective shell and inner kernel, with oil extracted from the mesocarp (CPO) and kernel (CPKO). The African oil palm is categorised into *dura*, *pisifera*, and *tenera* varieties based on endocarp thickness; *tenera* is a hybrid of *dura* & *pisifera*. *E. guineensis* is characterised by a balanced fatty acid profile, making it suitable for frying and other food industry uses. The demand for palm oil as a key player in the global vegetable oil market has risen

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due to population growth and its versatility in food and non-food uses, including biofuel applications (Alhaji et al., 2024).

Oil palm rapid expansion has led to the conversion of biodiversity-rich areas into extensive plantations (Acobta et al., 2025), due to its cost-efficiency, with 6–10 times more productivity compared with other oilseed crops (Stradling et al., 2025). Growing demand for palm oil worldwide, driven by food processing (Tang et al., 2025), encouraged individual smallholders and agro-industrial firms to expand their oil palm operations (Suherman et al., 2025).

By-products, such as palm kernel cake, palm fronds, and solid decanter, can be formulated into nutritional and ecologically sustainable cattle feed (Santoso et al., 2025). Sustainability was implemented by combining oil palm cultivation with cattle farming, utilising by-products for cattle feed and using the cattle manure as organic fertiliser (Rohaeni et al., 2025).

Water, oil and free fatty acid (FFA) concentrations are important internal quality indicators for determining the maturity and overall quality of oil palm fresh fruit bunches (FFBs). These characteristics have a considerable impact on the efficiency of oil extraction and the quality of CPO produced. The biochemical composition of FFB, including moisture content and lipid profile, has a direct impact on the extracted oil's physicochemical qualities. High-quality FFB is often distinguished by low residual water content and FFA levels, lowering the risk of spoiling, hydrolysis and soap generation during processing. High water and FFA concentrations, on the other hand, might make processing more difficult, raise refining costs, and diminish oil stability. Furthermore, a high oil content in the FFB is desirable since it correlates with increased oil yield per bunch, increasing economic returns. Maintaining appropriate internal quality features in FFB is thus critical for manufacturing high-grade CPO with desirable physicochemical and nutritional properties, which eventually affects market value and consumer acceptance of the end product (Nanda et al., 2025).

Climate change significantly affects oil palm plantations, mainly through changes in temperature, rainfall and humidity. Most studies focus on Southeast Asia, particularly Malaysia (palm oil represents 5% of exports) and Indonesia (palm oil represents 10% of exports), as the major producers of the *E. guineensis* cultivar (Thompson-Morrison et al., 2024), with limited studies in Africa and South America. Strategies to mitigate climate change effects include certification frameworks like the Roundtable on Sustainable Palm Oil (RSPO), Malaysian Sustainable Palm Oil (MSPO) and Indonesian Sustainable Palm Oil (ISPO). Effective adaptation has proceeded for developing

climate-resilient cultivars that tolerate varying environmental stressors, enabling continued productivity amid extreme conditions (Wulandari et al., 2025).

In recent years, the demand for palm oil has expanded into regions where local production is limited, including the Middle East and North Africa, prompting interest in evaluating the quality of palm oil produced within these regions. The increasing consumption of imported edible oils has sponsored rising interest in producing new cultivars, with distinctive characters varying from the traditional imported sources to be suitable for increasing production in the importing countries (Abd El-Baset et al., 2024). Therefore, the current study aimed to determine whether palm oil produced from locally cultivated oil palm in Egypt meets established international quality requirements. Its specific goal was to evaluate the physicochemical characteristics and quality of palm oil produced in Egypt to internationally accepted standards. By identifying the key factors that determine oil quality, this study hopes to create acceptable standard quality requirements for locally produced oils. Overall, the findings will provide insights on how to improve processing procedures, enforce quality standards and promote sustainable palm oil production in Egypt.

MATERIALS AND METHODS

Materials

The present study was carried out at the Horticultural Research Institute, Agricultural Research Centre, Giza, Egypt, with geographical coordinates 30° 00' 34" N, 31° 12' 31" E, where the *E. guineensis* trees of 6-year-old (Figure 1), cultivated by hybrid seeds of the *tenera* variety imported from Nigeria, West Africa, in 2019. The mature FFB (the 2nd year of fruiting) were used for investigation of morphological characteristics and oil extraction (Figure 2).

All chemicals and solvents used in the study were of analytical and high-performance liquid chromatography (HPLC) grade and were obtained from Sigma-Aldrich, USA.

Methods

Sampling, handling and pre-processing procedures. In this study, FFBs were harvested from a well-kept oil palm farm in Giza, Egypt. To ensure representativeness and account for variability across individual palms, three separate FFB samples were collected at random from different oil palms in the same plantation. To ensure consistency, the palms were chosen at similar ages and growth stages.



Figure 1. The *Elaeis guineensis* trees grown at Giza, Egypt.



Figure 2. Fresh fruit bunch (FFB) with transverse sections.

Each sample contained a sufficient number of ripe FFBs, representing the overall crop maturity. The FFB samples were immediately placed in clean, perforated polypropylene baskets to allow for aeration and prevent condensation development. To minimise metabolic changes and microbial activity, the samples were transported to the laboratory under chilled circumstances, at a temperature of about 4°C. The samples were processed within 2 hr of arrival to ensure their freshness and quality.

Pre-processing and sample preservation. In the laboratory, the FFB samples were precisely cleaned to remove any excess debris and grime. The fruits were then autoclaved at 121°C for 15 min to remove microbial contamination and deactivate enzymes that could affect oil quality. After sterilisation, the fruits were allowed to cool before being manually sorted into mesocarp and kernels. The samples were then processed immediately after sterilisation to extract crude oils using conventional techniques.

Extraction of CPO and CPKO. A flow chart detailing the extraction processes of CPO and CPKO (Figure 3) shows the extraction process of CPO using the screw press configuration from the fresh fruit mesocarp (flesh) after sterilisation by autoclave at 121°C for 15 min, threshing, digesting & mashing, pressing, clarification & filtration,

drying & storage. While CPKO was extracted from the kernels, which were separated after removing fibre during nut recovery, nut cracking, kernel separation and cleaning, drying and grinding, soaking in pure n-hexane for 48 hr at room temperature, clarification and filtration, drying and storage after collecting miscella, filtered three times using pure solvent to extract CPKO. Then the combined miscella was desolventised under vacuum at 40°C. The CPO and CPKO were dried using anhydrous sodium sulfate and filtered using a Whatman No. 1 filter paper, then transferred into dark brown glass bottles and kept at -18°C till analysis.

Analytical Methods

Analysis of morphological characteristics and sectioning of oil palm fruits. Morphological characteristics of oil palm fruits were determined, starting with the apparent colour of the well-developed fruits and measurement of length and diameter using a precision calliper. Internal structure of fruits was examined after making many longitudinal and cross-sections using a sterilised scalpel for the examination of mesocarp and kernel development; then images were captured in high-resolution to document the morphology and measurements (Martin et al., 2025).

Moisture and oil contents of CPO and CPKO. Moisture contents in CPO and CPKO were determined according to ISO 662:2016 (International Organisation for Standardisation [ISO], 2016), whereas oil contents were determined according to ISO 659:2009 (ISO, 2009).

Physicochemical characteristics of CPO and CPKO. The physicochemical characteristics of CPO and CPKO under study were classified into two groups of analyses of physical and chemical characteristics.

Physical characteristics of CPO and CPKO. Physical characteristics determined according to the Palm Oil Research Institute of Malaysia (PORIM) Test Methods as the official methods of analysis (PORIM, 1995) were: Refractive index (at 50°C for CPO; 40°C for CPKO), relative density (at 50°C for CPO; 40°C for CPKO: Water at 20°C), apparent density (kg/L) (at 50°C for CPO; 40°C for CPKO), slip melting point and colour measurement.

Chemical characteristics of CPO and CPKO. Chemical characteristics determined according to the PORIM Test Methods (PORIM, 1995) were: Solid fat content (SFC) (at 5°C, 10°C, 15°C, 20°C, 25°C, 30°C, 35°C and 40°C), acidity, peroxide value (PV) and carotene content, with determination of

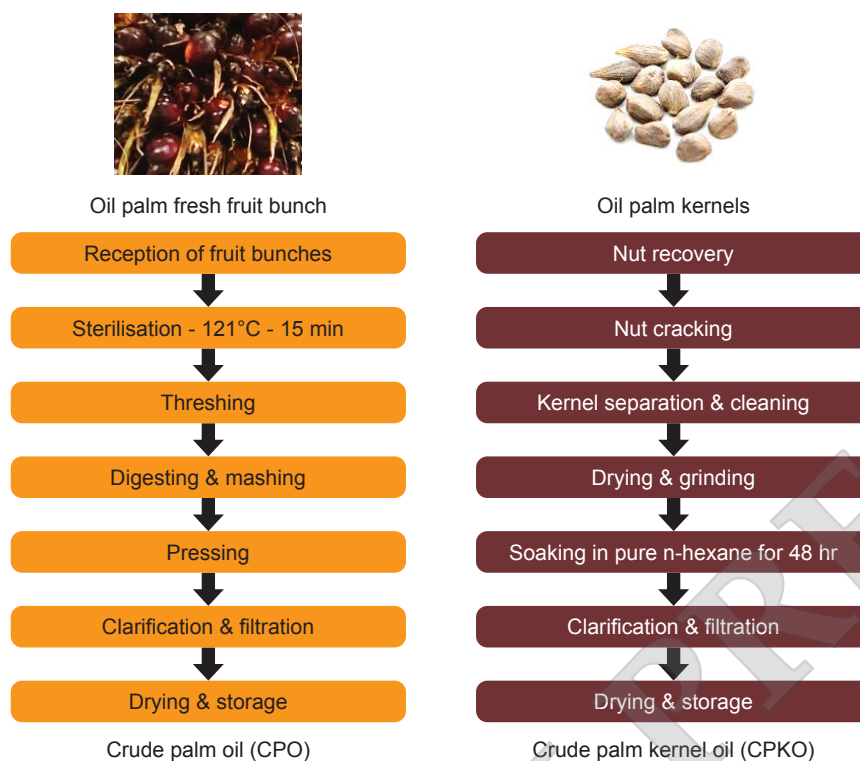


Figure 3. A flow chart detailing the extraction processes of CPO and CPKO.

saponification value (SV) (American Oil Chemists' Society [AOCS], 2024b), unsaponifiable matter (USM) (AOCS, 2024c), oxidative stability (AOCS, 2024a), fatty acid composition (ISO, 2017) and iodine value (IV) by calculation from the fatty acid composition (Kyriakidis & Katsiloulis, 2000).

Statistical Analysis

All measurements were performed in triplicate. Data were presented as mean $\pm$ standard deviation (SD). Analysis of variance (ANOVA) was conducted with SPSS software at $P < 0.05$.

RESULTS AND DISCUSSION

Analysis of Morphological Characteristics and Sectioning of Oil Palm Fruits

The morphological characteristics of oil palm fruits, like size, colour, mesocarp and kernel ripeness development, offer interesting insights into the productivity of CPO and CPKO, expressed as quality and yield, depends on the quality of produced FFB arriving at the laboratory. Loose fruits with longitudinal and cross-sections in the fruit sample revealed the appropriate maturity and readiness for oil extraction. Nevertheless, the variety and age of the tree, agronomic, environmental, handling and transportation conditions, and harvesting technique used also have significant effects on oil properties.

The yellowish base of the fruit and easy detachment of the fruit from the bunches were indicators utilised for fruit maturity and readiness for oil extraction.

The data summarised in Table 1 show that the average fruit weight was 13 g and the cross-sections in the fruit showed the soft, oily flesh (the mesocarp) and the white kernel. Both fruit components (mesocarp and kernel) were subjected to oil extraction. The fruits have an average dimension of 5 cm in length and 3 cm in diameter. Measurements of proportions of fruit to bunch, mesocarp to fruit, shell to fruit and kernel to fruit mean values were 66.66%, 82.32%, 10.26% and 7.50%, respectively. The mesocarp and kernel demonstrated considerably high oil content of 62.12% and 56.16%, respectively, on a dry basis, with oil contents of 42.41% and 45.04%, on a wet basis, respectively. Measurements of proportions of oil to wet mesocarp were 30.64%, oil to whole fruit was 25.23%, and oil to bunch was 15.14%. Moisture content in mesocarp (31.73%) was greater than the value in kernel (19.80%). The obtained results agreed with Ramli et al. (2025).

Physicochemical Characteristics of CPO and CPKO

Table 2 summarises the physicochemical characteristics of the extracted CPO and CPKO. These evaluated parameters provide useful information on the physical and chemical properties of the studied oils, compared with the Codex Standard values (Codex Alimentarius Commission [CAC], 2024).

TABLE 1. AVERAGE MEASUREMENTS OF FRESH FRUIT BUNCH (FFB) COMPONENTS

Fruit components	Measurement
Fruit weight (g)	13.00 ± 0.33
Fruit length (cm)	5.00 ± 0.23
Fruit diameter (cm)	3.00 ± 0.07
Fruit to bunch (%)	66.66 ± 0.50
Mesocarp to fruit (%)	82.32 ± 0.76
Shell to fruit (%)	10.26 ± 0.11
Kernel to fruit (%)	7.50 ± 0.08
Oil to wet mesocarp (%)	30.64 ± 0.74
Oil to whole fruit (%)	25.23 ± 0.33
Oil to bunch (%)	15.14 ± 0.13
Moisture (%) of mesocarp	31.73 ± 0.09
Moisture (%) of kernel	19.80 ± 0.21
Oil (%) of mesocarp on dry weight	62.12 ± 0.96
Oil (%) of kernel on dry weight	56.16 ± 0.55
Oil (%) of mesocarp on wet weight	42.41 ± 0.32
Oil (%) of kernel on wet weight	45.04 ± 0.63

Note: Values are mean ± standard deviation (n = 3).

Physical Characteristics of CPO and CPKO

Physical characteristics of CPO and CPKO, including refractive index (RI), relative density, apparent density, slip melting point and colour, were determined and compared to those of Codex Standard (CAC, 2024). RI can be used in the identification of oils and for the estimation of the degree of unsaturation. The RI of CPO was 1.4556, whereas the RI of CPKO was 1.4518, with a significant difference ($P < 0.05$). These results were closer to those of the Codex Standard (CAC, 2024). The values obtained in this study reflect the degree of unsaturation and the chain length, and are expected to indicate the presence of oleic ($C_{18:1}$) and linoleic ($C_{18:2}$) acids in the proportions observed. These data are in accordance with Almoselhy et al. (2021), Léonce et al. (2021), and Ramli et al. (2020).

Also, as shown in Table 2, the apparent density (0.8943) and relative density (0.8983) of CPO at 50°C both complied with specified limits. In contrast, the relative density of CPKO at 40°C recorded a lower value (0.8877) than the Codex Standard (CAC, 2024). The slip melting point of CPO is 34.5°C,

TABLE 2. PHYSICOCHEMICAL CHARACTERISTICS OF CRUDE PALM OIL (CPO) AND CRUDE PALM KERNEL OIL (CPKO)

Characteristics	CPO	Codex Standard	CPKO	Codex Standard
Refractive index (at x°C)	1.4556 ± 0.0001 ^a x = 50°C	1.454–1.456	1.4518 ± 0.0001 ^b x = 40°C	1.448–1.452
Apparent density (at x°C)	0.8943 ± 0.0002 ^a x = 50°C	0.889–0.895	0.8794 ± 0.0002 ^b x = 40°C	n.a.
Relative density (x°C/ water 20°C)	0.8983 ± 0.0002 ^a x = 50°C	0.891–0.899	0.8877 ± 0.0002 ^b x = 40°C	0.899–0.914
Slip melting point (°C)	34.5 ± 0.15 ^a	n.a.	28.1 ± 0.14 ^b	n.a.
Color	R 16 ± 0.1 ^a Y 20 ± 0.1 ^a	n.a. n.a.	R 2 ± 0.1 ^b Y 20 ± 0.1 ^a	n.a. n.a.
Acidity (%)	1.42 ± 0.01 ^a	Max 5	0.14 ± 0.01 ^b	Max 5
Peroxide value (meq. O ₂ /kg oil)	7.66 ± 0.01 ^a	Max 15	1.47 ± 0.01 ^b	Max 15
Iodine value (g I ₂ /100 g oil)	60.74 ± 0.02 ^a	50.0–55.0	20.86 ± 0.01 ^b	14.1–21.0
Saponification value (mg KOH/ g oil)	197.14 ± 0.23 ^b	190–209	234.05 ± 0.31 ^a	231–244
Unsaponifiable matter (%)	0.63 ± 0.01 ^a	≤1.20	0.38 ± 0.01 ^b	≤1.00
Carotene content (ppm)	389.70 ± 0.74 ^a	500–2,000	23.00 ± 0.34 ^b	n.a.
Solid fat content (SFC) (%) at temperature				
5°C	50.60 ± 0.13 ^b	n.a.	70.01 ± 0.26 ^a	n.a.
10°C	40.30 ± 0.11 ^b	n.a.	67.00 ± 0.22 ^a	n.a.
15°C	29.50 ± 0.15 ^b	n.a.	55.70 ± 0.21 ^a	n.a.
20°C	11.90 ± 0.17 ^b	n.a.	40.00 ± 0.31 ^a	n.a.
25°C	6.70 ± 0.14 ^b	n.a.	17.10 ± 0.19 ^a	n.a.
30°C	3.80 ± 0.11 ^a	n.a.	0.20 ± 0.13 ^b	n.a.
35°C	1.60 ± 0.09 ^a	n.a.	0.12 ± 0.11 ^b	n.a.
40°C	0.20 ± 0.06 ^a	n.a.	0.06 ± 0.07 ^b	n.a.
Oxidative stability (hr) at 110°C by Rancimat	16.08 ± 0.03 ^b	n.a.	40.51 ± 0.03 ^a	n.a.

Note: R - red; Y - yellow; n.a. - not available; values are mean ± standard deviation (n = 3). Means in the same row with different superscripts are significantly different ($P < 0.05$).

which was very close to body temperature, while CPKO was at 28.1°C with a significant difference ($P < 0.05$). Regarding the colours of the tested oils, their values ranged from 2.00 on the red scale in CPKO to 16.00 in CPO, with a significantly higher value of red colour for CPO, which appears in its apparent red colour. Whereas CPO and CPKO have identical values of yellow colour (20.00). The obtained measures were in harmony with those of De Almeida et al. (2021), Léonce et al. (2021) and Ramli et al. (2020).

Chemical Characteristics of CPO and CPKO

Determination of chemical characteristics of an edible oil is pivotal and crucial to identify the quality and safety of the oil and its suitability to be utilised as food for human consumption via food processing, such as in cooking and deep frying, along with other industrial uses of vegetable oils in non-food manufacturing of cosmeceuticals, cosmetics and soap industries. Measured values were compared with standards stipulated by the Codex Standard (CAC, 2024).

Thus, concerning the above-mentioned chemical characteristics, the results in Table 2 revealed that the acidity (% FFA) in CPO and CPKO was lower than that of the Codex Standard (CAC, 2024), as they were 1.42% and 0.14%, respectively, with a significant difference ($P < 0.05$). It is widely documented in the field of edible oil quality assessment that a reduced acidity level in vegetable oils correlates directly with improved oil quality. This is because the acidity of vegetable oil is mostly determined by the presence of FFAs, which are formed during the hydrolysis of triglycerides during processing, storage, or incorrect handling. Elevated FFA levels are generally indicative of degradation, hydrolysis, or spoiling, which can have a detrimental impact on the oil's sensory attributes, nutritional value and stability. Conversely, a decrease in acidity, as seen by a decreased FFA percentage, indicates that the oil has experienced minimal hydrolysis and oxidation, preserving its purity, freshness, and overall quality. As a result, monitoring and managing acidity levels is crucial to producing high-quality vegetable oils for consumption, processing and long-term storage. The present content of FFAs in CPO was determined as palmitic acid, and in CPKO was determined as lauric acid. High-quality FFB are characterised by low residual water content and low FFA levels, which are significantly affected by post-harvest handling, storage duration and rapid processing to minimise lipase activity and hydrolysis.

The PV detects the early stages of lipid oxidation, which indicates the presence of peroxides and hydroperoxides produced during oxidative

degradation. It is a reliable measure of oil freshness and shelf life. Elevated PV indicates oxidative rancidity, which results in unpleasant tastes, smells and nutritional loss. Low PV is crucial for oils used for direct consumption, frying, or long-term storage (Almoselhy et al., 2020). Therefore, it is crucial to determine the PV as a measure of the extent of oxidation of a fat or oil. CPO and CPKO had PV values of 7.66 and 1.47, respectively, with a significant difference ($P < 0.05$), which were within the limits stipulated by the Codex Standard (CAC, 2024).

The IV measures the degree of unsaturation in fats and oils. Higher IV indicates more unsaturated bonds, which affects oil fluidity, nutritional composition and oxidative stability. Oils with a high IV (greater unsaturation) are more susceptible to oxidation, which reduces shelf life and stability, particularly during frying or storage. Oils having a lower IV are more saturated and stable with less fluidity. Oils are classified into drying, semi-drying, and non-drying according to their IV. CPO exhibited a moderate level of unsaturation, as indicated by an IV of 60.74, which is threefold that of CPKO (20.86) with a significant difference ($P < 0.05$). According to the Codex Standard (CAC, 2024), the IV of CPO (60.74) was marginally higher than the typical Codex specification (50.00–55.00), whereas that of CPKO (20.86) fell well within the established range of 14.1–21.0. These variations in IV may be attributed to natural agricultural variability or analytical factors. Nonetheless, both oils can be categorised as non-drying oils whose IV is less than 100 and generally aligns with Codex requirements.

The SV indicates the average molecular weight of fatty acids, which determines soap production. SV is related to the average molecular weight of an edible oil, giving an idea about the nature of the chain length of the fatty acids. CPO had lower SV (197.14) than CPKO (234.05) with a significant difference ($P < 0.05$). The obtained results agreed with the limits set by the Codex Standard (CAC, 2024).

The USM represents bioactive substances such as sterols and carotenoids, which influence nutritional and functional qualities. The USM content was 0.63% for CPO and 0.38% for CPKO, with a significant difference ($P < 0.05$). These values agree with the limits specified by the Codex Standard (CAC, 2024). The carotene content of CPO was 389.70 ppm, which is responsible for the orange-red colour of CPO and contributes to the stability and nutritional properties of palm oil as the richest natural plant source of carotenes; however, this value of carotene is slightly lower than the reference value (500–2,000 ppm) set by the Codex Standard (CAC, 2024). This finding may be due to the newly cultivated attributes,

which will be enhanced to meet the standards in time. The carotene content of CPKO was much lower (23.00 ppm) with a significant difference ($P < 0.05$).

The SFC influences texture, melting behaviour and application appropriateness. Controllable parameters include fatty acid composition, processing temperatures and blending. SFC refers to the content of fat in an edible oil that is solid at a given temperature, but it can transform into other forms, such as semi-solid, semi-liquid, or liquid at another temperature. SFC is considered a substantial property in the characterisation of an edible oil, as it related to the functionality of edible oil and its suitability to various applications in different physical forms ranging from solid, semi-solid and liquid, as the SFC influences the texture, stability, fluidity of an edible oil to be suitable for industrial applications in manufacturing of confectionery products, shortening and margarine. SFC is related to many organoleptic attributes needed to satisfy the needs of consumers. In this study there was significant variations were observed in the values of SFC at different temperatures and among different oils (CPO vs. CPKO). The measured values of SFC at different temperatures for CPO were: 50.60% (5°C), 40.30% (10°C), 29.50% (15°C), 11.90% (20°C), 6.70% (25°C), 3.80% (30°C), 1.60% (35°C), 0.20% (40°C). Whereas the measured values of SFC at different temperatures for CPKO were recorded: 70.01% (5°C), 67.00% (10°C), 55.70% (15°C), 40.00% (20°C), 17.10% (25°C), 0.20% (30°C), 0.12% (35°C), 0.06% (40°C). The variation in values of SFC at different temperatures among the two oils under study, CPO and CPKO, is well related to the chemical composition of the two oils and the fatty acid composition, which will be discussed later, to show that the different fatty acid profiles have different attributes and effects on many physicochemical characteristics.

Oxidative Stability of CPO and CPKO

CPKO had the highest induction period 40.51 hr, indicating greater oxidation resistance. The oxidative stability of CPKO was about 2.5 times that of CPO (16.08 hr.). Consequently, the superior resistance of CPKO was attributed to the lower IV, less linoleic acid and higher percentage of saturated fatty acids in this oil compared to the CPO. The high percentage of palmitic and oleic acids in CPO makes it desirable in terms of high stability during cooking and frying. It is worth mentioning that the oil industry has given much attention to high oleic vegetable oils. Subsequently, it could be concluded that the tested oils had relatively high stability against oxidation, which makes the oils very useful for healthy edible oils and some food industry applications.

Fatty Acid Composition of CPO and CPKO

The fatty acid composition of CPO and CPKO is tabulated in *Table 3*. The predominant fatty acid composition in CPO shows high contents of palmitic acid ($C_{16:0}$) at 38.50% and 39.94% for oleic acid ($C_{18:1}$). It is noteworthy to mention the slightly lower value of palmitic acid compared to the Codex Standard for palmitic acid (39.30%–47.50%) and oleic acid (36.0%–44.0%). For CPKO, lauric acid ($C_{12:0}$) was the predominant fatty acid, with an amount of 44.83%. This was marginally lower than the reference range of 45.00%–55.00% established by the Codex Standard (CAC, 2024).

A variety of environmental and agronomic factors could explain the observed discrepancies in the main fatty acid concentrations of CPO and CPKO. These variances could be related to the region's unique environmental variables, such as temperature swings, rainfall patterns and humidity levels, all of which can have an impact on lipid biosynthesis in oil palm trees. The Egyptian climate particularly poses distinct problems, with high daytime temperatures averaging approximately 30°C–35°C and lower nocturnal temperatures, combined with sporadic and limited rainfall, all of which influence plant growth and oil buildup. Soil type is also important; in Egypt, sandy or calcareous soils with low organic matter concentration might have an impact on nutrient availability and root development, influencing fatty acid composition. Furthermore, the relatively short time of cultivation and the young age of the trees in the early planting stages may lead to variances in oil composition, as maturity indices such as bunch weight, oil content, and fruit ripeness are still evolving. Agronomic methods such as irrigation scheduling, fertilisation regimes, and pest management all have an impact on the physiological status of the young palm trees, which in turn affects the fatty acid profile of the oils produced. The environmental and managerial factors explain the observed differences. It highlights the need to modify cultivation methods to improve oil quality in Egypt's climate.

In addition, the CPKO contained appreciable amounts of short-chain fatty acids such as caprylic ($C_{8:0}$) and capric ($C_{10:0}$) acids. Regarding fatty acid saturation, the CPKO is indeed highly saturated compared to CPO. It was found that the saturated fatty acid content was 78.50% in CPKO, while it was 44.83% in CPO. The obtained results agreed with the limits prescribed by the Codex Standard (CAC, 2024). Monounsaturated fatty acids count for 40.24% and 18.78%, and polyunsaturated for 14.93% and 2.72%, in CPO and CPKO, respectively. This typical composition of CPKO is reflected in its IV (20.86), which is significantly less compared to CPO (60.74). From the thorough examination of the fatty acid composition in *Table 3*, it is perceived

that CPO contains 44.83% saturated fatty acids and 55.17% unsaturated fatty acids, which comprise monounsaturated and polyunsaturated fatty acids at 40.24% and 14.93%, respectively. Whereas CPKO contains 78.50% saturated fatty acids and 21.50% unsaturated fatty acids, with the total percentages of monounsaturated and polyunsaturated fatty acids at 18.78% and 2.72%, respectively. These findings relate to the high SFC in CPKO at low temperatures (5°C–25°C) compared to CPO with lower SFC at the same range of temperatures, which is also due to the higher percentage of unsaturated fatty acids (55.17%) compared to the lower percentage of unsaturated fatty acids (21.5%) in CPKO.

Comparison of Egyptian Palm Oil with Malaysian and Indonesian Palm Oils

When comparing Egyptian palm oil to Malaysian and Indonesian palm oils, the leading worldwide producers, the physicochemical and fatty acid profiles reveal significant parallels and variances. Egyptian palm oil had a fatty acid composition with oleic acid ($C_{18:1}$) at 39.94%, palmitic acid ($C_{16:0}$) at 38.5%, and a PV of 7.66 meq. O_2 /kg. This is similar to Malaysian and Indonesian oils, which typically have oleic acid ($C_{18:1}$) at 36.00%–44.00% and palmitic acid ($C_{16:0}$) at 39.00%–47.00%, indicating similar genetic features of the *tenera* hybrid cultivar (Léonce et al., 2021; Ramli et al., 2020). Malaysian and Indonesian

palm oils have comparable oxidative stability, with PV ranging from 5.00–10.00 meq. O_2 /kg. However, processing and storage conditions may cause variances. While Egyptian palm oil has physicochemical and nutritional properties comparable to those of major producers (Malaysia and Indonesia), regional environmental conditions and genetic backgrounds impart unique features that affect oil stability, fatty acid composition and bioactive content. These findings highlight the significance of tailoring cultivation and processing procedures to enhance oil quality within Egypt's specific environment, thereby boosting its potential as a sustainable regional alternative. Based on quality parameters such as low FFA, PV, fatty acid profile and oxidative stability, the Egyptian palm oil demonstrates qualities comparable to international standards. However, comprehensive assessments including sensory analysis and refining parameters are necessary for full qualification as high-quality edible oil.

CONCLUSION

The current novel pioneering study confirms the viability of cultivating oil palms in Egypt, with locally produced palm oil matching internationally recognised quality criteria. The oils have positive physicochemical and fatty acid profiles, as well as outstanding stability, indicating that they are

TABLE 3. FATTY ACIDS COMPOSITION OF CRUDE PALM OIL (CPO) AND CRUDE PALM KERNEL OIL (CPKO)

Fatty acids	CPO (%)	Codex Standard	CPKO (%)	Codex Standard
Caproic ($C_{6:0}$)	ND	ND	0.16 ± 0.00	ND–0.8
Caprylic ($C_{8:0}$)	ND	ND	2.83 ± 0.01	2.4–6.2
Capric ($C_{10:0}$)	ND	ND	2.82 ± 0.01	2.6–5
Lauric ($C_{12:0}$)	0.02 ± 0.00 ^b	ND–0.5	44.83 ± 0.24 ^a	45.0–55.0
Myristic ($C_{14:0}$)	0.70 ± 0.00 ^b	0.5–2.0	16.50 ± 0.04 ^a	14.0–18.0
Palmitic ($C_{16:0}$)	38.50 ± 0.05 ^a	39.3–47.5	9.32 ± 0.01 ^b	6.5–10.0
Palmitoleic ($C_{16:1}$)	0.21 ± 0.00 ^a	ND–0.6	0.04 ± 0.00 ^b	ND–0.2
Margaric ($C_{17:0}$)	0.08 ± 0.00 ^a	ND–0.2	0.02 ± 0.00 ^b	ND
Stearic ($C_{18:0}$)	5.17 ± 0.00 ^a	3.5–6.0	1.91 ± 0.00 ^b	1.0–3.0
Oleic ($C_{18:1}$)	39.94 ± 0.04 ^a	36.0–44.0	18.65 ± 0.02 ^b	12.0–19.0
Linoleic ($C_{18:2}$)	14.62 ± 0.00 ^a	9.0–12.0	2.72 ± 0.00 ^b	1.0–3.5
Linolenic ($C_{18:3}$)	0.31 ± 0.00	ND–0.5	ND	ND–0.2
Arachidic ($C_{20:0}$)	0.36 ± 0.00 ^a	ND–1.0	0.11 ± 0.00 ^b	ND–0.2
Gadoleic ($C_{20:1}$)	0.09 ± 0.00 ^a	ND–0.4	0.09 ± 0.00 ^a	ND–0.2
Saturated fatty acids	44.83 ± 0.09 ^b	43.3–57.2	78.50 ± 0.02 ^a	71.5–98.2
Monounsaturated fatty acid	40.24 ± 0.08 ^a	36.0–45.0	18.78 ± 0.02 ^b	12.0–19.4
Polyunsaturated fatty acid	14.93 ± 0.03 ^a	9.0–12.5	2.72 ± 0.01 ^b	1.0–3.7

Note: ND - not detected. Values are mean ± standard deviation (n = 3). Means in the same row with different superscripts are significantly different ($P < 0.05$).

suitable for a wide range of food and industrial applications. The findings show Egypt's potential for developing a sustainable oil palm economy, which would contribute to agricultural diversification and economic growth. Climate limits and water scarcity necessitate strategic management; yet, Egyptian oil palm farming can be optimised by targeted research, water-efficient practices and supportive regulations. Overall, this pioneering endeavour is consistent with Sustainable Development Goals (SDGs), emphasising responsible resource use, environmental conservation, and socioeconomic advantages. Future study should focus on agronomic optimisation and value-added processing to increase production and quality, through optimising growing strategies for Egypt's environmental circumstances, investigating drought- and heat-tolerant oil palm types, and developing processing techniques to increase production and quality. Furthermore, adopting sustainable water management techniques and completing economic feasibility studies will be critical to establishing a profitable and environmentally responsible palm oil industry in Egypt.

Implementing oil palm cultivation in Egypt encounters several challenges, including climatic constraints due to the arid environment, water scarcity affecting irrigation, unsuitable soil types, high initial investment costs, limited local expertise, fluctuating market prices and environmental concerns. Recommended strategies to address these challenges include identifying suitable locations with better humidity and soil conditions, utilising water-efficient technologies, investing in research for adapted oil palm varieties, building local capacity through training, promoting sustainable practices, developing supportive policies and incentives, integrating oil palm with other cropping systems and conducting comprehensive feasibility studies. With proper management, these efforts can yield economic benefits and enhance agricultural diversification.

The present study successfully aligns palm oil extraction and utilisation with the United Nations' SDGs by advocating for sustainable agricultural practices, conserving biodiversity, minimising environmental impacts and fostering social and economic benefits for involved communities. Specifically, the study addresses objectives such as responsible consumption and production, climate action, life on land, decent work and economic growth and the establishment of effective partnerships. It successfully advances these goals through promoting responsible sourcing of palm oil, reducing greenhouse gas emissions, implementing sustainable land management practices, preventing deforestation, ensuring fair labour conditions and strengthening global collaborations.

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