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Effect of *Curcuma longa* L. on the antioxidant capacity of three fractions of palm oil.

Efecto de la *Curcuma longa* L. sobre la capacidad antioxidante de tres fracciones de aceite de palma

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Abstract

Enrichment through maceration or infusion facilitates the extraction of fat-soluble active ingredients that act as a kind of organic solvent. Turmeric is one of the most important spices due to its active biochemical activities. Anti-inflammatory, antioxidant, antibacterial and hypoglycemic qualities have been discovered in curcumin. The composition of the oil plays an important role, this research used three fractions of palm oil, resulting in that for crude oil and olein there was an increase in volatile compounds and a decrease in the peroxide index, while superolein behaved inversely. In terms of phenolic content and antioxidant capacity, the fraction that was the best was palm olein; however, superolein is favored with the inclusion of curcuminoids, given that it is the fraction most susceptible to oxidation. Therefore, the inclusion of this type of extract favored all the fractions studied.

Keywords: Turmeric, enriched oil, palm oil, antioxidant capacity.

Resumen

El enriquecimiento mediante maceración o infusión facilita la extracción de ingredientes activos liposoluble que actúa como una especie de disolvente orgánico. La cúrcuma es una de las especias más importantes debido a sus activas actividades bioquímicas. Se han descubierto en la curcumina cualidades antiinflamatorias, antioxidantes, antibacterianas e hipoglucemiantes. La composición del aceite juega un rol importante, esta investigación empleo tres fracciones de aceite de palma, obteniendo como resultado que para el aceite crudo y la oleína hubo un incremento de los compuestos volátiles y una disminución del índice de peróxido, mientras la superoleina se comportó de manera inversa. En cuanto a contenido de fenoles y la capacidad antioxidante la fracción que resulto mejor fue la oleína de palma, sin embargo, la superoleina se ve favorecida con la inclusión de los curcuminoides, dado que es la fracción más susceptible a la oxidación. Por tanto, la inclusión de este tipo de extracto favoreció a todas las fracciones estudiadas

Palabras clave: *Curcuma, aceite enriquecido, aceite de palma, capacidad antioxidante*

1. Introduction

Among the solvents industrially used for extracting non-polar edible natural products such as colorants, flavors, fragrances, or lipids, hexane is the most widely utilized, forming part of the list of extraction solvents permitted in the manufacture of food products or food ingredients. However, this substance is also known to be toxic (Cravotto et al., 2022), and substantial scientific evidence highlights the adverse effects associated with solvents like n-hexane. Another vital aspect to consider when implementing an extraction technique is economic viability, particularly when scaling up to an industrial level. A techno-economic cost-benefit analysis must include byproduct valorization and the added value derived from enhanced oil quality through the co-extraction of secondary compounds (Rodríguez-Blázquez et al., 2025).

Plant secondary metabolites are commonly extracted using conventional techniques such as maceration, hydrodistillation, Soxhlet extraction, and heat-reflux. Despite their efficiency, these methods carry the risk of degrading target compounds due to high temperatures and prolonged extraction times. Efforts to overcome the drawbacks of conventional extraction methods have led to the implementation of 'green technologies'. These approaches offer multiple processing advantages while minimizing environmental impact by significantly reducing or entirely replacing organic solvents with green alternatives (Wong-Paz et al., 2020).

Vegetable oils serve as ecological alternatives to petroleum-derived solvents like hexane due to their excellent solvating properties. They represent a versatile class of substances in the chemical industry, and their utilization as solvents, co-solvents, or raw materials for derivative compounds is highly valuable within the field of Green Chemistry. Economically, they are readily available and low-cost. From a biosecurity standpoint, they are non-toxic and safe for small- and large-scale operations. Their application as solvents is gaining increasing traction in the pharmaceutical, cosmetic, and food industries, where they have been successfully employed in drug delivery formulations (Cheikhyoussef & Cheikhyoussef, 2021). These non-polar substances offer the distinct advantage of being non-toxic, non-volatile, and non-irritating, ensuring that endogenous micronutrients—such as phospholipids, sterols, monoglycerides, and diglycerides—do not impede food, cosmetic, or nutraceutical applications (Yara et al., 2017). Consequently, edible oils can be effectively regarded as 'green' solvents for compound extraction.

Curcuma longa, commonly known as turmeric, is an annual herb featuring a short stem, large oblong leaves, and yellowish-brown oval, elliptical, or pear-shaped rhizomes that are occasionally branched. It is widely recognized as a panacea in herbal medicine due to its broad spectrum of pharmacological effects (Jyotirmayee & Mahalik, 2022). Contemporary research confirms that turmeric contains diverse active ingredients, including diarylheptanoids, terpenoids, aromatics, steroids, fatty acids, minerals, and nucleosides. Furthermore, it contains various macro- and microelements, such as K, Mg, Ca, Na, Al, Cr, Cu, Mn, Rb, Sr, and Zn (Tian et al., 2025). Whether administered as a powder, extract, or isolated compound, turmeric demonstrates extensive pharmacological activity with minimal adverse effects. The methoxy group of curcumin on the phenyl ring, alongside its phenolic and 1,3-diketone systems, plays a crucial role in its diverse pharmacological actions. Numerous curcumin- or turmeric-enriched products addressing various health conditions are available in both domestic and international markets. Unlike other phytoantioxidants, curcumin is safe, non-toxic, and acts as a potent natural component (Jyotirmayee & Mahalik, 2022).

Curcumin rapidly degrades via autoxidative transformation into various chemical species, a mechanism suggested to be driven by oxidative stress induction (reactive oxygen species, ROS). The stability of these compounds is closely linked to the solvent medium. In this regard, edible vegetable oils have proven to be promising green solvents for extraction and have gained popularity for isolating bioactive compounds. These oils are renewable and non-toxic resources, as their fatty acid esters do not emit volatile organic compounds (VOCs) and offer technical performance comparable to organic solvents used in extracting biocompounds from plant matrices (Cardoso et al., 2024).

This research investigates the incorporation of bioactive compounds present in Curcuma longa L. using three palm oil fractions as extraction solvents: crude palm oil (CPO), palm olein (PO), and palm superolein (SOP), evaluating their subsequent effect on antioxidant capacity. The resulting products can be defined as flavored or gourmet oils, depending on the botanical source of the extracted compound.

2. Experimental procedure

2.1. Treatment of turmeric rhizomes

Turmeric rhizomes were manually washed to remove all soil traces, then drained and dried at room temperature for six (6) hours. Subsequently, they were sliced into approximately 4 mm thick flakes and dried in a convection oven at 45 °C until reaching a constant weight. The dried flakes were milled and sieved using an 8" x 2" stainless steel ASTM N° 80 sieve (180 µm mesh opening) and stored at room temperature in airtight polyethylene bags. A proximate analysis of the resulting turmeric powder was performed using Near-Infrared Spectroscopy (NIR).

2.2. Characterization of palm oil fractions

The three palm oil fractions (crude palm oil, palm olein, and palm superolein) were characterized by determining their relative density using pycnometry at 20 °C (COVENIN 703, 1996); the iodine value using the Wijs method (COVENIN 324, 1996); free acidity by volumetric titration with 0.1 N KOH, expressed as oleic acid (COVENIN 325, 1996); the peroxide value by volumetric titration of the released iodine with 0.01 N $Na_2S_2O_3$ in a mixture of acetic acid and chloroform (COVENIN 508, 1997); the refractive index, measured directly at 15 °C with a refractometer (COVENIN 702, 1996); the saponification index by volumetric titration with 0.5 N HCl following saponification with 0.5 N methanolic KOH (COVENIN 323, 1981); and the unsaponifiable matter according to COVENIN 326 (1997).

2.3. Extraction of bioactive compounds using vegetable oils as solvents

The extraction was carried out by maceration, placing the turmeric powder in contact with the different palm oil fractions at a sample-to-solvent ratio of 3:17 (w/w). Maceration was conducted at room temperature for 48 hours. Following extraction, the mixtures were centrifuged at 2,000 rpm to separate the solid residue from the enriched vegetable oil. The resulting oils were bottled in amber glass containers and stored at 8 °C until subsequent analysis. The bioactive-enriched oils were characterized by determining the percentage of volatile compounds and total phenolic content using the Folin-Ciocalteu colorimetric method, with results expressed as milligrams of gallic acid equivalents per gram of sample (mg GAE/g). All assays were performed in triplicate, and antioxidant capacity was determined using the DPPH radical scavenging assay.

3. Results and Discussion

Curcumin is a natural polyphenolic compound and a potent hydrophobic bioactive compound. It is a yellow dye found in the rhizome of turmeric (Curcuma longa). Turmeric contains between 3% and 5% curcuminoids, which include curcumin (77%), demethoxylation (17%), demethoxylation (3%), and a negligible amount of cyclocurcumin. Often, the term 'curcumin' is used interchangeably with the term curcuminoids (Sabet et al., 2021).

3.1. Proximate analysis of turmeric powder

Table 1 shows the results of the proximal analysis of powder obtained from turmeric rhizomes. Moulick et al. (2023) reported a moisture content of 8.68% and fat of 7.27% in turmeric rhizomes. Meanwhile, a more recent study shows that the moisture, protein, fiber, fat, ash, and carbohydrate content are 5.59, 8.73, 7.06, 5.61, 5.06, and 67.95%, respectively (Olayinka, 2024), with fat and ash values close to those found in this sample, while the latter is richer in fiber. However, the chemical composition closely depends on the soil conditions where it is grown.

Table 1. Proximate analysis of *Curcuma longa* powder

Parameter	%
Moisture	2.07
Protein	12.00
Fat	4.78
Ash	8.84
Crude Fiber	29.67
Carbohydrates	42.64

3.2. Physicochemical characterization of palm oil fractions

Table 2 shows the physicochemical characteristics of the different fractions of palm oil. The acidity and peroxide index for crude palm oil indicate that it is prone to degradation. Peroxides are free radicals that can oxidize and affect the bioactive compounds that you want to extract. In the case of olein and superolein, the values are low, making them good candidates as extraction solvents, ensuring chemical stability and no alteration of the compound to be extracted.

Table 2. Physicochemical characterization of the different palm oil fractions.

Parameter	Crude Palm Oil	Palm Olein	Palm Superolein
Relative density at 20 ºC	0.899 ± 0.006	0.913 ± 0.004	0.901 ± 0.001
Refractive index at 40 ºC	1.451 ± 0.002	1.457 ± 0.003	1.464 ± 0.002
Iodine value (g I_2/100g)	55.68 ± 0.97	58.30 ± 0.28	64.83 ± 0.03
Free acidity (% oleic acid)	0.074 ± 0.001	0.045 ± 0.000	0.015 ± 0.001
Peroxide value (meq O_2/kg)	0.141 ± 0.022	0.000 ± 0.000	0.000 ± 0.000
Acidity index (mg KOH/g oil)	3.460 ± 0.080	0.425 ± 0.035	0.355 ± 0.007
Volatile compounds (%)	0.059 ± 0.001	0.049 ± 0.001	0.355 ± 0.001

Palm oil is a complex mixture of palmitic acid (saturated) and oleic acid (monounsaturated). Fractionation into liquid (olein) and solid (stearin) components yields products with different optical properties. The Codex Alimentarius has reported refractive index values for crude/refined palm oil ranging from 1.4550 to 1.4590, for olein from 1.458 to 1.4600, and for superolein from 1.463 to 1.461. Meanwhile, Azad et al. (2021) reported refractive indices of 1.474 and 1.479 for olein and superolein, respectively, correlating these values with the degree of unsaturation in the oils. They also reported iodine values for the olein and superolein fractions of 187.41 mg/g and 205.46 mg/g, respectively—values close to those found in this study.

The reported values (Table 2) show that the vegetable oils are of good quality and can therefore be used as solvents for the extraction of bioactive compounds. The use of edible vegetable oils as solvents has also been considered for the extraction of volatile aromatic compounds, due to their excellent extractability properties for such compounds (Nevado et al., 2012; Li et al., 2014; Sousa et al., 2014; Karoui et al., 2016; Heinrich et al., 2017). Edible vegetable oils used in the green extraction of bioactive compounds offer significant advantages over organic solvents, as they are non-toxic and have minimal impacts on the environment and human health; furthermore, the resulting extracts do not require additional purification steps, since they are already suitable for human consumption or use (Cardoso et al., 2024).

According to other studies, palm oil contains nearly equal amounts of saturated fatty acids (primarily palmitic acid, 44–45%) and unsaturated fatty acids (oleic acid, 39–40%, and linoleic acid, 10–11%). High-quality palm oil used in the edible oil industry contains a large amount of neutral triglycerides. Superolein, on the other hand, is produced by fractionating palm olein, and its content of oleic and linoleic fatty acids is higher than that of palm olein. As the fractionation process progresses, the oil's iodine value increases (Birsen et al., 2021). Palm superolein has a higher content of volatile compounds than palm olein; this is related to the chemical structure and composition of each fraction.

3.3. Characterization of bioactive-enriched oils

Enrichment through maceration or infusion facilitates the extraction of fat-soluble active ingredients simply by incorporating and mixing plant extracts into a fatty substance (the oil used for enrichment), which acts as a type of organic solvent (Oubannin et al., 2024). Curcuminoids tend to dissolve in oil due to affinity, which allows them to remain stable in a food matrix.

One of the main bioactive components of turmeric rhizome extract is curcumin, a yellow, hydrophobic polyphenol. It has also been shown to possess therapeutic potential, as well as antioxidant, anticancer, antimicrobial, anti-inflammatory, hypoglycemic, hepatoprotective, and neuroprotective properties, among others. Curcumin's non-toxic nature makes it an ideal therapeutic agent, but its limited bioavailability is a major concern in its application (Sohn et al., 2021).

Table 3 shows the values for the oils enriched with turmeric. In the case of crude palm oil, it can be seen that its peroxide value decreases after being enriched with turmeric; the phenolic compounds present may be responsible for the observed activity. Djikeng et al. (2025) found that supplementation with an antioxidant reduced the peroxide value; this antioxidant contains various compounds such as calebin-A, vanillic acid, vanillin, quercetin, etc., which eliminate free radicals, increase the activity of antioxidant enzymes, and inhibit lipid peroxidation; it exhibits strong free-radical scavenging activity.

Table 3. Properties of turmeric-enriched palm oil fractions.

Parameter	Crude Palm Oil	Palm Olein	Palm Superolein
Peroxide value (meq O_2/kg)	0.087 ± 0.006	0.000 ± 0.000	0.000 ± 0.000
Volatile compounds (%)	0.24 ± 0.02	0.20 ± 0.02	0.18 ± 0.02
Phenolic compounds (mg GAE/g)	56.70 ± 0.01	58.80 ± 0.01	39.30 ± 0.01
Antioxidant capacity (%)	62.76 ± 0.01	64.74 ± 0.01	53.26 ± 0.01

As for volatile compounds, the levels in crude palm oil and olein increased. This increase in volatile compounds is associated with their transformation and a decrease in the peroxide value. This value is a measure of the oxygen content chemically absorbed as lipid hydroperoxides (LOOH), which are considered the primary oxidation products. This implies that the rapid weight gain due to oxygen absorption occurs almost simultaneously with the dramatic decomposition of LOOH into volatile secondary oxidation products (Pashaei & Farhoosh, 2025).

On the other hand, superolein is more susceptible to oxidation; however, the addition of natural antioxidants interferes with the oxidation of its lipid portion, thereby reducing the volatile secondary compounds (Table 3). The most common approach to preventing or delaying lipid oxidation is the addition of natural or synthetic antioxidants to food products. Antioxidants can be defined as any substance capable of delaying or inhibiting substrate oxidation, even at low concentrations (De Oliveira et al., 2025).

The results show that the phenolic compound levels are similar to those reported by Djikeng et al. (2025), who reported a total phenolic content of 40.97 mg EAE/100 g in turmeric extracted with palm oil. Meanwhile, Array et al. (2018) demonstrated that the total phenolic content of the ethanolic turmeric extract was 40.80 mg EAE/100 g. The higher activity of curcumin can be attributed to its purity. The slight variations in the total phenolic content of turmeric extract compared to the literature can be attributed to the plant's region of origin, its climatic maturity, soil characteristics, genetic factors, etc. The phenolic content may increase with the addition of turmeric and its incorporation into the lipid matrix.

The phenolic compounds in turmeric are known for their antioxidant properties and ability to scavenge free radicals. According to the literature, the oxidative stability of various oils enriched with plant extracts is associated with their polyphenol composition and antioxidant potency (De Oliveira et al., 2025).

The best oxidative stability was observed in the palm olein fraction, which not only had a high content of phenolic compounds but also greater antioxidant potential, resulting in greater stability compared to the other palm oil fractions. The antioxidant capacity of olein (56.19%) and superolein (67.27%) has been reported (Djikeng et al., 2025). Crude oil contains higher amounts of antioxidants (carotenoids and tocotrienols) that provide a protective effect.

The palm oil fractions obtained have different chemical compositions (particularly in terms of triacylglycerol composition and diacylglycerol levels), so their thermal properties can significantly affect the physical quality (especially thermal behavior and sensory characteristics) of the final products. In addition, it is a source of valuable micronutrients, such as sterols, tocopherol, and carotene, which are key factors influencing the product's oxidative stability or shelf life (Jin et al., 2018).

Therefore, adding natural antioxidants to enrich an oil provides greater benefits; in the case of olein, these antioxidants could improve its chemical properties, as curcuminoids donate electrons to free radicals, thereby reducing the peroxide value. In superolein—the fraction most susceptible to oxidative changes—these compounds act as protectors of the double bonds in oleic and linoleic acids, reducing the formation of volatile compounds. Likewise, enriching oils with curcuminoids transforms them into nutraceutical foods with anti-inflammatory, antibacterial, and antioxidant effects, among others.

4. Conclusión

The composition of the oil plays an important role; this study used three palm oil fractions and found that, for crude oil and olein, there was an increase in volatile compounds and a decrease in the peroxide value, while superolein exhibited the opposite behavior. In terms of phenolic content and antioxidant capacity, the best-performing fraction was palm olein; however, superolein benefits from the inclusion of curcuminoids, as it is the fraction most susceptible to oxidation. Therefore, the inclusion of this type of extract helps control free radicals.

Conflict of Interest:

The authors declare that there is no conflict of interest.

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