TEKNOTAN, Vol. 20, No. 2, Agustus 2026
ISSN 1978-1067 (Print), ISSN 2528-6285 (Online)
DOI 10.24198/jt.vol20n2.4

Advances in Red Palm Oil as Functional Food Ingredient: Composition, Stability, and Applications in Food Systems

Perkembangan Terkini Minyak Sawit Merah Sebagai Bahan Pangan Fungsional: Tinjauan Komposisi, Stabilitas, dan Aplikasinya Dalam Pangan

Rivan Satria Jaluwardhana[1,2]*, Yana Cahyana[2], Asep Mulyono[3], Heni Radiani Arifin[2], Herlina Marta[2], Ratih Nurjayati[4], Hakiki Melanie[5], Apriliana Cahya Khayrani[1]

[1]Department of Chemical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia
[2]Department of Food Industrial Technology, Faculty of Agroindustrial Technology, Universitas Padjadjaran, Sumedang 45363, Indonesia
[3]Research Center for Limnology and Water Resources, Earth Sciences and Maritime Affairs Research Organization, National Research and Innovation Agency (BRIN), South Tangerang 15314, Indonesia
[4]Research Center for Environmental Technology and Clean Technology, Energy and Manufacture Research Organization, National Research and Innovation Agency (BRIN), South Tangerang 15314, Indonesia
[5]Research Center for Molecular Chemistry, Nanotechnology and Materials Research Organization, National Research and Innovation Agency (BRIN), South Tangerang 15314, Indonesia
*E-mail: rivan21001@mail.unpad.ac.id

Submitted: 22 January 2026; Accepted: 6 July 2026

ABSTRACT

Indonesia, as one of the world's leading producers of palm oil, plays a strategic role and has significant potential to develop palm oil–derived products, such as red palm oil (RPO), as future functional food ingredients. The growing demand for nutritious and sustainable foods has spurred exploration of natural resources with enhanced functional and technological value. This comprehensive review summarizes recent advances in the utilisation of RPO as a functional food ingredient, with particular emphasis on its composition, bioactive compounds, physicochemical stability, and processing versatility. The literature search was conducted using a Narrative Literature Review (NLR) approach to identify relevant publications from 2000 to 2024 across major scientific databases. Priority was given to studies published within the last ten years to capture recent developments, while earlier publications were included as foundational and theoretical references that remain relevant to the field. RPO is rich in β-carotene, tocopherols, and tocotrienols, which contribute to its antioxidant activity, distinctive red–orange colour, and oxidative stability. These characteristics support the incorporation of RPO into a wide range of food formulations, including bakery products, spreads, and emulsion-based systems. This review integrates current evidence on the role of RPO in sustainable food diversification, provides insights into its technological applications, and highlights future research opportunities to optimise its utilisation in modern food innovation.

Keywords: Bioactive compounds; carotenoids; functional foods; red palm oil; stability

ABSTRAK

Indonesia, sebagai salah satu produsen utama minyak sawit dunia, memiliki peran strategis dan potensi besar dalam pengembangan produk turunan kelapa sawit, seperti minyak sawit merah (red palm oil, RPO), sebagai bahan baku pangan fungsional masa depan. Meningkatnya permintaan terhadap pangan yang bergizi dan berkelanjutan telah mendorong eksplorasi sumber daya alam yang memiliki nilai fungsional dan teknologi yang lebih tinggi. Tinjauan komprehensif ini merangkum kemajuan terkini dalam pemanfaatan minyak sawit merah (RPO) sebagai bahan pangan fungsional, dengan penekanan khusus pada komposisi, senyawa bioaktif, stabilitas fisikokimia, serta fleksibilitasnya dalam proses pengolahan. Pencarian literatur dilakukan menggunakan pendekatan Narrative Literature Review (NLR) untuk mengidentifikasi publikasi yang relevan pada periode 2000–2024 melalui berbagai basis data ilmiah utama. Studi yang dipublikasikan dalam sepuluh tahun terakhir diprioritaskan untuk merepresentasikan perkembangan terkini, sementara publikasi yang lebih lama digunakan sebagai rujukan dasar dan teoretis yang masih relevan hingga saat ini. RPO kaya akan β-karoten, tokoferol, dan tokotrienol yang berkontribusi terhadap aktivitas antioksidan, warna merah-oranye khas, serta stabilitas oksidatifnya. Karakteristik tersebut mendukung pemanfaatan RPO dalam berbagai formulasi pangan, termasuk produk bakery, olesan (spreads), dan sistem berbasis emulsi. Tinjauan ini mengintegrasikan bukti terkini mengenai peran RPO dalam diversifikasi pangan berkelanjutan, memberikan wawasan terkait aplikasi teknologinya, serta menyoroti peluang penelitian di masa depan untuk mengoptimalkan pemanfaatannya dalam inovasi pangan modern.

Kata Kunci: *Karotenoid; minyak sawit merah; pangan fungsional; senyawa bioaktif; stabilitas*

INTRODUCTION

Elaeis guineensis, commonly known as oil palm, is among the most economically and agriculturally significant crops worldwide, attributed to its exceptional yield. The extracted oil exhibits remarkable functional properties, making it highly valuable across various industries (Mozzon *et al*., 2013). The oil palm tree (*Elaeis guineensis*) was brought to Indonesia from West Africa in 1848 and later spread throughout Southeast Asia (Henson, 2012). According to the FAO (2021), Indonesia is a major producer of palm oil, accounting for around 60% of the global supply in 2021. Furthermore, Malaysia is the second-largest producer of oil palm. In 2021, up to 18.12 million tons of crude palm oil (CPO) were produced from a planted area of 5.74 million hectares, accounting for more than two-thirds of the agricultural land (Zolfagharnassab *et al.*, 2022; Megananda *et al*., 2026).

The oil palm industry is Indonesia's most vital agricultural sector, contributing approximately 7.5% of the country's total exports (Harahap *et al*., 2020). Data from the Indonesian Palm Oil Association indicate that Indonesia produced 46.73 million tons of CPO in 2022, thereby affirming its status as the world's largest producer. The palm oil industry plays a vital role in Indonesia's economy, supporting food manufacturing and export growth.

The cultivation of oil palm (*Elaeis guineensis*) began in Malaysia in 1917, and it has since become the country's most economically significant crop. By 2018, export revenue from this crop exceeded RM 67.12 billion (Tan *et al*., 2021). Palm oil and its derivatives predominantly serve as essential ingredients in culinary applications, including shortenings, frying oils, margarine, vanaspati, cooking oils, and specialized lipid formulations. (Gunstone, 2005). Various products on the market consist of palm oil or its blends with palm kernel oil or other vegetable oils.

In 2020, oil palm was the largest global source of vegetable oil, producing 40% of the total 1,062.7 million tonnes, while occupying only 10% of the 275.3 million hectares of land used for oil crops and oilseeds (FAO, 2022). The oil palm fruit produces two distinct types of oil: palm oil and palm kernel oil. Palm oil is derived from the mesocarp through mechanical pressing and solvent extraction, whereas palm kernel oil is extracted from the kernel using similar processing techniques (Tan *et al*., 2009; Cheng *et al*., 2011; Ali *et al*., 2014; Rutz *et al*., 2017; Gonçalves Albuquerque *et al*., 2019). Palm oil primarily consists of triglycerides, with other minor components accounting for around 1% (Wan Mohamad *et al*., 2017; Emmanuel *et al*., 2021). Among the minor components found in palm oil are carotenoids, tocopherols, tocotrienols, sterols, triterpenic alcohols, phospholipids, glycolipids, terpenic hydrocarbons, and aliphatic compounds (Silva *et al*., 2014; Riyadi *et al*., 2016).

RPO is a specialized form of palm oil that preserves its naturally occurring carotenoids and vitamin E, distinguishing it from refined, bleached, and deodorized (RBD) palm oil despite sharing comparable physicochemical characteristics. Unlike conventional RBD processing, RPO undergoes minimal refinement, omitting bleaching and other treatments that typically deplete carotenoids, vitamin E, and sterols (Abidi, 2003). The distinctive red hue of RPO is attributed to its elevated carotene concentration, and it also exhibits relatively low free fatty acid content, thereby enhancing its nutritional and oxidative stability (Purnama *et al*., 2020). RPO is produced by mild processing of CPO, whereas RBD palm oil is obtained by either physical or chemical refining of crude palm oil (Tan *et al*., 2021).

The bleaching process, which utilizes bleaching clay, eliminates colour pigments and residual soaps from the oil. During the deodorisation phase of physical refining, the oil is exposed to high temperatures (250–270°C) and low pressures (3–5 torr) to remove free fatty acids (FFA) and volatile compounds that influence its odour and flavour. Palm carotenoids are removed during refining to produce a clear oil, which is preferred for consumer acceptance and industrial applications (Rodriguez-Amaya *et al*., 2023).

RPO is globally known for its excellent quality. It has a well-balanced fatty acid profile, consisting of approximately 50% saturated, 40% monounsaturated, and 10% PUFAs. RPO can be incorporated into various food products, including cooking oil, shortening, spreads, salad dressings, and margarine (Purnama *et al*., 2020). In Indonesia, margarine has significant potential for development using RPO, as it serves as both a fat source and a provider of natural colouring and high nutritional value due to its rich phytonutrient content, particularly carotenoids.

With increasing interest in natural and functional ingredients, RPO has gained considerable attention for its potential use in food formulation, fortification, and product diversification. Previous reviews have provided valuable insights into specific aspects of RPO. For instance, Loganathan *et al*., (2017) focused primarily on the nutritional properties and health-promoting effects of RPO based on evidence from animal and human studies, while Purnama *et al*., (2020) reviewed its processing, characteristics, nutritional properties, and potential applications. More recently, Tan *et al*., (2021) further discussed the physicochemical properties, health benefits, and food applications of RPO.

However, existing reviews have largely addressed these aspects independently, resulting in limited integration of the relationships among bioactive composition, oxidative stability, and technological functionality in food systems. In addition, recent advances in stabilisation and delivery strategies, including encapsulation, nanoemulsion, and Pickering emulsion technologies, have not been comprehensively synthesized despite their growing importance in improving the stability, retention, and functionality of RPO bioactive compounds. Therefore, an updated and integrated review is needed to connect the compositional characteristics, stability mechanisms, and emerging food applications of RPO from a food systems perspective.

The novelty of this review lies in its integrated food systems perspective, which systematically links the compositional attributes of RPO with its oxidative stability, technological functionality, and utilisation in food products. Furthermore, this review critically evaluates emerging stabilisation and delivery approaches to highlight their roles in enhancing the stability and functionality of RPO bioactive compounds. By integrating these aspects within a single framework, this review provides an updated perspective on the opportunities and challenges associated with the development of RPO as a functional food ingredient.

Therefore, this review aims to comprehensively summarize recent advances in the bioactive composition, oxidative stability, technological functionality, and food applications of RPO as a functional ingredient, highlighting its potential contribution to sustainable and innovative food development.

METHODOLOGY

Review Approach

This review article was developed using a *Narrative Literature Review* (NLR) approach, supported by a structured literature search to establish a robust conceptual foundation. The NLR approach was intentionally selected to enable a critical and integrative synthesis of diverse research findings related to RPO, particularly in areas where methodological heterogeneity and evolving technological applications limit the feasibility of a fully systematic review. While systematic reviews emphasize highly standardized selection procedures and exhaustive reproducibility, the NLR framework allows for

TEKNOTAN, Vol. 20, No. 2, Agustus 2026
ISSN 1978-1067 (Print), ISSN 2528-6285 (Online)
DOI 10.24198/jt.vol20n2.4

flexibility in integrating foundational theories, emerging evidence, and applied studies.

Accordingly, this review focuses on RPO as the central theme, synthesizing relevant peer-reviewed studies into a coherent, critical, and conceptually grounded discussion.

Literature Search Strategy

This review was conducted using a NLR approach, supported by a structured and transparent literature search to synthesize recent and relevant studies on RPO. The review focuses on the physicochemical characteristics, bioactive compounds, stability, and functional applications of RPO in functional food systems. To ensure comprehensive coverage of the topic, electronic databases including Scopus, PubMed, ScienceDirect, MDPI, SINTA, and Google Scholar were systematically searched.

Peer-reviewed literature published between 2000 and 2024 was identified using combinations of the following keywords and Boolean operators: ("RPO" OR "*Elaeis guineensis*") AND ("bioactive compounds" OR "carotenoids" OR "tocopherols" OR "tocotrienols") AND ("stability" OR "processing" OR "functional food" OR "health applications"). Studies published within the last decade were prioritized to reflect recent developments, while earlier publications were included as foundational references where relevant.

Eligibility Criteria

A structured eligibility framework was applied to enhance consistency and transparency during the literature selection. This framework guided the identification of studies addressing the composition, bioactive compounds, stability, and food-related applications of RPO that were considered relevant for narrative synthesis. To enhance transparency and maintain thematic focus, eligibility criteria were applied to guide the selection of relevant literature for this narrative review. These criteria were used as a guiding framework rather than a fully systematic screening procedure. The inclusion and exclusion criteria are summarized in Table 1.

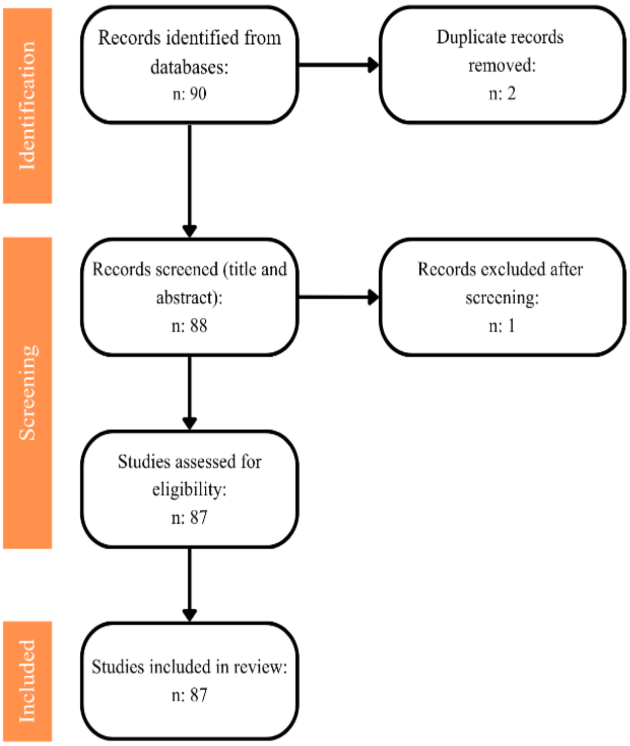

Figure 1. Literature identification, screening, and selection process used in this narrative review

Literature Selection Process

The literature search initially identified 90 records from the selected databases. After removing duplicate publications (n = 2), the remaining 88 articles were screened based on titles and abstracts for relevance to RPO composition, physicochemical characteristics, stability, bioactive compounds, health-related properties, and food applications. One article was excluded during the screening stage, resulting in 87 studies for full-text assessment and narrative synthesis. The overall literature identification and selection workflow is presented in Figure 1.

RESULT AND DISCUSSIONS

Palm Oil Characteristics

The oil palm (*Elaeis guineensis* Jacq.) is one of the world's most significant oil-producing crops. Oil palm trees are categorized into three types, *dura*, *pisifera*, and *tenera*, according to fruit morphology (Soonsuwon *et al*., 2020). The classification of oil palm fruit morphology can be presented in Table 2. Due to its female sterility, *pisifera* is commonly used as a male parent in breeding. The *tenera* variety, a hybrid resulting from the cross between *dura* and *pisifera*, yields higher-quality FFB compared to its parent types and is therefore the dominant variety used in commercial palm oil production.

The differences in fruit morphology among *dura*, *pisifera*, and *tenera* have important implications for oil yield and industrial utilisation. Compared with *dura*, which possesses a thicker shell and a lower proportion of oil-bearing mesocarp, *tenera* exhibits a thinner shell and a substantially higher mesocarp content, resulting in greater oil recovery during processing. This characteristic explains why *tenera* has become the dominant commercial variety for palm oil production worldwide. From a food ingredient perspective, the higher mesocarp content is particularly advantageous because it serves as the primary source of carotenoids, tocopherols, and tocotrienols that contribute to the nutritional value and functional properties of RPO.

RPO is produced from FFB and retains many of the bioactive compounds naturally found in CPO. Unlike conventional palm oil refining, the production of RPO applies milder processing conditions during degumming, neutralisation, and deodorisation to limit the loss of carotenoids, tocopherols, and tocotrienols (Purnama *et al*., 2020). Representative morphological appearances of *dura*, *pisifera*, and *tenera* fruits are illustrated in Table 3, highlighting differences in endocarp thickness and fruit structure. The predominance of the *tenera* variety in commercial cultivation is therefore advantageous for RPO production, as its higher mesocarp content supports greater recovery of oil and bioactive compounds, particularly carotenoids responsible for the distinctive red-orange coloration of RPO.

Physicochemical Characteristics

Physicochemical characteristics, including various physical and chemical parameters of edible oils, were utilized to assess their compositional quality (Ceriani *et al*., 2008; Khaneghah *et al*., 2012). Commonly, the physicochemical parameters of oils considered include peroxide value (PV), iodine value (IV), density, viscosity, and saponification value (SV) as presented in Table 4. Numerous studies have examined the effects of temperature on oil stability, viscosity, PV, and IV to evaluate its quality and functionality (Farhoush *et al*., 2008; He *et al*., 2010; PAN *et al*., 2011). The classification of the physicochemical characteristics of palm oil is divided into RPO, red palm olein (RPOL), and red palm stearin (RPS), which are generally distinguished by the slight differences in their processing methods.

RPO is a specialized derivative of palm oil that, despite exhibiting comparable physicochemical attributes to refined, bleached, and deodorized (RBD) oil, preserves its intrinsic carotenoid and vitamin E composition, enhancing its nutritional profile and functional properties. Unlike conventional refining and bleaching processes, which significantly reduce vitamin E, carotenoid, and sterol levels, RPO undergoes minimal processing. Its characteristic red hue is attributed to its high carotene concentration and its exceptionally low free fatty acid content (Purnama *et al*., 2020).

Meanwhile, RPOL is produced through the fractionation of palm oil, resulting in a liquid fraction (Purnama *et al*., 2020) that retains many of the phytonutrients present in RPO, including carotenoids, vitamin E, phytosterols, CoQ_{10}, phospholipids, and squalene (Nainggolan & Sinaga, 2021). Although both RPO and RPOL possess similar nutritional attributes, fractionation modifies their physicochemical properties and technological functionality. As shown in Table 4, RPOL exhibits a lower slip melting point (23.0-23.8℃) and a higher IV (55.7-56.7 g I_2/100 g) than RPO, indicating greater fluidity and a higher degree of unsaturation. These characteristics make RPOL particularly suitable for liquid oil applications and emulsion-based food systems, whereas RPO may provide advantages in formulations requiring greater structural stability. Therefore, fractionation not only alters the physical behaviour of palm oil fractions but also broadens their potential applications in food products.

The physicochemical differences between RPO and RPOL indicate that fractionation not only alters the physical behaviour of palm oil fractions but also influences their technological applications. The higher IV and lower slip melting point of RPOL suggest greater fluidity and improved suitability for liquid oil and emulsion-based formulations. Conversely, the semi-solid nature of RPO may be advantageous in bakery products, spreads, and structured lipid systems where greater physical stability is required. Although interest in RPO and RPOL continues to increase, available physicochemical data remain fragmented because most studies focus on only a few quality parameters. As a result, direct comparisons among studies are often difficult, particularly when different processing methods and analytical approaches are employed.

As summarized in Table 5, RPO is characterised by relatively high concentrations of carotenoids (approximately 500-750 ppm) and tocopherols/tocotrienols (600-1000 ppm), which are important contributors to its oxidative stability and nutritional properties. Comparable values have been reported by Tan *et al*., (2021), although noticeable variations exist among studies. These differences may arise from variations in cultivar, fruit maturity, processing conditions, and analytical methodologies (Madoromae & Lertcanawanichakul, 2025). Such variability highlights the need for more standardized characterisation of RPO, while also confirming the importance of these bioactive compounds in preserving oil quality during storage and processing.

RPO is characterized by a diverse composition of fatty acids, encompassing both saturated and unsaturated forms. It exhibits a well-balanced fatty acid profile, with approximately 50% saturated fatty acids, 40% monounsaturated fatty acids, and 10% PUFAs (A.O. Ayeleso, 2012). The optimal fatty acid composition of RPO contributes to its semi-solid state, enhancing its stability and making it more resistant to lipid oxidation when compared to other vegetable oils with elevated concentrations of monounsaturated fatty acids (Tan *et al*., 2021).

The balanced fatty acid composition of RPO presents an important trade-off between oxidative stability and nutritional quality. While the relatively high saturated fatty acid content contributes to enhanced resistance against oxidation, the presence of unsaturated fatty acids supports desirable nutritional and functional properties. This balance may contribute to the suitability of RPO for both food processing and functional food applications.

Table 1. Eligibility criteria applied to support the focus and coherence of the narrative literature review**.**

Criteria	Inclusion	Exclusion
Study type	Original research, scientific reputable book, and review articles related to RPO	Editorials, non-peer-reviewed papers, conference abstracts
Focus	RPO composition, bioactive compounds, stability, processing, or food/health applications	Studies unrelated to RPO or focusing on other vegetable oils
Publication year	Primarily 2000–2024, with selected earlier studies included where necessary to provide theoretical or foundational context	Outdated studies with limited relevance or unavailable full text
Availability	Full-text accessible	Non-reputable abstract

Table 2. The classification of oil palm fruit morphology

Types	*Dura*	*Pisifera*	*Tenera*
Homozygous Genotype	$sh^{+}sh^{+}$ [(2)]	$sh^{-}sh^{-}$ [(2)]	$sh^{+}sh^{-}$ [(2)]
Shell Characteristics	Thick shell (2–8 mm) [(4)]	Lacks a shell but has a fibrous ring encasing the kernel [(4)]	Thin shell (0.5–4 mm) [(4)]
Palm Kernel (%)	4-20 [(1,2)]	3-8 [(1,2)]	3-15 [(1,2)]
Mesocarp Oil Contents	Relatively small proportion of oil-rich mesocarp (35–70% of the fruit's weight) [(2)]	leaving the oil-bearing mesocarp as the primary component of the fruit (92 – 97%) [(2)]	High oil-bearing mesocarp content (60–95%) [(2)].

Source: [1]Romano *et al*., (2022); [2]Soonsuwon *et al*., (2020)

TEKNOTAN, Vol. 20, No. 2, Agustus 2026
ISSN 1978-1067 (Print), ISSN 2528-6285 (Online)
DOI 10.24198/jt.vol20n2.4

Table 3. Morphological characteristics of *dura*, *pisifera*, and *tenera* oil palm fruits

Dura	*Pisifera*	*Tenera*
 1,2	 1,2	 1,2
 3	 3	 3

Adapted from**:** [1]Purnama *et al*., (2020); [2]Alhaji *et al*., (2024); [3]Soonsuwon *et al*., (2020)

Table 4. Physicochemical characteristics (properties) of RPO

Characteristics	RPO (Kamaruzaman *et al*., 2015)	Unrefined RPOL (Kumar & Krishna, 2015)	RPOL (El-Hadad *et al*., 2010)
FFA (%)	0.1	11.4	0.1
Moisture & impurities (%)	0.04	-	0.5
IV (g I_2/100 g)	51.6	55.7	56.7
PV (meqO_2 per kg)	-	7.2	1.5
Slip melting point (°C)	37.0	23.0	23.8
Refractive index (40°C)	-	1.5	1.5
Acid value (mg KOH/g)	-	-	0.3

Adapted from Tan *et al*., (2021)

.

Table 5. General lipid composition and phytonutrient content of RPO

Components	RPO		
	Cassiday, (2017)	Gao *et al*., (2023)	Delisle (2018)
Total saturated fatty acids (%)	50	46.05-49.91	49.9
Total monounsaturated fatty acids (%)	42	38.99-42.27	39.2
Total polyunsaturated fatty acids (PUFAs) (%)	-	10.70-12.13	10.5
Total carotenes (ppm)	513	91-154.04	500-700
Total tocopherols & tocotrienols (ppm)	707	473.43 (tocotrienols)	600-1000

Adapted from Tan *et al*., (2021) with modification

The fatty acid profile of RPO is dominated by palmitic acid, oleic acid, and linoleic acid, which together account for the majority of total fatty acids. Variations in the proportions of saturated and unsaturated fatty acids influence the physicochemical properties, oxidative stability, melting behaviour, and technological functionality of RPO in food systems. Minor fatty acids such as myristic, palmitoleic, arachidic, and stearic acids are also present, although at considerably lower concentrations. The concentrations of each fatty acid present in RPO are presented in Table 6.

Gao *et al*., (2023) in Table 5 reported that RPO exhibits a relatively balanced fatty acid composition, consisting of approximately 46–49.91% saturated fatty acids, 38.99–42.27% monounsaturated fatty acids, and 10.70–12.13% polyunsaturated fatty acids. Palmitic acid, oleic acid, and linoleic acid were identified as the predominant fatty acids, contributing to the unique physicochemical and functional characteristics of RPO, as shown in **Table 6**. Reported carotenoid concentrations vary considerably among RPO products, ranging from approximately 91–154 mg/kg in commercial samples reported by Gao *et al*., (2023) to more than 500 ppm in other studies, suggesting that processing conditions, refining practices, raw material quality, and product type may substantially influence carotenoid retention. In addition to carotenoids and vitamin E, RPO also contains phytosterols. Delisle (2018) reported that modified refining processes were able to retain approximately 65% of phytosterols, indicating that processing conditions play an important role in preserving minor bioactive compounds.

Table 6. Fatty acid profile content of RPO, palm olein, and palm stearin

Components	RPO				Palm Olein	Palm Stearin
	Nagendran *et al*., (2000)	Cassiday, (2017)	Gao *et al*., (2023)	Delisle (2018)	Malaysian Standards, (2007a)	Malaysian Standards, (2007b)
Myristic acid (14:0) (%)	1.09	0.8	0.90-2.33	1.0-1.5	0.9-1.2	1.1-1.7
Palmitic acid (16:0) (%)	40.93	42.0	34.95-42.96	42.0-47.0	38.2-42.9	49.8-68.1
Palmitoleic acid (16:1) (%)	-	-	-	-	0.1-0.3	<0.05-0.1
Arachidic acid (20:0) (%)	0.37	-	N.D.-0.55	-	0.2-0.5	0.3-0.6
Oleic acid (18:1) (%)	41.51	42.0	38.99-42.27	37.0-41.0	39.8-43.9	20.4-34.4
Linoleic acid (18:2) (%)	11.64	10.0	10.70-11.57	9.0-11.0	10.4-12.7	5.0-8.9
Linolenic acid (18.3) (%)	0.40	-	N.D.-0.55	0.4	0.1-0.6	0.1-0.5
Stearic acid (18:0) (%)	4.18	5.1	3.87-5.83	4.0-5.0	3.7-4.8	3.9-5.6

Adapted from Tan *et al*., (2021)
Note: N.D.= Not Detected

There are several components, aside from fatty acids, carotenoids, tocopherols, and tocotrienols, present in RPO. Below is an explanation along with their respective uses: CoQ_{10} and also known as Ubiquinone, has been characterized by its diverse functions, including its role as an oxidant in signal generation, as well as in the regulation of phospholipid composition, cellular redox balance, and membrane structure (Gutierrez-Mariscal *et al*., 2020). Squalene, other phytonutrients contained in RPO, has been the subject of numerous studies that have demonstrated evidence supporting the bioactivities of squalene.

Based on the research data reported by Loganathan *et al*., (2017), the percentage range of phytonutrients expressed in ppm units contained in RPO for Ubiquinone is 18–25%, which is identical to the percentage range found in Co-Enzyme Q_{10} (CoQ_{10}) (18–25%), while squalene constitutes 14–15%. These concentrations or percentages are significantly lower compared to other bioactive compounds present in RPO, including carotenoids and vitamin E in the forms of tocopherols and tocotrienols.

Overall, the physicochemical characteristics of RPO are strongly influenced by its unique combination of fatty acids and bioactive compounds. While current studies demonstrate the potential of RPO as a functional food ingredient, comprehensive characterisation remains limited by inconsistencies in analytical parameters and reporting methods. Future research should employ standardized physicochemical, rheological, thermal, and oxidative stability analyses to better establish the relationship between composition, functionality, and food application performance.

Production (Processing) of RPO

RPO is produced through a series of pre-processing steps, including deodorisation and deacidification (Lee *et al*., 2018). The production process typically involves a chemical refining procedure, which includes degumming (removing impurities with phosphoric acid and gums), neutralisation, and deacidification (neutralizing FFA by adding NaOH), followed by deodorisation (eliminating the characteristic "*palmy*" odour through moderate heating)(Purnama *et al*., 2020).

A major challenge in RPO production is balancing the removal of undesirable compounds with the retention of bioactive constituents. While refining processes are necessary to reduce FFA, impurities, and undesirable odors, excessive thermal treatment may accelerate the degradation of carotenoids and vitamin E. Consequently, mild refining conditions have been developed to preserve these phytonutrients while maintaining acceptable oil quality and safety standards.

Compared with conventional RBD palm oil production, RPO processing employs milder refining conditions to minimize the loss of carotenoids and vitamin E. However, this preservation of bioactive compounds may result in a more pronounced colour, flavour, and aroma profile, which can influence consumer acceptance and product formulation.

There are several procedures for producing the RPO as shown in Figure 2. The bunch reception or FFB receiving process includes assessing the quality of palm fruit to determine whether the fruits are suitable for oil extraction and performing threshing to separate the fruit from the bunches (Poku & Nations, 2002; Owolarafe *et al*., 2002). Sterilisation is an essential process that utilizes high-temperature steam to deactivate enzymes and inhibit the formation of FFA (Tan *et al*., 2021).

Palm oil extraction is typically performed using two primary methods: the wet method and the dry method. The wet method utilizes water to extract oil from the fruit, with hot water added to facilitate the breakdown of gums and resins that cause foaming during high-temperature frying. These substances are later removed during the oil clarification process. After pressing, the mesocarp fibre typically retains approximately 5–6% of the oil. In contrast, the dry method employs mechanical apparatus, such as hydraulic and screw presses, to extract oil from the processed material. Hydraulic presses are typically used in batch systems, whereas screw presses are more commonly employed in continuous systems (Poku & Nations, 2002; Obibuzor *et al*., 2012).

The mild processing of RPO helps preserve the majority of its carotenes, tocotrienols, and natural colour. Nevertheless, the refining process does not entirely eliminate volatile compounds, leading to a subtle yet distinctive taste and aroma in RPO. Consumers may perceive the flavour and aroma of RPO as distinctive, distinguishing it from other vegetable oils (Riyadi *et al*., 2016).

Despite the nutritional advantages of RPO, large-scale production remains challenging because the preservation of carotenoids and vitamin E requires careful process control throughout refining and storage. In addition, maintaining bioactive retention while ensuring product stability, sensory quality, and economic feasibility continues to be a major consideration for industrial implementation. Recent developments in RPO processing have shifted from maximizing refining efficiency toward preserving phytonutrients, reflecting growing consumer demand for functional and minimally processed food ingredients.

ISSN 1978-1067 (Print), ISSN 2528-6285 (Online)
DOI 10.24198/jt.vol20n2.4

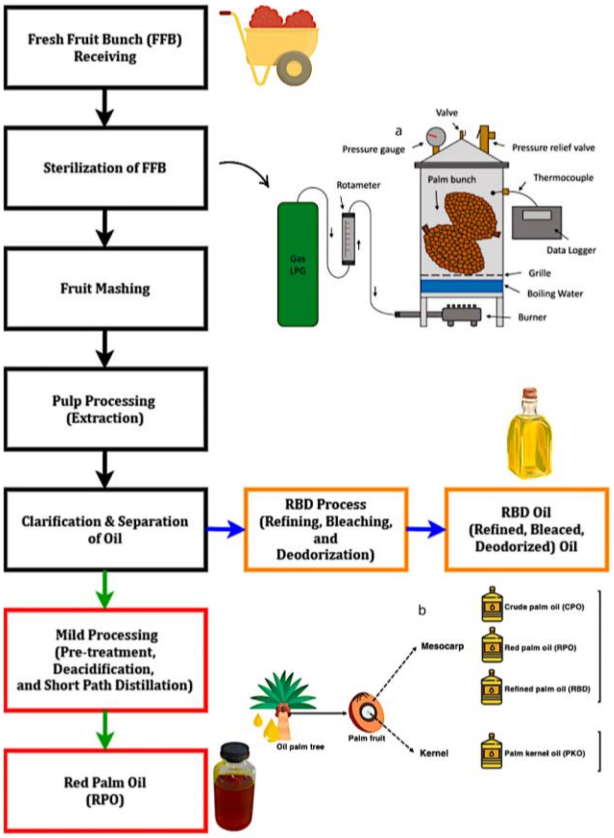

Figure 2. RPO Production (Processing)
Adapted from: Tan *et al*., (2021)
Images Source: [a]Wae-hayee *et al*., (2022); [b]Izuddin *et al*., (2023)

Bioactive Compounds of RPO

Bioactive compounds are molecules that engage with components of living tissues, eliciting beneficial effects on human health (Martirosyan & Miller, 2018). Broadly, these compounds—originating from plant, animal, or microbial sources—encompass PUFAs, peptides, polyphenols, vitamins, and carotenoids (Cláudia da Costa Rocha *et al*., 2021). Carotenoids and vitamin E (tocopherols and tocotrienols) are bioactive compounds present in relatively significant quantities, followed by several other bioactive compounds.

Carotenoids Compounds

Carotenoids are naturally occurring tetraterpene pigments with lipophilic characteristics, comprising over 750 compounds that are chiefly responsible for the orange, red, and yellow coloration in plants. Additionally, they can be bioaccumulated in animals and synthesized by microorganisms, as well as specific arthropods, including hemipterans such as aphids, phylloxerids, and adelgids (Dias *et al*., 2018; Rodriguez-Concepcion *et al*., 2018; Maoka, 2020). Carotenoids also have benefits for every sector, especially in the health sector. Many food and beverage products contain carotenoid compounds that have the potential to be developed as functional foods. These pigments are widely used as health-promoting food ingredients and enhance the sensory qualities of food products.

The exceptionally high carotenoid concentration of RPO distinguishes it from most conventional edible vegetable oils and represents one of its primary functional advantages. In addition to imparting the characteristic red-orange colour, carotenoids contribute significantly to provitamin A activity and antioxidant protection. However, these compounds are highly susceptible to degradation during thermal processing, light exposure, and prolonged storage, creating a major challenge for maintaining the nutritional quality and functional value of RPO in food systems (Putra *et al*., 2025). Therefore, preserving carotenoid stability remains a critical consideration during processing and product development. Reported carotenoid concentrations vary among studies because of cultivar differences, fruit maturity, and processing conditions (Madoromae & Lertcanawanichakul, 2025).

Vitamin E (Tocopherols and Tocotrienols)

Tocopherols (T) and tocotrienols (T_3), collectively known as tocol-related compounds, are essential bioactive components found in vegetable oils. These compounds are part of the vitamin E family, characterized by their chromanol-based structure (Abidi, 2003). Vitamin E serves as a vital antioxidant, enhancing the stability of oils by preventing oxidative degradation. Additionally, the combination of vitamin E and carotene offers synergistic protection against both photooxidation and autooxidation of unsaturated triglycerides (Nagendran *et al*., 2000). The vitamin E profile of palm oil is distinctive, with tocotrienols constituting the predominant fraction (approximately 70%), while tocopherols account for the remaining 30%. Among these compounds, α-tocopherol and γ-tocotrienol represent the major contributors to the total tocopherol and tocotrienol content. Naturally occurring tocopherols, particularly α-tocopherol, exhibit strong radical chain–breaking antioxidant activity and are considered more effective than their synthetic counterparts (Teh & Lau, 2021; Alkandari, Al-Hassawi, *et al*., 2021).

Unlike many vegetable oils in which tocopherols are the predominant form of vitamin E, palm oil possesses a unique vitamin E profile characterized by a high proportion of tocotrienols. This distinctive composition is particularly important because tocotrienols have been reported to exhibit stronger antioxidant activity and broader biological functions than tocopherols. Nevertheless, the retention of tocopherols and tocotrienols remains highly dependent on refining conditions and storage environments, emphasizing the importance of mild processing strategies to preserve their functional benefits.

Other Bioactive Compounds

Other bioactive compounds contained in RPO are PUFAs and phytosterols. RPO features a well-balanced fatty acid profile, containing approximately 10% PUFAs (Gao *et al*., 2023). PUFAs in the form of linoleic acid and linolenic acid can be reviewed in terms of quantity based on reports from several previous studies.

Trace phytochemicals, such as phytosterols, polyphenols, squalene, ubiquinones, and CoQ_{10}, have been identified in low concentrations (Cassiday, 2017). In RPO, squalene concentrations range from 14 to 15 parts per million, phytosterol levels range from 325 to 365 parts per million, while CoQ_{10} and ubiquinones are present at concentrations between 18 and 25 parts per million (Loganathan *et al*., 2017). The quantities of CoQ_{10}, polyphenols, phytosterols, squalene, and ubiquinones can be further examined based on findings from various prior studies.

Although these minor bioactive compounds occur at considerably lower concentrations than carotenoids and vitamin E, they may contribute synergistically to the overall antioxidant capacity and functional properties of RPO. However, current research has primarily focused on carotenoids and vitamin E, while the stability, bioavailability, and technological functionality of phytosterols, squalene, ubiquinones, and CoQ_{10} remain relatively underexplored.

Further studies are therefore needed to clarify their specific contributions to the nutritional and functional performance of RPO-based food products.

Stability of RPO

RPO is generally unstable, prone to degradation when exposed to light, and easily oxidised, making it unsuitable for long-term storage (Dewandari & Sofwan, 2022). The stability of RPO, particularly its carotenoid content, exhibits a decline during storage. Under ambient conditions, RPO can remain viable for up to 8 months, during which its carotene concentration diminishes from 500 ppm to 370.1 ppm (Gonçalves Albuquerque *et al*., 2019, as cited in Purnama *et al*., 2020). Vitamin E and carotenes play a crucial role in protecting oils from oxidative deterioration. Overall, both oils demonstrated stability due to their high antioxidant content.

Despite the presence of endogenous antioxidants such as carotenoids and vitamin E, RPO remains susceptible to oxidative deterioration during storage. This apparent contradiction arises because carotenoids and tocotrienols not only function as antioxidants but are also vulnerable to degradation when exposed to oxygen, light, and elevated temperatures. Consequently, preserving these bioactive compounds is critical for maintaining both the nutritional quality and oxidative stability of RPO.

RPOL is particularly rich in carotenes, which give it its distinctive orange-reddish colour. Both oils are abundant in tocotrienols and tocopherols, though RPOL contains higher levels compared to palm olein. While there was a slight increase in oxidation parameters, including *p-anisidine* value (AnV), FFA value, and PV, the antioxidant levels remained unaffected (Loganathan *et al*., 2020).

Compared with conventional palm olein, the higher concentrations of carotenoids and vitamin E in RPOL provide additional protection against oxidative deterioration. Nevertheless, gradual increases in PV, FFA, and AnV during storage indicate that endogenous antioxidants alone may not completely prevent oxidation, particularly during prolonged storage or under unfavourable environmental conditions.

Ali *et al*., (2014), in their research, reported that during the 30-minute storage period, the oil quality remained favourable, characterized by low levels of FFA and moisture. However, additional heating of the fruits after sterilisation resulted in a slight decrease in both the DOBI and carotene content. Renee Boyer., (2009) noted that sealed cooking oils could remain fresh for at least a year. However, once opened, their stability at room temperature lasted only one to three months. Meanwhile, based on the product specifications provided by Carotino Sdn. Bhd., RPOL has a shelf life of 24 months.

Reported shelf-life values vary considerably depending on processing conditions, packaging systems, and storage environments. While commercially packaged RPOL products may achieve shelf lives of up to 24 months, exposure to oxygen after opening can significantly accelerate oxidative deterioration. These findings highlight the importance of both processing and packaging strategies in preserving the quality of RPO-based products.

The stability of RPO can be achieved through techniques such as encapsulation and emulsification. Encapsulating RPO within polymers or microcapsules effectively preserves its nutritional integrity and enhances its overall stability (Sathasivam *et al*., 2018). Encapsulation performed without heat further enhances stability while protecting the active components from degradation during storage and processing (Lee *et al*., 2018). The potential emulsion system that can be processed by emulsification is a nanoemulsion. According to previous research, nanoemulsion is considered effective in enhancing the stability of RPO. An oil-in-water (o/w) nanoemulsion serves as an alternative approach to improve the solubility and stability of the bioactive components present in palm oil (Dewandari & Sofwan, 2022).

Recent studies have further demonstrated the potential of nanoliposomal systems for improving the stability of RPO bioactive compounds in food matrices. Rodsamai *et al*., (2026) reported that co-encapsulation of RPO and curcumin in nanoliposomes enhanced the retention of β-carotene and antioxidant activity during refrigerated storage of fortified yogurt. Interestingly, an intermediate fortification level (3% nanoliposomes) provided greater protection against β-carotene degradation than higher concentrations, suggesting that formulation optimisation is critical for maximizing the stability of encapsulated bioactive compounds.

Although encapsulation has demonstrated considerable potential for protecting carotenoids and vitamin E, several challenges remain, including encapsulation efficiency, encapsulating agent selection, production cost, and scalability. These factors may influence the commercial feasibility of encapsulated RPO products. In addition, the use of an encapsulating agent or emulsifier may increase production costs and limit large-scale implementation.

Besides nanoemulsion, Pickering emulsion can be the potential solution to maintain the stability of RPO. Pickering emulsions generally offer greater stability compared to traditional surfactant-based emulsions, with additional benefits including lower production costs, reduced adverse effects, low toxicity, and excellent biocompatibility (Marto *et al*., 2015; Sanchez-Salvador *et al*., 2019; Yang *et al*., 2017).

Recent research trends indicate increasing interest in Pickering emulsions as a clean-label alternative to conventional surfactant-based systems. Their superior physical stability and reduced reliance on synthetic emulsifiers make them particularly attractive for functional food applications. Nevertheless, challenges associated with food-grade particle selection, large-scale production, and regulatory acceptance remain important barriers to commercial implementation.

Overall, the stability of RPO is governed by a complex interaction between its fatty acid composition and bioactive compounds, particularly carotenoids and vitamin E. While these compounds contribute significantly to oxidative resistance, they are themselves susceptible to degradation during processing and storage. Consequently, recent research has increasingly focused on advanced stabilisation strategies, including encapsulation, nanoemulsion, and Pickering emulsion systems. Although these approaches have demonstrated promising results at the laboratory scale, further studies are required to evaluate their long-term stability, economic feasibility, and scalability for industrial food applications.

Benefits and Applications of RPO

RPO exhibits significant potential for application in several sectors, particularly in food systems due to its high content of bioactive compounds and functional lipids. One of the potential sectors to utilize RPO is the food sector. This is because the content of RPO has a good functional effect on health, so it has the potential to be a functional food. RPO is abundant in phytonutrients like phytosterols, carotenoids, tocopherols, and tocotrienols (Witasari *et al.*, 2025).

The potential health benefits of RPO have been largely attributed to its high content of carotenoids and vitamin E, particularly in relation to vitamin A metabolism and antioxidant activity. Recent evidence from an animal study by Jin *et al*., (2024) demonstrated that carotenoid-rich refined red palm-pressed mesocarp olein (PPMO) significantly increased retinol and retinyl palmitate levels and upregulated several genes involved in retinoid metabolism and visual

ISSN 1978-1067 (Print), ISSN 2528-6285 (Online)
DOI 10.24198/jt.vol20n2.4

cycle pathways in vitamin A-deficient rats, suggesting a potential role in supporting visual function and vitamin A status. However, these findings were obtained under controlled animal experimental conditions, and further human clinical studies are required to confirm the physiological relevance and long-term health implications of RPO consumption.

Sensory evaluation of RPO revealed that it is of high quality and is well-accepted, similar to RBD palm oil. The oil can be used in a variety of dishes such as salad dressings, curries, sauces, and others, and it imparts an appealing colour to French fries.

Benefits and Applications as a Functional Product for Foods or Beverages

RPO is rich in beneficial phytonutrients, particularly carotene, which is naturally produced without the need for fortification, making it a more cost-effective option for the food industry. RPO has the potential to be utilized in the development of various food products in Indonesia and the entire world. The health advantages associated with RPO-based products are likely to drive increased consumer demand for these items (Purnama *et al*., 2020). The consumption of foods high in these antioxidant vitamins offers considerable health benefits to consumers (Anishas *et al*., 2014; Gonzalez-Diaz *et al*., 2021).

Recent research has shifted from evaluating RPO solely as a cooking oil toward exploring its application as a multifunctional ingredient for food fortification and functional food development. This trend is largely driven by increasing consumer demand for naturally derived sources of provitamin A and antioxidants.

Several studies have investigated the incorporation of RPO into various food products and evaluated its associated benefits. Gonçalves Albuquerque *et al*., (2019) reported that RPO is suitable for use as a cooking oil, and Nagendran *et al*., (2000) reported a similar statement that RPO is highly suitable for use as a cooking oil. Wu & Wu., (2017) reported in their research that the carotenoid concentration in pilot gravies enriched with RPO was higher compared to pilot and commercial gravies without RPO. Additionally, gravies formulated with RPO exhibited superior oxidative stability.

Collectively, these studies demonstrate that RPO can be successfully incorporated into a wide range of food products while enhancing carotenoid and vitamin E contents. However, the level of incorporation must be carefully optimised because excessive inclusion may alter sensory attributes such as flavour, colour, and consumer acceptability. Gong *et al*., (2022) reported in their study that they examined the impact of replacing tallow with RPO on the shelf life of flavouring oil gravies, comparing one commercial sample with two pilot samples containing different ingredients.

Alkandari *et al*., (2021) reported that the functional foods they developed contained substantial levels of β-carotene and total vitamin E, demonstrating the feasibility of creating foods rich in these essential antioxidant vitamins from natural sources. Their findings suggest that high-quality digestive biscuits, pan bread, and extruded snacks can be effectively developed to provide healthier dietary options for consumers in the region, thereby enhancing overall health and productivity. Ng *et al*., (2012) in their research suggest that snacks made with RPO are well-received and can serve as a valuable source to enhance the dietary intake of provitamin A carotenoids among "*Malaysian Orang Asli*" children.

Sidhu *et al*., (2007) found that incorporating RPOL in the production of biscuits, snacks, and bread enhanced the phytochemical content of these foods. However, snacks prepared with red palm shortening exhibited notably lower concentrations of β-carotene. This study highlights the potential of RPOL and RPS in creating antioxidant-enriched functional confectionery products. Although these studies consistently demonstrate nutritional enhancement following RPO incorporation, the optimal inclusion level varies among food products due to differences in formulation requirements, processing conditions, and consumer acceptance.

Other food applications of RPO include spreads and ice cream. Kumar & Gopala, (2016) discovered that incorporating 20% retained palm olein (PRPOL) phytonutrients with butterfat in a chocolate spread achieved optimal market acceptance, as determined by sensory attributes. Solehah *et al*., (2023) conducted a study presenting the potential of RPO as a substitute for dairy fat in hard ice cream formulations, utilizing various stabilizers such as maltodextrin (MALTOD) and modified starch (MSTARCH). Rosnani *et al*., (2009) conducted a study and found that ice creams containing 5%, 8%, and 10% RPOL blended with non-milk fat solids received higher ratings for meltability, texture, taste, and colour.

The successful application of RPO in spreads and ice cream highlights its versatility as a lipid ingredient. Beyond improving nutritional quality, the unique fatty acid composition of RPO may influence texture, melting behaviour, and mouthfeel, making formulation optimisation a critical factor in product development.

Palm oil serves as an advantageous lipid source in ice cream formulations due to its utilisation without necessitating modification processes such as esterification and hydrogenation, which are known to generate trans-fatty acids detrimental to human health. Moreover, palm oil exhibits a lower cholesterol content compared to milk fat, making it a preferable alternative, particularly for individuals with lactose intolerance (Nazaruddin *et al*., 2008). Abd-ElGhany *et al*., (2020) demonstrate that incorporating RPO as a fat substitute in ice milk formulations yields desirable physicochemical properties suitable for production. Its inclusion enhances textural attributes, contributing to a softer and smoother mouthfeel. Additionally, RPO significantly impacts melting resistance, resulting in a lower resistance to melting compared to alternative formulations. Furthermore, its presence intensifies the yellowness of the product due to its high β-carotene and vitamin E content while also influencing viscosity and overrun percentage, thereby optimizing the overall formulation quality.

RPO can be used as a fortification agent, for example, in Cassava Garri and food supplements. Zhu *et al*., (2015) have done research that reported boiled biofortified cassava rich in β-carotene has the potential to increase retinyl palmitate levels in triacylglycerol-rich plasma, potentially helping to alleviate vitamin A deficiency. However, cassava requires thorough preparation to reduce its cyanogenic glucoside content, which can be toxic. Wayenbergh *et al*., (2024) demonstrated that toasted wheat bran can partially stabilize vitamin A as retinyl palmitate (RP) during the storage of RP-fortified gari. Among the various fortification methods tested, including the addition of RP, RPO, and yellow cassava, the addition of RPO proved to be the most promising strategy. Zeba *et al*., (2006), from their research, concluded that regular consumption of small amounts of RPO seems to be very effective in reducing vitamin A deficiency. RPO warrants further consideration as a food supplement for vitamin A and as a potential source of income for rural communities in Sahelian countries.

Despite its promising nutritional and functional attributes, the wider adoption of RPO in food products faces several challenges. The intense red-orange colour, characteristic flavour, oxidative instability, and consumer perception associated with palm oil products may limit its acceptance in certain food categories. Furthermore, concerns related to sustainability, production costs, and regulatory requirements continue to influence its commercial implementation.

Based on its content and characteristics for the foods and beverages, as previously summarized, the information can be concluded in the following Table 7:

FUTURE RESEARCH AND RECOMMENDATIONS

Comprehensive RPO Physicochemical Characterisation

Although interest in RPO and its fractions as functional food ingredients continues to grow, their physicochemical characteristics have not been systematically documented. Most studies report only a limited number of quality parameters, such as FFA content, PV, IV, or slip melting point. Consequently, it remains difficult to determine which physicochemical properties are most relevant to functionality and performance in different food systems. Differences in processing methods, analytical procedures, and reporting approaches further complicate comparisons among RPO, RPOL, and RPS.

Future research should provide a more comprehensive evaluation of RPO and its fractions by including physicochemical, rheological, thermal, and oxidative stability analyses. A better understanding of how composition influences functionality would help identify suitable applications in different food products. In addition, the development of standardized datasets for RPO and its fractions would improve product formulation, quality assessment, and the wider use of these materials in food processing.

Table 7. Various food products with potential applications of RPO

Products	References
Fortified Infant Milk	(Megananda *et al*., 2026)
Cookie Cream	(Mohamad Shah *et al*., 2022)
Pan Bread	(Alkandari, Al-hassawi, *et al*., 2021)
Fortified Cookies	(Perez-Santana *et al*., 2021)
Cooking Oil	(Gonçalves Albuquerque *et al*., 2019);
Potato Cookies	(Xu *et al*., 2022)
Biscuit	(Alkandari, Al-hassawi, *et al*., 2021)
Mayonnaise	(Ayu *et al*., 2023)
Ice Cream	(Solehah *et al*., 2023); (Rosnani *et al*., 2009)
Extruded Snack	(Alkandari, Al-hassawi, *et al*., 2021)
Gravy Oil	(Wu & Wu, 2017); (Gong *et al*., 2022)
Milk Ice	(Abd- ElGhany *et al*., 2020)

Advanced Stabilisation Technologies

The stability of carotenoids, tocopherols, and tocotrienols remains one of the major challenges limiting the broader utilisation of RPO in food systems. Recent studies have demonstrated that advanced stabilisation and delivery technologies, including encapsulation (Putra *et al*., 2025), Pickering emulsions (Zhou *et al*., 2025), and nanoemulsion systems (Rodsamai *et al*., 2026), can significantly improve the protection, retention, and bioavailability of these bioactive compounds during storage and processing. However, most existing studies have been conducted at the laboratory scale and primarily focus on short-term stability evaluations.

Whether the stability improvements observed under controlled laboratory conditions can be sustained during industrial processing and long-term storage remains unclear. In addition, limited information is available regarding the scalability, economic feasibility, and compatibility of these systems with food-grade materials. Particular attention should be given to the development of clean-label and sustainable stabilisation approaches that align with current consumer preferences and industrial requirements. Such advances would facilitate the commercial implementation of RPO as a functional ingredient in a wider range of food products.

Bioavailability and Health Validation

Most evidence regarding the health benefits of RPO comes from *in vitro* and animal studies. Although these studies suggest potential benefits related to antioxidant activity, vitamin A nutrition, and cardiovascular health, evidence from human studies remains limited. In addition, several biological activities associated with RPO bioactive compounds, including anti-inflammatory, neuroprotective, antimicrobial, and skin-health effects, have primarily been demonstrated in experimental models rather than well-controlled clinical trials (Madoromae & Lertcanawanichakul, 2025). Consequently, the extent to which these findings translate into long-term health benefits in humans remains uncertain.

More human studies are needed to clarify the bioavailability, metabolic fate, and long-term health effects of RPO consumption. Future research should also investigate dose–response relationships and factors affecting nutrient absorption to strengthen the scientific basis of health claims related to RPO. In addition, evidence from *in vitro*, animal, and clinical studies should be interpreted separately, as each type of study provides different levels of evidence regarding the potential health benefits of RPO.

Future studies should also investigate how different food matrices, processing conditions, and delivery systems influence the bioaccessibility and absorption of carotenoids, tocopherols, and tocotrienols from RPO. Understanding how these compounds behave across different food systems may help explain why similar carotenoid levels do not always yield comparable nutritional outcomes.

Product Development and Consumer Acceptance

The application of RPO in products such as snacks, spreads, bakery products, fortified foods, and ice cream highlights its potential as a functional food ingredient. To date, research has mainly examined product quality, nutritional composition, and physicochemical characteristics, with relatively little attention given to consumer-related aspects. A better understanding of sensory perception, product acceptance, and purchasing decisions across different consumer groups would help clarify the prospects for wider adoption of RPO-based foods.

Particular attention should be given to the influence of RPO's characteristic red-orange colour, aroma, and flavour on product acceptability, as these attributes may vary depending on the food matrix and consumer expectations. Although the characteristic red-orange colour of RPO may enhance the nutritional image of food products, it may also alter product appearance and influence consumer acceptance depending on the food category, cultural preferences, and market expectations. In addition, pilot-scale production trials and shelf-life studies are needed to assess the product consistency, commercial feasibility, and market competitiveness of RPO-based foods. Such efforts will be essential for facilitating the broader adoption of RPO in food fortification programs and functional food development.

Sustainability and Industrial Challenges

The growing interest in RPO as a functional food ingredient has brought greater attention to several sustainability, safety, and industrial considerations. Environmental concerns associated with palm oil cultivation, particularly deforestation, biodiversity loss, and greenhouse gas emissions (Madoromae & Lertcanawanichakul, 2025), continue to shape public perception and may influence the acceptance of palm oil-derived products. Consequently, the extent to which sustainability initiatives, including certified sustainable palm oil schemes and resource-efficient processing practices, can improve consumer confidence and reduce environmental impacts remains an important area of discussion. Future research should evaluate green extraction technologies, including supercritical CO_2 and enzyme-assisted extraction, to improve bioactive retention while reducing environmental impacts associated with conventional processing methods.

Food safety represents another key consideration. Processing contaminants such as 3-monochloropropane-1,2-diol (3-MCPD) esters and glycidyl esters may be formed during refining and continue to raise concerns regarding their potential health implications. In addition to environmental and regulatory issues, emerging contaminants may represent a growing challenge for the RPO industry. Saati *et al*., (2025) detected several microplastic polymers in commercial RPO samples and highlighted their potential implications for food safety. Consequently, greater attention should be directed toward contamination control and monitoring strategies to support the safety and market acceptance of RPO-based products.

At the industrial level, questions also remain regarding the scalability of RPO production, supply chain reliability, techno-economic viability, and compliance with regulatory requirements in different markets. The economic implications of bioactive retention technologies should also be considered, as additional processing and stabilisation steps may increase production costs and affect the commercial competitiveness of RPO-based products. A clearer understanding of these environmental, safety, and industrial factors would support the responsible development and wider adoption of RPO-based products within modern food systems.

CONCLUSION

RPO, a minimally processed variant of CPO, retains its natural carotenoids and vitamin E compounds that are often lost during conventional refining. These bioactives, together with a balanced fatty acid composition, contribute to its oxidative stability, colour, and functional properties in food systems. The available evidence indicates that the technological performance of RPO is closely associated with the preservation of these bioactive constituents, highlighting the importance of processing conditions in maintaining both product quality and functionality.

RPO demonstrates strong potential as a functional ingredient for food applications due to its stability, simple processing, and compatibility with various formulations such as margarine, spreads, shortening, bakery products, and emulsion-based systems. However, its broader utilisation remains influenced by several factors, including bioactive degradation during processing and storage, variability in physicochemical characteristics, consumer acceptance, and industrial feasibility. Recent advances in stabilisation technologies, including encapsulation, nanoemulsion, nanoliposomal, and Pickering emulsion systems, provide promising opportunities to improve the retention and delivery of RPO bioactive compounds.

Future research should focus on optimising processing techniques and formulation strategies to enhance the stability, sensory attributes, and bioactive retention of RPO-based products. Greater attention should also be directed toward comprehensive physicochemical characterisation, human health validation, sustainability considerations, and industrial scalability.

Establishing standardized quality parameters and recommended intake levels will further strengthen the scientific basis for RPO utilisation and support its integration into modern food innovation and sustainable food systems.

ACKNOWLEDGEMENT

The authors would like to thank Department of Food Industrial Technology, Universitas Padjadjaran, Department of Chemical Engineering, Universitas Indonesia, and Sustainability of Environmental Resources Research Group, Research Center for Environmental Technology and Clean Technology, National Research and Innovation Agency (BRIN) Indonesia for the development of this work. The authors extend their heartfelt gratitude to Ministry of Higher Education, Science, and Technology of the Republic of Indonesia for providing the necessary facilities

REFERENCES

Ayeleso, A.O. (2012). Effects of dietary intake of RPO on fatty acid composition and lipid profiles in male Wistar rats. *African Journal of Biotechnology*, *11*(33), 8275–8279. https://doi.org/10.5897/ajb11.4080

Abd-ElGhany, M., Hegazy, A., Basuny, A., & Zaghlool, A. (2020). Using of RPO as milk fat healthy replacer in ice milk. *Al-Azhar Journal of Agricultural Research*, *45*(1), 8–22. https://doi.org/10.21608/ajar.2020.126614

Abidi, S. L. (2003). Tocol-derived minor constituents in selected plant seed oils. *Journal of the American Oil Chemists' Society*, *80*(4), 327–333. https://doi.org/10.1007/s11746-003-0698-9

Alhaji, A. M., Almeida, E. S., Carneiro, C. R., da Silva, C. A. S., Monteiro, S., & Coimbra, J. S. dos R. (2024). Palm Oil (*Elaeis guineensis*): A Journey through Sustainability, Processing, and Utilization. *Foods*, *13*(17), 2814. https://doi.org/10.3390/foods13172814

Ali, F. S., Shamsudin, R., & Yunus, R. (2014). The Effect of Storage Time of Chopped Oil Palm Fruit Bunches on the Palm Oil Quality. *Agriculture and Agricultural Science Procedia*, *2*, 165–172. https://doi.org/10.1016/j.aaspro.2014.11.024

Alkandari, S., Al-Hassawi, F., Aldughpassi, A., Sidhu, J. S., Al-Amiri, H. A., Al-Othman, A., Ahmed, N., & Ahmad, A. (2021). Pilot scale production of functional foods using RPOL: Antioxidant, vitamins' stability and sensory quality during storage. *Saudi Journal of Biological Sciences*, *28*(10), 5547–5554. https://doi.org/10.1016/j.sjbs.2021.06.032

Anishas, C., Idris, C., Karupaiah, T., Sundram, K., Ai, Y., Balasundram, N., Leow, S., Shaqinah, N., & Sambanthamurthi, R. (2014). Oil palm phenolics and vitamin E reduce atherosclerosis in rabbits. *Journal of Functional Foods*, *7*, 541–550. https://doi.org/10.1016/j.jff.2014.01.002

Ayu, D. F., Pratama, J. P., Johan, V. S., Dewi, Y. K., & Hamzah, F. H. (2023). Effect of deodorization temperature on the making of RPO mayonnaise as tropical plantation products. *IOP Conference Series: Earth and Environmental Science*, *1241*(1). https://doi.org/10.1088/1755-1315/1241/1/012077

Cassiday, L. (2017). RPO. *International News on Fats, Oils and Related Materials*, *28*(2), 6–10. https://doi.org/10.21748/inform.02.2017.06

Ceriani, R., Paiva, F. R., Gonçalves, C. B., Batista, E. A. C., & Meirelles, A. J. A. (2008). Densities and Viscosities of Vegetable Oils of Nutritional Value. *Journal of Chemical & Engineering Data*, *53*(8), 1846–1853. https://doi.org/10.1021/je800177e

Cheng, S. F., Nor L., M., & Chuah, C. H. (2011). Microwave pretreatment: A clean and dry method for palm oil production. *Industrial Crops and Products*, *34*(1), 967–971. https://doi.org/10.1016/J.INDCROP.2011.03.002

Cláudia da Costa Rocha, A., José de Andrade, C., & de Oliveira, D. (2021). Perspective on integrated biorefinery for valorization of biomass from the edible insect Tenebrio molitor. *Trends in Food Science & Technology*, *116*, 480–491. https://doi.org/10.1016/j.tifs.2021.07.012

Delisle, H. (2018). *The nutritional value of RPO*. *October*, 217–232. https://doi.org/10.19103/as.2017.0018.33

Department of Standards Malaysia. (2007a). Palm Olein - Specification MS 816:2007. 816(MS 816:2007), 1–13.

Department of Standards Malaysia. (2007b). Palm Stearin - Specification (Second Revision). *SIRIM Berhad*, *815*.

Dewandari, K. T., & Sofwan, G. (2022). Effects of Variation Emulsifier on Stability of RPO Nanoemulsion (*Elaeis guineensis Jacq*). *IOP Conference Series: Earth and Environmental Science*, *1024*(1). https://doi.org/10.1088/1755-1315/1024/1/012007

Dias, M. G., Olmedilla-Alonso, B., Hornero-Méndez, D., Mercadante, A. Z., Osorio, C., Vargas-Murga, L., & Meléndez-Martínez, A. J. (2018). Comprehensive Database of Carotenoid Contents in Ibero-American Foods. A Valuable Tool in the Context of Functional Foods and the Establishment of Recommended Intakes of Bioactives. *Journal of Agricultural and Food Chemistry*, *66*(20), 5055–5107. https://doi.org/10.1021/acs.jafc.7b06148

El-Hadad, N., Abou-Gharbia, H. A., Abd El-Aal, M. H., & Youssef, M. M. (2010). RPOL: Characterization and Utilization in Formulating Novel Functional Biscuits. *Journal of the American Oil Chemists' Society*, *87*(3), 295–304. https://doi.org/10.1007/s11746-009-1497-x

Emmanuel, O., Okezie, U. M., Iweala, E. J., & Ugbogu, E. A. (2021). Pretreatment of red palm oil extracted from palm fruit (*Elaeis guineensis*) attenuates carbon tetrachloride induced toxicity in Wistar rats. *Phytomedicine Plus*, *1*(4), 100079. https://doi.org/10.1016/j.phyplu.2021.100079

FAO. (2022). *FAOSTAT Statistical Database*.

Farhoush, R., Mousavi, S. M. R., & Sharif, A. L. I. (2008). Investigation on frying oils quality in terms of color index, refractive index and viscosity values during frying process.

Gao, Z., Zhu, Y., Jin, J., Jin, Q., & Wang, X. (2023). Chemical–Physical Properties of RPOs and Their Application in the Manufacture of Aerated Emulsions with Improved Whipping Capabilities. *Foods*, *12*(21). https://doi.org/10.3390/foods12213933

Gonçalves Albuquerque, T., Costa, H., Silva, M., & Oliveira, M. (2019). Are chloropropanols and glycidyl fatty acid esters a matter of concern in palm oil? *Trends in Food Science & Technology*, *105*. https://doi.org/10.1016/j.tifs.2019.01.005

Gong, G., Wu, X., Wu, S., Yoong, J., Ji, M. I. N., & Hu, M. (2022). *Estimating the shelf life of flavouring oil gravy consisting of RPO*. *Journal of Oil Palm Research, 34*(September), 571–579. https://doi.org/10.21894/jopr.2022.0011

Gonzalez-Diaz, A., Pataquiva-Mateus, A., & García-Núñez, J. A. (2021). Recovery of palm phytonutrients as a potential market for the by-products generated by palm oil mills and refineries–A review. *Food Bioscience*, *41*, 100916. https://doi.org/10.1016/j.fbio.2021.100916

Gunstone, F. D. (2005). Vegetable Oils. In *Bailey's Industrial Oil and Fat Products*. https://doi.org/10.1002/047167849X.bio018

Gutierrez-Mariscal, F. M., Larriva, A. P. A. De, Limia-Perez, L., Romero-Cabrera, J. L., Yubero-Serrano, E. M., & López-Miranda, J. (2020). Coenzyme q10 supplementation for the reduction of oxidative stress: Clinical implications in the treatment of chronic diseases. *International Journal of Molecular Sciences*, *21*(21), 1–19. https://doi.org/10.3390/ijms21217870

Harahap, F., Leduc, S., Mesfun, S., Khatiwada, D., Kraxner, F., & Silveira, S. (2020). Meeting the bioenergy targets from palm oil based biorefineries: An optimal configuration in Indonesia. *Applied Energy*, *278*, 115749. https://doi.org/10.1016/J.APENERGY.2020.115749

He, L., Guoying, Z., Huaiyun, Z., & Yuanhao, H. (2010). *Chemical constituents and biological activities of saponin from the seed of Camellia oleifera*. *5*(25), 4088–4092.

Henson, I. E. (2012). A Brief History of the Oil Palm. Palm Oil: Production, Processing, Characterization, and Uses, 1–29. https://doi.org/10.1016/B978-0-9818936-9-3.50004-6

Izuddin, W. I., Loh, T. C., Nayan, N., Akit, H., Noor, A. M., & Foo, H. L. (2023). Blood lipid profiles, fatty acid deposition and expression of hepatic lipid and lipoprotein metabolism genes in laying hens fed palm oils, palm kernel oil, and soybean oil. *Frontiers in Veterinary Science*, *10*(July). https://doi.org/10.3389/fvets.2023.1192841

Jin, Y., Teh, S. S., Yap, W. H., Lau, H. L. N., & Mah, S. H. (2024). *In vivo* retinoid metabolic and visual cycle pathways assessment of carotenoid-rich refined red palm-pressed mesocarp olein. *Journal of Functional Foods*, *116*, 106140. https://doi.org/10.1016/j.jff.2024.106140

Kamaruzaman, N., Babji, A., Ismail, W. R. W., & Peng, F. S. (2015). Vitamin e contents and oxidative stability of RPOs blended chicken nuggets during frozen storage. *Malaysian Journal of Analytical Sciences*, *19*, 202–212.

Khaneghah, M., Shoeibi, S., & Ameri, M. (2012). Effects of storage conditions and PET packaging on quality of edible oils in Iran. *Advances in Environmental Biology*, 694–702.

Kumar, P. K. P., & Gopala, T. J. A. G. (2016). Physicochemical characteristics of phytonutrient retained RPOL and butter-fat blends and its utilization for formulating chocolate spread. *Journal of Food Science and Technology*, *53*(7), 3060–3072. https://doi.org/10.1007/s13197-016-2279-8

Kumar, P. K. P., & Krishna, A. G. G. (2015). Effect of Different Deacidification Methods on Phytonutrients Retention in Deacidified Fractionated Palm Oil. *Journal of the American Oil Chemists' Society*, *92*(5), 645–658. https://doi.org/10.1007/s11746-015-2626-3

Lee, W. J., Tan, C. P., Sulaiman, R., Smith, R. L., & Chong, G. H. (2018). Microencapsulation of RPO as an oil-in-water emulsion with supercritical carbon dioxide solution-enhanced dispersion. *Journal of Food Engineering*, *222*, 100–109. https://doi.org/10.1016/J.JFOODENG.2017.11.011

Liu, Y., Liu, J., Cong, P., Zhang, T., Xue, C., Xu, J., Wang, Y., Mao, X., & Wang, J. (2021). Exogenous phosphatidylglucoside alleviates cognitive impairment by improvement of neuroinflammation, and neurotrophin signaling. In *Clinical and Translational Medicine* (Vol. 11, Issue 3, p. e332). https://doi.org/10.1002/ctm2.332

Loganathan, R., Subramaniam, K. M., Radhakrishnan, A. K., Choo, Y. M., & Teng, K. T. (2017). Health-promoting effects of RPO: Evidence from animal and human studies. *Nutrition Reviews*, *75*(2), 98–113. https://doi.org/10.1093/nutrit/nuw054

Loganathan, R., Tarmizi, A. H. A., Vethakkan, S. R., & Teng, K. T. (2020). Storage stability assessment of RPOL in comparison to palm olein. *Journal of Oleo Science*, *69*(10), 1163–1179. https://doi.org/10.5650/jos.ess20036

Madoromae, H., & Lertcanawanichakul, M. (2025). Red Palm Oil: Nutritional Composition, Bioactive Properties, and Potential Applications in Health and Cosmetics: A Narrative Review. In *Molecules* (Vol. 30, Issue 22, p. 4402). https://doi.org/10.3390/molecules30224402

Maoka, T. (2020). Carotenoids as natural functional pigments. *Journal of Natural Medicines*, *74*(1), 1–16. https://doi.org/10.1007/s11418-019-01364-x

Martirosyan, D., & Miller, E. (2018). Bioactive compounds: The key to functional foods. *Bioactive Compounds in Health and Disease*, *1*(3), 36–39. https://doi.org/10.31989/bchd.v1i3.539

Marto, J., Gouveia, L., Jorge, I. M., Duarte, A., Gonçalves, L. M., Silva, S. M. C., Antunes, F., Pais, A. A. C. C., Oliveira, E., Almeida, A. J., & Ribeiro, H. M. (2015). Starch-based Pickering emulsions for topical drug delivery: A QbD approach. *Colloids and Surfaces B: Biointerfaces*, *135*, 183–192. https://doi.org/10.1016/J.COLSURFB.2015.07.024

Mayneris-Perxachs, J., Guerendiain, M., Castellote, A. I., Estruch, R., Covas, M. I., Fitó, M., Salas-Salvadó, J., Martínez-González, M. A., Aros, F., Lamuela-Raventós, R. M., & López-Sabater, M. C. (2014). Plasma fatty acid composition, estimated desaturase activities, and their relation with the metabolic syndrome in a population at high risk of cardiovascular disease. *Clinical Nutrition*, *33*(1), 90–97. https://doi.org/10.1016/j.clnu.2013.03.001

Megananda, R. C., Nafisa, A. S., Raharjo, S., Brück, W. M., & Witasari, L. D. (2026). Encapsulation of interesterified red palm oil and sacha inchi oil by using canna porous starch (*Canna edulis Kerr.*) as infant milk formula fortification. *Industrial Crops and Products*, *241*, 122607. https://doi.org/10.1016/j.indcrop.2025.122607

Mohamad Shah, N. K., Sanny, M., Ab Karim, N. A., Kuppan, K., & Mat, Y. M. (2022). Enhanced natural antioxidant compounds in RPOL-based shortening developed for sandwich cookie cream. *Food Research*, *6*(2), 172–181. https://doi.org/10.26656/fr.2017.6(2).118

Mozzon, M., Pacetti, D., Lucci, P., Balzano, M., & Frega, N. G. (2013). Crude palm oil from interspecific hybrid *Elaeis oleifera* × *Elaeis guineensis*: Fatty acid regiodistribution and molecular species of glycerides. *Food Chemistry*, *141*(1), 245–252. https://doi.org/10.1016/J.FOODCHEM.2013.03.016

Nagendran, B., Unnithan, U. R., Choo, Y. M., & Sundram, K. (2000). Characteristics of RPO, a carotene- and vitamin E-rich refined oil for food uses. *Food and Nutrition Bulletin*, *21*(2), 189–194. https://doi.org/10.1177/156482650002100213

Nainggolan, M., & Sinaga, A. (2021). Characteristics of fatty acid composition and minor constituents of RPOL and palm kernel oil combination. *Journal of Advanced Pharmaceutical Technology and Research*, *12*(1), 22–26. https://doi.org/10.4103/japtr.JAPTR_91_20

Nazaruddin, R., Syaliza, A. S., & Wan Rosnani, A. I. (2008). The effect of vegetable fat on the physicochemical characteristics of dates ice cream. *International Journal of Dairy Technology*, *61*(3), 265–269. https://doi.org/10.1111/j.1471-0307.2008.00413.x

Ng, T. K. W., Low, C. X., Kong, J. P., & Cho, Y. L. (2012). Use of RPO in local snacks can increase intake of provitamin A carotenoids in young aborigines children: a Malaysian experience. *Malaysian Journal of Nutrition*, *18*(3), 393–397.

Obibuzor, J. U., Okogbenin, E. A., & Abigor, R. D. (2012). *11* - Oil Recovery from Palm Fruits and Palm Kernel (O.-M. Lai, C.-P. Tan, & C. C. B. T.-P. O. Akoh (eds.); pp. 299–328). AOCS Press. https://doi.org/10.1016/B978-0-9818936-9-3.50014-9

Owolarafe, O. K., Faborode, M. O., & Ajibola, O. O. (2002). Comparative evaluation of the digester–screw press and a hand-operated hydraulic press for palm fruit processing. *Journal of Food Engineering*, *52*(3), 249–255. https://doi.org/10.1016/S0260-8774(01)00112-1

Pan, J., Shen, H., You, J., & Luo, Y. (2011). Changes in Physiochemical Properties of Myofibrillar Protein From Silver Carp (*Hypophthalmichthys Mollitrix*) During Heat Treatment. *Journal of Food Biochemistry*, *35*(3), 939–952.https://doi.org/10.1111/j.1745-4514.2010.00431.x

Perez-Santana, M., Cagampang, G. B., Gu, L., MacIntosh, I. S., Percival, S. S., & MacIntosh, A. J. (2021). Characterization of physical properties and retention of bioactive compounds in cookies made with high oleic RPOL. *LWT*, *147*, 111499. https://doi.org/10.1016/j.lwt.2021.111499

Poku, K., & Nations, F. and A. O. of the U. (2002). *Small-scale Palm Oil Processing in Africa*. Food and Agriculture Organization of the United Nations. https://books.google.co.id/books?id=cET5PdWGbIQC

Purnama, K. O., Setyaningsih, D., Hambali, E., & Taniwiryono, D. (2020). Processing, Characteristics, and Potential Application of RPO - A review. *International Journal of Oil Palm*, *3*(2), 40–55. https://doi.org/10.35876/ijop.v3i2.47

Putra, B. S., Raharjo, S., & Witasari, L. D. (2025). Encapsulation of red palm oil using porous starch from Canna edulis Kerr. *Food Chemistry Advances*, *7*, 100989. https://doi.org/10.1016/j.focha.2025.100989

Renee Boyer, J. M. (2009). Food Storage Guidelines For Consumers. *Virginia Cooperative Extension*, *348–960*, 1–12.

Riyadi, A. H., Muchtadi, T. R., Andarwulan, N., & Haryati, T. (2016). Pilot Plant Study of RPO Deodorization Using Moderate Temperature. *Agriculture and Agricultural Science Procedia*, *9*, 209–216. https://doi.org/10.1016/j.aaspro.2016.02.129

Rodriguez-Amaya, D. B., Esquivel, P., & Meléndez-Martínez, A. J. (2023). Comprehensive Update on Carotenoid Colorants from Plants and Microalgae: Challenges and Advances from Research Laboratories to Industry. *Foods*, *12*(22). https://doi.org/10.3390/foods12224080

Rodriguez-Concepcion, M., Avalos, J., Bonet, M. L., Boronat, A., Gomez-Gomez, L., Hornero-Mendez, D., Limon, M. C., Meléndez-Martínez, A. J., Olmedilla-Alonso, B., Palou, A., Ribot, J., Rodrigo, M. J., Zacarias, L., & Zhu, C. (2018). A global perspective on carotenoids: Metabolism, biotechnology, and benefits for nutrition and health. *Progress in Lipid Research*, *70*(April), 62–93. https://doi.org/10.1016/j.plipres.2018.04.004

Rodsamai, T., Chaijan, M., Panpipat, W., & McClements, D. J. (2026). Nanoliposomal co-delivery of red palm oil and curcumin: Physicochemical and functional characterization in fortified yogurt. *Grain & Oil Science and Technology*, *9*(2), 159–172. https://doi.org/10.1016/j.gaost.2026.03.003

Romano, R., Lestari, P. P., Kembaren, E. T., Agribisnis, P. S., Pertanian, F., Kuala, U. S., Kimia, J. T., Indonesia, A. T., Agribisnis, P. S., Pertanian, F., Malikussaleh, U., Agribisnis, P. S., Pertanian, F., & Umar, U. T. (2022). *Oil Palm Fresh Fruits (FFB) Rendement*. *2*(1), 897–908.

Rosnani, W., Isa, A., Idris, N. A., & Ibrahim, A. R. (2009). Physical Properties of Red Palm-based Ice Cream. 59(November), 18–24.

Rutz, J. K., Borges, C. D., Zambiazi, R. C., Crizel-Cardozo, M. M., Kuck, L. S., & Noreña, C. P. Z. (2017). Microencapsulation of palm oil by complex coacervation for application in food systems. *Food Chemistry*, *220*, 59–66. https://doi.org/10.1016/j.foodchem.2016.09.194

Saati, E. A., Setyobudi, R. H., Iswahyudi, I., Asiyah, R., Taufiq, M., Churochman, M., Aula, M., Wahono, S. K., Hidayati, A., Garfansa, M. P., Hartati, F. K., Puspitarini, A. D., Diksa, G. S. P., & Amani, S. A. (2025). Number and characteristics of microplastics contamination in commercial red palm oils. *Food and Humanity*, *5*, 100737. https://doi.org/10.1016/j.foohum.2025.100737

Sanchez-Salvador, J. L., Balea, A., Monte, M. C., Blanco, A., & Negro, C. (2019). Pickering emulsions containing cellulose microfibers produced by mechanical treatments as stabilizer in the food industry. *Applied Sciences (Switzerland)*, *9*(2). https://doi.org/10.3390/app9020359

Sathasivam, T., Muniyandy, S., Chuah, L. H., & Janarthanan, P. (2018). Encapsulation of RPO in carboxymethyl sago cellulose beads by emulsification and vibration technology: Physicochemical characterization and in vitro digestion. *Journal of Food Engineering*, *231*, 10–21. https://doi.org/10.1016/J.JFOODENG.2018.03.008

Sidhu, J. S., Ahmad, A., Ahmed, N., Mansor, I. B., & Minal, J. (2007). Developing Functional Foods Using RPOL : Pilot-Scale Studies Using RPOL : *2912*. https://doi.org/10.1081/JFP-120022491

Silva, S. M., Sampaio, K. A., Ceriani, R., Verhé, R., Stevens, C., De Greyt, W., & Meirelles, A. J. A. (2014). Effect of type of bleaching earth on the final color of refined palm oil. *Lwt*, *59*(2P2), 1258–1264. https://doi.org/10.1016/j.lwt.2014.05.028

Solehah, N., Zaini, M., Mansor, N., & Yusoff, M. M. (2023). Physico-chemical and Sensory Properties of RPO-based Ice Cream Using Maltodextrin or Modified Starch as Stabilizers. *818*(9), 811–818.

Soonsuwon, W., Eksomtramage, T., Nakkanong, K., Songsr, N., & Kaewsrisom, H. (2020). Identifying F2 Oil Palm (*Elaeis guineensis Jacq*.) Trees for Their Dura, Pisifera and Tenera Types using Fruit Morphology and SSR Markers. *Indian Journal of Agricultural Research*, *54*(3), 399–403. https://doi.org/10.18805/IJARe.A-502

Tan, C. H., Lee, C. J., Tan, S. N., Poon, D. T. S., Chong, C. Y. E., & Pui, L. P. (2021). RPO: A review on processing, health benefits and its application in food. *Journal of Oleo Science*, *70*(9), 1201–1210. https://doi.org/10.5650/jos.ess21108

Teh, S. S., & Lau, H. L. N. (2021). Quality assessment of refined red palm-pressed mesocarp olein. *Food Chemistry*, *340*, 127912. https://doi.org/10.1016/j.foodchem.2020.127912

Wae-hayee, M., Pakdeechot, S., Hanifarianty, S., & Suksuwan, W. (2022). Minimizing water consumption in oil palm sterilization using direct steaming: Effects of sterilization pressure and time. *Journal of Food Engineering*, *315*, 110804. https://doi.org/10.1016/j.jfoodeng.2021.110804

Wan Mohamad, W. A. F., Buckow, R., Augustin, M. A., & McNaughton, D. (2017). In situ quantification of β-carotene partitioning in oil-in-water emulsions by confocal Raman microscopy. *Food Chemistry*, *233*, 197–203. https://doi.org/10.1016/J.FOODCHEM.2017.04.086

Wayenbergh, E. Van, Boakye, A. A., Baert, J., Langenaeken, N. A., Appaw, W. O., Foubert, I., Oduro, I. N., & Courtin, C. M. (2024). Vitamin A stability during storage of forti fi ed gari produced using different forti fi cation strategies. *Npj Science of Food*, 1–9. https://doi.org/10.1038/s41538-024-00350-2

Witasari, L. D., Salim, J. S., Jason, B., Kurniawan, E. W., Pratama, Y., & Nusantoro, B. P. (2025). Physicochemical properties of enzymatically interesterified red palm oil. *Journal of Food Composition and Analysis*, *146*, 107860. https://doi.org/10.1016/j.jfca.2025.107860

Wu, X., & Wu, S. (2017). RSC Advances Influence of RPO on the physicochemical and sensory qualities of flavouring oil gravy for. *RSC Advances*, *8*, 1148–1158. https://doi.org/10.1039/C7RA12387F

Xu, J., Liu, Y. Y., Olajide, T. M., Liu, H. A., & Weng, X. C. (2022). The effect of replacing red palm stearin with RPOL in baked potato cookies. *Grasas y Aceites*, *73*(2). https://doi.org/10.3989/GYA.0441211

Yang, Y., Fang, Z., Chen, X., Zhang, W., Xie, Y., Chen, Y., Liu, Z., & Yuan, W. (2017). An overview of pickering emulsions: Solid-particle materials, classification, morphology, and applications. *Frontiers in Pharmacology*, *8*(MAY), 1–20. https://doi.org/10.3389/fphar.2017.00287

Zeba, A. N., Prével, Y. M., Somé, I. T., & Delisle, H. F. (2006). The positive impact of RPO in school meals on vitamin A status : study in Burkina Faso. *10*, 1–10. https://doi.org/10.1186/1475-2891-5-17

Zhou, B., Hao, Q., Liang, Y., & Kong, E. (2023). Protein palmitoylation in cancer: molecular functions and therapeutic potential. *Molecular Oncology*, *17*(1), 3–

ISSN 1978-1067 (Print), ISSN 2528-6285 (Online)
DOI 10.24198/jt.vol20n2.4

26. https://doi.org/10.1002/1878-0261.13308

Zhou, L., Ali, I., Goh, B. H., Fu, J. Y., Manickam, S., Tang, S. Y., & Shen, Q. (2025). Enhancing meat emulsion gels with soy protein fibril and red palm oil Pickering emulsions: The role of emulsification techniques in chicken fat substitution. *LWT*, *216*, 117348. https://doi.org/10.1016/j.lwt.2025.117348

Zhu, C., Cai, Y., Gertz, E. R., La Frano, M. R., Burnett, D. J., & Burri, B. J. (2015). RPO–supplemented and biofortified cassava gari increase the carotenoid and retinyl palmitate concentrations of triacylglycerol-rich plasma in women. *Nutrition Research*, *35*(11), 965–974. https://doi.org/10.1016/j.nutres.2015.08.003

Zolfagharnassab, S., Shariff, A. R., Ehsani, R., Jaafar, H. Z., & Aris, I. B. (2022). Classification of Oil Palm Fresh Fruit Bunches Based on Their Maturity Using Thermal Imaging Technique. In *Agriculture* (Vol. 12, Issue 11, p. 1779). https://doi.org/10.3390/agriculture12111779

Halaman ini sengaja dikosongkan