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A review of chemistry, extraction, functional properties, and sustainable food applications of rambutan (Nephelium lappaceum L.)

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Abstract: Rambutan (Nephelium lappaceum L.), a delicious tropical fruit, is cultivated extensively in the Southeast Asian region. Processing of rambutan generates a lot of seed waste as seeds are discarded when the edible portion of the fruit is stripped off. On an average, rambutan seeds form 5-10% of the total mass of the fruit. The kernel contained within the seeds, which is a fatty tissue extracted for its valuable content, contains about 30-40% of fat on a dry weight basis. A range of 20-41% has been mentioned in the literature due to variation in seed fraction, cultivar, and extraction process utilized for fat extraction from the kernels. Though considered a waste product, rambutan seeds are rich sources of edible fat. It is rich in oleic and arachidic acids, which give it unique physicochemical properties. These properties are similar to those of cocoa butter, making rambutan seed fat a promising ingredient for food applications.

This review summarizes the current knowledge on rambutan seeds as an underutilized agro-industrial by-product. It highlights their chemical composition, methods of fat extraction, physicochemical properties and potential food applications. The review discusses conventional extraction methods such as mechanical pressing extraction and solvent extraction. It also reviews new green extraction technologies such as supercritical CO2 extraction, ultrasound-assisted extraction, microwave-assisted extraction, and enzyme-assisted extraction. The review also describes the thermal behavior, crystallization, triacylglycerol profile, polymorphism and structural features of rambutan seed fat by using different analytical methods.

The functional attributes of rambutan seed fat, including its flexibility, oxidative stability, melting behavior, and emulsifying properties, are also evaluated in this research. Additionally, nutritional value, safety, and presence of antinutritional components of rambutan seed fat are also discussed. The study highlights the significance of using rambutan seed waste as a valuable resource rather than discarding it. It demonstrates how the circular economy and waste valorization are supported by the use of rambutan seed waste. Additionally, this method contributes to the Sustainable Development Goals (SDG) of the United Nations.

Keywords: Rambutan seed fat, Nephelium lappaceum, cocoa butter substitute, seed waste valorization, extraction technology, fat crystallization, circular economy

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1. Introduction

Cocoa butter is the primary fat used in chocolate and confectionery items. It has the sensory attributes and texture that customers like, including gloss, hardness, a clean snap, quick melting at body temperature, and a smooth mouthfeel. However, one of the priciest materials required to make chocolate is cocoa butter. The availability of cocoa is more affected by changes in its production. Price volatility and worries about long-term supply have been exacerbated by pest and disease outbreaks, climate change, and increased global demand. These difficulties have led to the discovery of substitute plant-derived fats that may serve as improvers, replacements, or counterparts of cocoa butter (Beckett, 2008). One of the promising fat types is the rambutan (Nephelium lappaceum L.) seed fat. This fat offers an opportunity of utilizing the seeds that are normally discarded as waste during the process of fruit production as a food item with increased value. Its potential is derived from the physicochemical properties similar to those of cocoa butter, particularly the solid fat and fatty acid composition, which make it a viable choice for confectionery applications.

Rambutan (Nephelium lappaceum L.), a tropical fruit that closely resembles lychee and longan belongs to the Sapindaceae family. It is widely cultivated in Southeast Asian countries such as Thailand, Malaysia, Indonesia, and the Philippines. Commercially it is also produced in Sri Lanka, Vietnam, Central America, and some parts of Africa. The fruit is mostly consumed fresh and is also processed into products such as canned fruits, juices, jams, jellies, and preserves. During its processing, large numbers of seeds are generated as by-products. These are often considered waste or used for low-value applications. Rambutan seeds make a considerable portion of the fruit and contain a relatively high amount of fat. However, this valuable resource remains largely underutilized. In addition to increasing the economic value of rambutan processing, recovering and using rambutan seed fat may aid in the reduction of agro-industrial waste.

Earlier reviews, including Jahurul et al. (2020) and Hernandez-Hernandez et al. (2019), cover the whole rambutan seed. This review is unique since it focuses solely on the fat. The main question it answers is if the fat is suitable as a substitute for cocoa butter. This review offers three novel aspects. First, the comparison of extraction procedures is provided (Section 4). Secondly, there is the comparison of the properties of the fat including crystallization and physicochemical characteristics with cocoa butter in standardized terminology (Section 5). Lastly, there is the distinction between the food applications that have been scientifically proven and those that are still theoretical (Section 7). There is one more aspect worth mentioning; no life-cycle and cost assessment studies support the sustainability of the fat yet (Section 9). Earlier reviews do not mention this gap. The goal of this review is practical. It is meant to help with formulation and process decisions. It is not meant to repeat the broader nutrition survey already done by Jahurul et al. (2020).

Literature was identified through Scopus, Web of Science, PubMed, ScienceDirect, and Google Scholar, using combinations of the terms 'rambutan,' 'Nephelium lappaceum,' 'seed fat,' 'seed oil,' 'cocoa butter substitute/equivalent/replacer,' 'seed waste valorization,' and specific extraction-technology terms (e.g., 'supercritical CO_2 extraction,' 'ultrasound-assisted extraction'). Searches were not date-restricted at the lower bound, given the limited total body of rambutan-specific literature, but prioritized publications from 2005 onward, with an emphasis on studies from the last fifteen years; the search was last updated july 2026. Englishlanguage, peer-reviewed journal articles, book chapters, and conference proceedings addressing rambutan seed or seed fat composition, extraction, physicochemical/functional characterization, food application, safety, or valorization were included.

2. Rambutan Production and Generation of Seed Waste

The majority of the world's rambutan is produced in Southeast Asia. The three main countries that produce and export rambutan are Thailand, Malaysia, and Indonesia. With an annual production of several hundred thousand tons, Thailand is the world's top producer among these nations (Mahisanunt et al., 2017 and Wall et al., 2011). On a lesser scale, rambutan is also grown in portions of Africa, the Philippines, Vietnam, Sri Lanka, southern China, Hawaii, and Central and South America. Over the last 200 years, its cultivation has progressively expanded to several tropical places worldwide.

Botanically, rambutan (Nephelium lappaceum L.) belongs to the Sapindaceae family and shares close taxonomic relationships with litchi (Litchi chinensis) and longan (Dimocarpus longan). It is an evergreen tree that usually grows to a height of 10 to 20 meters. The fruit has many delicate, hair-like spines on its outer rind and is typically round to oval in shape, with a diameter of 3 to 6 cm. The name rambutan, which comes from the Malay language rambut, meaning "hair," is a reflection of this feature (Tripathi & Karunakaran, 2013). The eatable part of the fruit is located below the skin and consists of a translucent flesh aril containing a single seed inside.

On average, the rambutan seed represents 5-10 percent of the total weight of the fruit, although the proportion depends on cultivar type and in some cultivars reaches up to 9 percent (Issara et al., 2014). In structure, the seed is enclosed in the testa, which is an outer shell of the seed protecting its kernel inside. Kernel is the most valuable component of the seed since it contains lots of fats, proteins, and carbohydrates and can be used for numerous industrial purposes. The kernel needs to be separated from the testa, dried to decrease its moisture content, and ground into powder prior to extraction of the fat.

Rambutan is usually processed into juices, preserving foods, and canned products. A considerable amount of seed waste is generated during consumption of fresh rambutan fruits. The amount of seed waste increases in accordance with the growth of production and processing of rambutan. Most of these seeds are discarded or used for low-value purposes such as animal feed, compost, and traditional medicine. Although the seeds contain a considerable amount of edible fat, only a small proportion is currently used for fat extraction. Better utilization of these seeds could help reduce waste and increase the value of rambutan processing. (Chai et at., 2019; Jahurul et al., 2020).

The growing amount of rambutan seed waste can create environmental problems if it is not managed properly. When the seeds are discarded without proper treatment, they add to the organic waste in the environment and lead to the loss of a potentially valuable resource. Rambutan seed fat has physicochemical and functional properties similar to cocoa butter. Therefore, using this underutilized by-product as an alternative fat source could reduce the demand for cocoa butter. This can also support the sustainable use of fruit-processing by-products by converting waste into value-added ingredients (Kumar et al., 2024).

The rambutan seed valorization pathway, from raw fruit through processing and extraction to the reintegration of by-products into the circular economy, is illustrated in Figure 1.

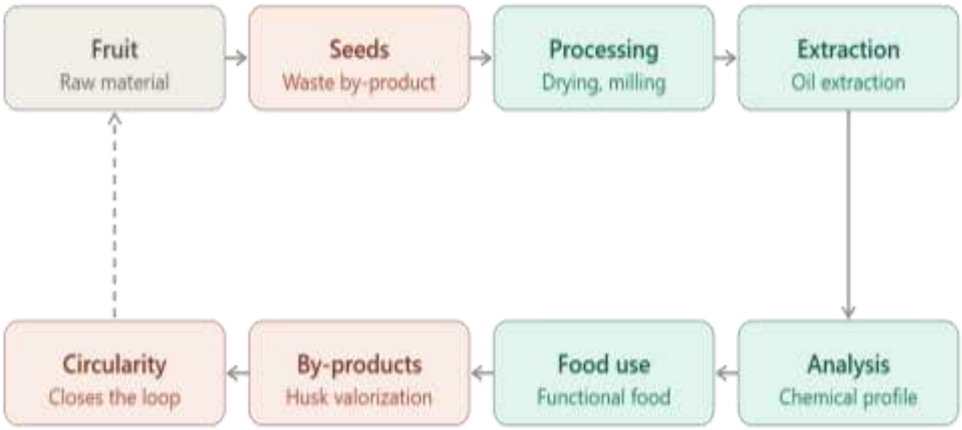

Figure 1: Rambutan seed valorization pathway, from raw fruit as the raw material through seed generation, processing, and fat extraction, to food-use applications and by-product reuse. The waste-stream loop (seeds, by-products, and recirculation) is shown in coral against the core processing chain shown in teal, illustrating how the pathway closes into a circular-economy system.

3. Chemistry of Rambutan Seed

The proximate composition of rambutan seeds varies among studies due to differences in cultivar, geographic origin, fruit maturity, and analytical methods. However, the overall composition remains similar. On a dry-weight basis, rambutan seeds generally contain 20–41% crude fat, 8–16% crude protein, 25–64% carbohydrates, 2–30% crude fibre, and 1–2.4% ash. (Sirisompong et al., 2011; Solis-Fuentes et al., 2010; Jahurul et al., 2020). These ranges reflect whole-seed (testa plus kernel) proximate analyses; where studies report the de-hulled kernel specifically, fat values cluster more narrowly around 30-40% dry-weight basis. The moisture content of fresh seeds is usually reported to be between 4% and 15%

The fat content of rambutan seeds is generally reported to be between 30% and 40% on a dry-weight basis. In some cultivars, higher fat contents have been reported depending on the extraction method used (Sirisompong et al., 2011; Solís-Fuentes et al., 2010). This makes rambutan seed one of the oil-rich by-products of fruit processing. The fatty acid composition of rambutan seed fat is unique. Oleic acid (C18:1) and arachidic acid (C20:0) together account for about 70–80% of the total fatty acids. Smaller amounts of palmitic acid (C16:0) and stearic acid (C18:0) are also present, while the content of polyunsaturated fatty acids is relatively low (Sonwai et al., 2014, Issara et al., 2014). The fatty acid composition of rambutan seed fat is different from that of most vegetable oils. Rambutan seed fat is rich in arachidic acid, a saturated fatty acid, and oleic acid, a monounsaturated fatty acid. This fatty acid composition keeps the fat solid at room temperature. Because of this, rambutan seed fat shows physical properties similar to cocoa butter, even though their triglyceride compositions are not the same. Compared with its fat content, the protein in rambutan seeds has been studied much less. The seeds contain about 8–16% crude protein, which suggests that the defatted seed meal remaining after oil extraction still has nutritional value (Chai et al., 2019; Jahurul et al., 2020). If anti-nutritional compounds are reduced or removed, this meal could be used as a protein-rich ingredient in food products or animal feed. However, very little information is available on the amino acid composition of rambutan seed protein, and more research is needed to better understand its nutritional quality.

Carbohydrates are the major component of rambutan seeds and are present mainly as starch. In many studies, the carbohydrate content is higher than both the protein and fat contents. After proper detoxification, the starch has been used in some regions for limited food applications. Rambutan seeds also contain small amounts of minerals, including potassium, calcium, magnesium, and phosphorus, similar to other tropical fruit seeds. However, detailed information on the mineral composition of rambutan seed fat, compared with the whole seed, is still limited (Chai et al., 2019).

Rambutan seeds contain several bioactive and anti-nutritional compounds, including tannins, saponins, alkaloids, and phenolic acids such as ellagic acid, corilagin, and geraniin (Jahurul et al., 2020). Raw seeds also contain small amounts of cyanogenic and other compounds that contribute to their bitter taste. Some of these compounds have beneficial properties, including antioxidant, antimicrobial, and antidiabetic activities. However, others act as anti-nutritional factors or may be mildly toxic in raw seeds. Therefore, appropriate processing methods such as roasting, fermentation, or heat treatment are necessary to reduce these compounds before the seeds or their fat can be safely used in food products (see Section 8).

4. Extraction Technologies

A range of extraction technologies has been applied to rambutan seed fat recovery. Long-established methods like mechanical and solvent-based methods through to green, energy-efficient techniques increasingly favored for oilseed and fruit by-product processing generally. Because no single method uniformly optimizes yield, oil quality, cost, and environmental footprint, the choice of technology in practice reflects a trade-off among these criteria, discussed below and summarized comparatively in Table 1.

4.1 Mechanical Pressing

Mechanical pressing, using either an expeller or a hydraulic press, is one of the simplest methods for extracting fat from oil-rich seeds. In this method, dried and ground seed kernels are compressed to break the cells and release the oil. Since no chemical solvents are used, the process is considered safe and environmentally friendly. The remaining press cake still contains most of the protein and fibre, making it useful for other applications such as animal feed or food ingredients. Mechanical pressing is easy to scale up and is widely used in the oil processing industry. However, it usually gives a lower oil yield than solvent extraction because some oil remains trapped in the press cake.

4.2 Soxhlet Extraction

Soxhlet extraction is a widely used laboratory method for extracting oil from seeds. It uses organic solvents such as hexane or petroleum ether to remove almost all the fat from the sample through continuous heating and reflux. Many studies on the composition of rambutan seed fat have used this method because it provides a high oil yield and reliable results (Solís-Fuentes et al., 2010; Sonwai et al., 2014). However, the process requires large amounts of flammable solvents and consumes considerable energy due to long extraction times and solvent recovery. For these reasons, Soxhlet extraction is more suitable for laboratory research than for large-scale industrial production.

4.3 Supercritical CO2 Extraction

Supercritical carbon dioxide (SC-CO_2) extraction is an advanced method used to extract oil without using organic solvents. In this process, carbon dioxide is kept at high pressure and moderate temperature so that it acts as an effective solvent for extracting lipids. This method has been used to extract rambutan seed fat and to study its fatty acid composition (Yoswathana, 2013, as cited in subsequent studies). SC-CO_2 extraction produces solvent-free oil and reduces the risk of heat damage to sensitive compounds because it operates at relatively low temperatures. The extraction conditions, such as pressure and temperature, can also be adjusted to improve the recovery of specific lipids or bioactive compounds (Nastic et al., 2025) However, the equipment required for this method is expensive, which limits its use in large-scale commercial production.

4.4 Ultrasound-Assisted Extraction

Ultrasound-assisted extraction (UAE) makes it easier for the solvent to extract the oil by employing sound waves to break thru the seed cell walls. Compared to conventional Soxhlet extraction, UAE uses less solvent, uses less energy, and requires less time. It also helps preserve the oil's purity and improves the recovery of beneficial compounds like phenolics. Although just a few studies have examined the UAE for rambutan seeds, successful results with other oilseeds show that it has great potential. UAE, either alone or in combination with methods like enzyme-assisted extraction or supercritical CO2, may be a helpful tactic for boosting the output of rambutan seed fat (Thilakarathna et al., 2023).

4.5 Microwave-Assisted Extraction

Microwave radiation is employed in order to rapidly heat the seed material from inside in the process of microwave-assisted extraction (MAE). As a result, cells of the plant are being broken, which increases the capability of the solvent to extract the oil. In microwave-assisted extraction (MAE) microwave radiation is applied to rapidly heat the seed material from inside. Cells of the plant are being broken because of this rapid heating, which increases the capability of the solvent to extract the oil. As a result, the process of the extraction is greatly accelerated, as compared to the conventional methods. MAE has been used as a pre-treatment method before supercritical CO2 extraction in some studies in order to increase the yield of fruit seed oils. Despite lack of research concerning MAE application for rambutan seed fat, it can be considered a promising approach.

4.6 Enzyme-Assisted Extraction

In the process of enzyme-assisted extraction (EAE) enzymes such as cellulase, hemicellulase and pectinase are used in order to break down seed cell walls before oil extraction. EAE is a more environmentally sustainable process since it employs water as the extraction medium instead of traditional techniques that rely on organic solvents. More oil can be released and the extraction yield can be increased by breaking down the cell wall. According to recent research, oil recovery from fruit seeds may be further increased by combining EAE with methods like supercritical CO2 extraction or ultrasound-assisted extraction (Rodriguez et al., 2025). The rough outer coating of rambutan seeds might make it challenging to extract the oil. This issue may be resolved and the quantity of oil extracted increased by treating the seeds with the appropriate enzymes prior to extraction.

The term green or environmentally friendly is often used for SC-CO2, UAE, MAE, and EAE because they reduce or avoid the use of organic solvents. However, this does not automatically

Table 1: Comparative overview of extraction technologies applicable to rambutan seed fat recovery

Method	Raw Material/ Pretreatment	Solvent/ Medium	Key Conditions	Yield	Fat Quality	Advantages	Limitations	Scale-up Evidence	Reference
Mechanical pressing	Dried, dehulled kernel; milled	None	Expeller/hydraulic press; ambient-moderate temperature	Lower than solvent methods; no rambutan-specific yield figure identified in the literature reviewed	Not extensively characterized separately from Soxhlet-extracted material	No solvent; simple; scalable; usable press cake by-product	Residual fat trapped in press cake; requires robust dehulling/ milling	High - compatible with existing oilseed infrastructure, based on general oilseed evidence	No rambutan-specific mechanical-pressing study identified; general oilseed-processing precedent only
Soxhlet extraction	Dried, milled kernel	Hexane or petroleum ether	Continuous reflux; duration not reported in Solis-Fuentes et al. (2010) or Sirisompong et al. (2011)	Near-exhaustive; 33.4% dry-weight fat reported by Solis-Fuentes et al. (2010); values as high as approximately 41% reported across cultivars by Sirisompong et al. (2011)	Saponification value approximately 186 mg KOH/g; iodine value approximately 47 g I2/100g	High recovery; well-characterized reference method	Organic solvent use; energy-intensive; solvent residue/safety concerns	Low for commercial scale; standard for laboratory analysis	Solis-Fuentes et al. (2010); Sirisompong et al. (2011)
Supercritical CO2	Dried, milled kernel	Supercritical CO2	34.8 MPa, 56.7°C, with 14.5 mL ethanol co-solvent (Yoswathana, 2013)	30.38% oil yield achieved under optimized conditions (Yoswathana, 2013)	Fatty acid profile reported to differ modestly from conventional extraction at these conditions	Solvent-residue-free; mild temperature; selective fractionation possible	High capital cost; specialized equipment/expertise required	Moderate; capital-intensive. No rambutan-specific pilot- or industrial-scale study identified.	Yoswathana (2013)

Ultrasound-assisted	Dried, milled kernel	Solvent or green solvent, with ultrasonic cavitation	No rambutan-specific operating conditions identified in the literature reviewed	No rambutan-specific yield study identified in the literature reviewed; this is noted here as a research gap (see Section 11)	No rambutan-specific fat-quality study identified	Shorter extraction time; lower solvent and energy use; can preserve antioxidants, based on comparable seed-oil matrices	Scale-up engineering still developing; effectiveness is matrix-dependent	Moderate; increasingly adopted at pilot and industrial scale for other seed oils	No rambutan-specific study identified. Thilakarathna et al. (2023) is cited for comparable seed-oil systems only.
Microwave-assisted	Dried, milled kernel	Solvent or aqueous medium, with microwave pretreatment	No rambutan-specific operating conditions identified in the literature reviewed	No rambutan-specific yield study identified in the literature reviewed; this is noted here as a research gap (see Section 11)	No rambutan-specific fat-quality study identified	Rapid heating; short processing time; energy savings, based on comparable seed-oil matrices	Risk of localized overheating or thermal degradation if not optimized	Moderate; typically used as a pretreatment step for other seed oils	No rambutan-specific study identified. General fruit-seed MAE literature is cited for comparison only.
Enzyme-assisted	Dried, milled kernel; cellulase/hemicellulase/pectinase pretreatment	Water (aqueous enzymatic extraction)	No rambutan-specific enzyme dose or incubation time identified in the literature reviewed	No rambutan-specific yield study identified in the literature reviewed; this is noted here as a research gap (see Section 11)	No rambutan-specific fat-quality study identified	Mild, aqueous conditions; no organic solvent; can be combined with UAE or SC-CO2, based on comparable seed-oil matrices	Enzyme cost; longer incubation time; optimization needed per matrix	Moderate; attractive for clean-label positioning	No rambutan-specific study identified. Rodriguez et al. (2025) is cited for comparable seed-oil systems only.

mean they are more sustainable overall. The SC CO2 process requires high energy input and special high-pressure equipment. UAE and MAE require specific machinery and energy assessments in case they are employed in industrial scale applications. The EAE process involves high recurring enzyme costs and is generally associated with the highest processing times. To make the comparison of the environmental and economic impact of the processes mentioned, one will have to acquire information on energy input and costs of rambutan seed processing, which currently is not available in the reviewed literature (see Section 10).

5. Physicochemical Properties

Fats that are used as modifiers or substitutes for cocoa butter are classified in three main groups. The cocoa butter equivalents (CBE) represent non lauric fats with the triglyceride composition, similar to cocoa butter, i.e., POP, POSt, StOSt, and that are capable of mixing with cocoa butter in any proportion without affecting its properties. The cocoa butter substitutes (CBS) are lauric fats that mimic cocoa butter melting profile, however, they are not completely compatible with it when mixed. The cocoa butter replacers (CBRs) are non-lauric fats that do not possess similar composition to cocoa butter and are partially compatible (Beckett, 2008). Unlike cocoa butter, which contains POP/POSt/StOSt, rambutan seed fat primarily consists of arachidoyl dioleoylglycerol (AOO), which is vastly different. Research shows that only 30% is compatible, after which the physical behavior changes (Issara et al., 2014). Thus, rambutan seed fat can only be defined as a partial cocoa butter replacer, but not an equivalent or a replacement. These terminologies will be used for the rest of this review.

The primary acids present in rambutan seed fat include oleic and arachidic with minor amounts of stearic and palmitic. Despite having different triglycerides based on this fatty acid composition, rambutan seed fat shares several functional characteristics with cocoa butter. Arachidoyl-dioleoylglycerol (AOO) is the predominant triglyceride in rambutan seed fat. In contrast, 1,3-dipalmitoyl-2-oleoylglycerol (POP), 1-palmitoyl-2-oleoyl-3-stearoylglycerol (POSt), and 1,3-distearoyl-2-oleoylglycerol (StOSt) are abundant in cocoa butter (Sirisompong et al., 2011; Ray et al., 2022). This difference in triglyceride composition leads to dissimilarities in behavior in melting and crystallization processes. However, since both fats are solid in room temperature conditions, rambutan seed fat can be a potential substitute for semi-solid fats.

When it comes to assessing the quality of rambutan seed fat, there are some chemical properties that can be investigated. Specifically, the saponification value of rambutan seed fat can be estimated in the range of 155-190 mg KOH/g. Meanwhile, the iodine value of the latter is rather high and ranges from 35 to 48 g I2/100 g, which indicates that there is some degree of unsaturation of the sample. Freshly extracted rambutan seed fat contains not more than 1 mg KOH/g of acid, and thus, it can be assumed that the sample under consideration is of a good quality. However, it should be noted that improper drying of the seeds and storing may lead to an increase in the acid value as a result of hydrolysis. Peroxide value of newly extracted rambutan seed fat is rather low, which indicates that the oxidation did not occur during the process of extraction. However, there may be some oxidation occurring during storing, which will raise the peroxide value. Therefore, it is necessary to monitor the latter on a regular basis to ensure fat stability (Solís-Fuentes et al., 2010; Sirisompong et al., 2011).

Table 2 below presents a comparison between the physicochemical and structural properties of cocoa butter and rambutan seed fat. It can be seen that rambutan seed fat is similar in fatty-acid composition and iodine value, but is different in triglycerides composition and melting properties. This suggests that this type of fat can serve as a cocoa butter substitute, especially when blended in controlled amounts.

Table 2: Direct comparison of cocoa butter and rambutan seed fat

Parameter	Cocoa Butter	Rambutan Seed Fat	Reference
Dominant triglycerides	POP, POSt, StOSt	AOO (arachidoyl-dioleoylglycerol)	Sirisompong et al. (2011); Ray et al. (2022)
Dominant fatty acids	Palmitic, stearic, oleic	Oleic, arachidic (minor palmitic, stearic)	Sonwai et al. (2014), Issara et al. (2014)
Saponification value	~188-198 mg KOH/g (Beckett, 2008)	~155-190 mg KOH/g	Solis-Fuentes et al. (2010); Sirisompong et al. (2011)
Iodine value	~33-42 g I2/100g (Beckett, 2008)	~35-48 g I2/100g	Solis-Fuentes et al. (2010)
Melting behaviour	Sharp melt, approximately 30-36°C (Beckett, 2008)	Broad range, ~ -14.5 to +51.8°C reported	Solis-Fuentes et al. (2010)
Stable crystal polymorph	β-V (β_2)	Not directly assigned in literature reviewed; multiple DSC transitions reported (see Section 5 revision)	Declerck et al. (2021); Solis-Fuentes et al. (2010)
Reported compatibility as partial replacer	Not applicable (reference fat)	Up to ~30% blend before divergence in hardness/melting/crystallization	Issara et al. (2014)

X-ray diffraction (XRD): By distinguishing distinct crystal structures, such as α, β′, and β, from their distinctive diffraction patterns, X-ray diffraction (XRD) is often employed to examine the polymorphic forms of fats. Because it provides chocolate its smooth texture, glossy look, firm snap, and easy release from molds, the creation of the stable β-V (β_2) crystal form in cocoa butter is very significant. Fat bloom, which manifests as a white crystalline coating on the top of chocolate, may occur if unstable crystal formations instead form and progressively change during storage (Declerck et al., 2021; Ray et al., 2022). There is currently little knowledge on the polymorphic behavior of rambutan seed fat. It may, however, develop many crystal structures during crystallization, according to the research that is now accessible. When considering rambutan seed fat for confectionary applications, whether as a replacement for cocoa butter or as a component of a cocoa butter blend, a complete grasp of its polymorphic variations is required. This information is vital for predicting the behavior of the mixture during crystallization and determining the suitability of this combination for certain uses.

Cocoa butter and rambutan seed fat have distinct differences in crystal structures. These variations arise mainly due to the differences in melting behavior and triglyceride composition. Thus, the proportion of the rambutan seed fat in the blend is a significant issue. According to some researchers, up to 30% substitution of rambutan seed fat for cocoa butter could maintain satisfactory physical properties. Further increase in this percentage would affect the fat's physical characteristics such as hardness, crystallization, and melting behavior, which distinguish it from cocoa butter (Issara et al., 2014).

There is no study where the crystallization behavior of rambutan seed fat has been discussed using the conventional α, β′, and β polymorphs of fat. The thermal data presented by Solis Fuentes et al. (2010) indicate that there are several types of crystallization and melting. It implies that there can be more than one polymorph or crystal population of rambutan seed fat. However, it should be noted that this conclusion has been made based on the DSC data but not the XRD data. Therefore, the XRD characterization of the rambutan seed fat compared to the conventional cocoa butter polymorph series is needed. This is identified as a specific research gap (see Section 11).

6. Functional Properties

The plasticity of fat describes its ability to be distributed and molded at various temperatures without undergoing structural change. This property is very important in baking and candy making because it affects not only the process but also the final texture of the product. Research has shown that rambutan seed fat possesses solid fat content (SFC) and hardness values similar to those of cocoa butter when consumed in moderation. But in both tempered and untempered forms, rambutan seed fat has a somewhat higher melting point, which may change its range of flexibility (Zzaman et al., 2017). Thus, in order to achieve a certain texture and quality of the product, there may be the need to make changes in the recipe or process when using more cocoa butter substitutes.

It is the presence of natural antioxidants and fatty acids present in the fat obtained from the rambutan seeds which will determine the oxidation resistance capability of the same. Compared to many vegetable fats and oils, this fat is oxidation-resistant owing to the higher levels of monounsaturated oleic acid and saturated arachidic acid. Examples of minor components responsible for preventing oxidation of the fat include tocopherols and phenolic antioxidants. However, oxidation of the fat could take place even as it is being stored because the fat contains some unsaturated fatty acids. It is therefore important to use proper extraction, packaging, and storage methods to prevent rancidity.

Khairy et al. (2018) employed flow models including Newton, Bingham, and Casson to compare the rheological properties of rambutan seed fat with cocoa butter. According to their research, under comparable circumstances, rambutan seed fat has a greater viscosity than cocoa butter. The research also found that rambutan seed fat forms a more extensive crystal network at around 25°C. This variation in crystal structure may have an impact on the end product's texture as well as how the fat behaves during processing.

The utilization of rambutan seed fat in chocolate and confectionery goods has received more research than its emulsifying and shortening qualities. Its triglyceride makeup and firm, plastic consistency at room temperature, however, imply that it may be used as a bread shortening. Shortening is a crucial ingredient in baked goods because it helps blend air into the batter or dough. Additionally, it prevents gluten from developing, giving goods a softer texture and better mouthfeel. Numerous tropical seed lipids have been discovered to have comparable functional characteristics. However, there is currently little study on using rambutan seed fat as a bakery shortening. To further comprehend its performance and ascertain if it is appropriate for certain baked goods, more research is required.

7. Food Applications

Applications of rambutan seed fat can be grouped into three levels of evidence. The first level is demonstrated. This indicates that there is experimental research available on the fat from rambutan seeds themselves. One such application is the use of rambutan seed fat as a partial substitute for cocoa butter in confectionery. The second tier is promising yet limited evidence. It is inferred from information about the chemical structure and physiological function of the fat from rambutan as well as information about other tropical seed fats. There is no experimental research conducted on formulations involving the fat from rambutan seed. Examples include bakery shortening and margarines/spreads. The third tier is conceptual or futuristic. It includes applications that are plausible by analogy to the functions performed by other structured fats and seed derived fats, but there is no experimental research involving rambutan seed fat. Examples include ice cream, milk alternatives, meat analogs, nano-emulsions, solid lipid nanoparticles, and encapsulation. This classification is used to avoid overstating the current evidence base.

Utilization of the fat from rambutan seeds as a substitute for cocoa butter in chocolates and confectioneries is one of the most extensively researched applications of the fat. According to Issara et al. (2014), cocoa butter mixed with a maximum of 30 percent rambutan seed fat had comparable hardness, melting pattern, and crystallization behavior with cocoa butter alone. These findings were established through physical and thermal analyses of laboratory blends of the two fats. When the percentage of substitution exceeded 30 percent, distinctions were observed in these parameters. Processed rambutan seeds have gained popularity owing to their high fat content and volatiles formed during fermentation and roasting process, providing a cocoa-like flavor. Such sensory development is in favor of utilizing rambutan seed fat and processed seed materials in chocolates and confectioneries (Khairy et al., 2018).

It is possible to apply the rambutan seed fat in several ways in the cooking process, but the use of this fat has been mainly researched as a replacement for the cocoa butter. The functional and physical properties of this fat make it an excellent candidate to be used in bakery products, such as cookies, cakes, and biscuits. Solid fats improve texture, support dough expansion, and maintain product quality throughout storage. Rambutan seed fat may be used in spread and margarine recipes as it is semi-solid at room temperature. A few studies have looked at its usage in ice cream and dairy or plant-based alternatives, where the crystallization behavior of the fat greatly affects the texture, mouthfeel, and melting qualities. However, there isn't as much knowledge about these goods as there is about its use in chocolate. Before its application may be extended to a greater variety of food items, further study is required to better understand its functional performance, sensory qualities, storage stability, and customer acceptability. (Kaushik et al., 2025)

Because of its smooth texture and emollient qualities, rambutan seed fat has been investigated for usage in cosmetic items in addition to culinary uses. Additionally, it has long been used in the manufacturing of candles and soaps. These uses predated the investigation of rambutan seed fat as an alternative to cocoa butter. Thus, rambutan seed waste may be used for both food and non-food purposes, which reduces agricultural waste.

8. Health and Nutritional Perspective

Rambutan seed fat contains mainly oleic acid, which is a monounsaturated fatty acid, and arachidic acid, which is a long-chain saturated fatty acid. These two are present in roughly similar amounts. This profile is dissimilar from fats rich in shorter chain saturated fatty acids. The clinical relevance and health significance of this particular profile have not been investigated in studies and experiments performed on rambutan seed fat. Present day investigations on the fat are limited to studies of the chemical profile and functional properties measured in laboratory experiments. There are no studies conducted on humans and their health after consumption of rambutan seed fat. All claims regarding the health significance of the fat can therefore be regarded only as inferences drawn from its composition (Jahurul et al., 2020). The following substances – ellagic acid, corilagin, geraniin, phenolic acids, and flavonoids – were found in the aqueous and ethanolic extracts of whole rambutan seeds. These compounds in the whole seed extract have antidiabetic, antibacterial, antifungal, and antioxidant properties in laboratory experiments (Jahurul et al., 2020; Afzaal et al., 2023; Thitilertdecha et al., 2008; Bhat & Al Daihan, 2014). In parts of Malaysia, rambutan seed powder, prepared by drying and grinding the whole seed or defatted meal, has been used traditionally to help manage blood glucose. These findings suggest that the whole seed is a source of bioactive compounds. Evidence for antioxidant or other bioactivity in the fat fraction alone is limited to co-extracted tocopherols and phenolics, and this has not yet been validated separately.

Small levels of naturally occurring antioxidants, such as tocopherols and phenolic compounds, are isolated from rambutan seed fat. These substances may provide some nutritional advantages in addition to enhancing the fat's oxidative stability. Nevertheless, the fat's antioxidant activity has only been assessed in a small number of trials. Instead of concentrating on the refined fat fraction, the majority of studies have examined entire rambutan seed extracts.

Similar research on other fermented seed fats suggests that lipolysis kinetics may be impacted by processing (fermentation, roasting) that decreases particle size and structural complexity; direct validation of this link in rambutan seed fat would be beneficial. However, neither in vivo nor in vitro digestive models tailored to this material have been used to fully assess the digestibility of rambutan seed fat.

Tests on rambutan seed fat extracted with supercritical CO_2 have only included an acute oral toxicity limit test in rodents. This test did not show harmful effects at the doses used. However, it is only a preliminary screen and not a full safety evaluation. This does not mean that the oil is safe for repeated use by humans. No sub-acute or chronic toxicity studies have been mentioned. No human safety information for rambutan seed fat has been obtained from any of the available literature.

Also, processing methods such as roasting and fermentation reduce the concentration of tannins, saponins and other anti-nutritional compounds. These results indicate that rambutan seed fat is considerably safer for food purposes when compared to the actual seed.

9. Sustainability

An excellent illustration of the circular economy idea is the valorization of rambutan seeds. The seeds may be turned into useful goods like edible fat rather of being discarded. By doing this, agricultural waste is decreased and resources are used more effectively. Additionally, it may lessen the need for cocoa butter, whose production is linked to issues connected to climate change and land-use change in areas that produce cocoa (Kumar et al., 2024)

Several Sustainable Development Goals (SDGs) of the United Nations are also supported by the usage of rambutan seed fat. By encouraging resource recovery and waste reduction, it directly promotes SDG 12 (Responsible Consumption and Production). Additionally, it could help achieve SDGs 2 (Zero Hunger) by offering substitute food ingredients, SDG 3 (Good Health and Well-Being) by using bioactive compounds, and SDG 13 (Climate Action) by encouraging the use of agricultural by-products and decreasing reliance on cocoa butter (Kumar et al., 2024).

The seeds from which the fat is obtained come from processing fruits, which implies that there is no need to cultivate them specifically for the purpose of obtaining fat. This could be an advantage regarding sustainability since it would imply saving additional amounts of land, water, and agrochemicals. However, this claim has not been proven yet. Every stage of production, including harvesting of seeds, their transportation, drying, de-hulling, milling, fat extraction, solvent or CO2 recovery, purification, packaging, and storing uses some amount of energy, water, and/or chemicals. Greenhouse gas emissions from all these stages of production have not been assessed for the rambutan seed fat. No life cycle assessment or techno-economic assessment has been conducted for the extraction of the fat from rambutan seeds. Until these studies become available, any claims of environmental superiority in relation to cocoa butter or other fats can be taken only as a hypothesis requiring testing. The lack of LCA and TEA studies in this regard is a distinct research gap (refer to Section 11).

Besides the extracted fat, other constituents of the seed can also be exploited. The defatted seed meal, being high in protein and dietary fibre content, can be used as a food additive or animal feed after reducing its anti-nutritional content. Rambutan seed by-products can also be employed in the manufacture of cosmetics, soap, and candles. Utilisation of both the fat and residual seed fraction will add to the economic value of rambutan seed processing.

10. Challenges

One of the main obstacles to the commercial production of rambutan seed fat is the expense of extraction. Because soxhlet extraction produces a high oil yield, it is often employed in labs. However, since it requires a lot of organic solvents, solvent recovery systems, and stringent safety precautions, it is not appropriate for large-scale manufacturing. Supercritical CO2, ultrasound-assisted, microwave-assisted, and enzyme-assisted extraction are examples of green extraction techniques that are more environmentally sustainable. Nevertheless, for effective extraction from the hard rambutan seed, these techniques need costly equipment and further tuning. Furthermore, the economic viability of different extraction techniques for rambutan seed fat has only been examined in a small number of investigations.

Another challenge is large-scale production. Most studies on rambutan seed fat have been carried out at laboratory or pilot scale. Very little information is available on industrial-scale processing. Efficient systems for collecting, transporting, and processing large quantities of rambutan seeds from different processing centres also need to be developed.

Another crucial element is consumer approval. Rambutan seed fat has a potential since a lot of people are interested in sustainable and repurposed food products. However, because the fat is a new product, some consumers might be apprehensive about using it. Therefore, consumer awareness and clear labeling are needed, particularly in the case where the fat of the rambutan seeds will be incorporated into chocolate or other confectioneries.

Getting regulatory approval is another difficulty in producing the fat. The regulatory approval of the rambutan seed fat depends on the particular nation. In most nations, the fat is a novel food additive, and hence there is a need for a safety assessment. Such a process entails toxicological assessment among others and it may prove to be costly and time consuming.

The other issue which needs more research is that of shelf life. Since the rambutan seed fat comprises unsaturated fatty acids, it will tend to oxidize during storage, just like any other fat that can be eaten. Few research works have been done in order to determine the shelf stability of the fat under different packaging conditions and temperatures although it is more stable than most vegetable oils. To establish appropriate storage conditions and ascertain the commercial shelf life of rambutan seed fat, further shelf-life research is required.

11. Future Research Directions

Future studies on the fat found in rambutan seeds may use the oleogel concept. Oleogels refer to the formation of structural oil with variable melting and textural properties. The use of rambutan seed fat in confectionaries, spreadable foods, dairy products, and other food items can increase through this method. Moreover, it can help reduce the level of saturated fats in some food products (Le et al., 2025; Wahid et al., 2026).

Structured lipid development is also a promising approach. This can be achieved by enzyme and chemical modification of rambutan seed fat with some other fats. This way, the properties of its triglycerides, melting and crystallization properties can be modified to resemble cocoa butter. Rambutan seed fat can be treated in a similar manner as other cocoa butter alternative.

A possible area of investigation is nanotechnology. The nanoemulsions may possibly comprise rambutan seed fat and bioactive compounds. The stability and bioavailability of beneficial compounds such as phenolic antioxidants can be improved via these systems. However, little investigation has been made in using this technology in relation to rambutan seed fat. Encapsulation is yet another possible technology. Protective material may possibly be utilized to encapsulate rambutan seed fat and bioactive compounds. This would help reduce any bitterness and enhance oxidative stability as well as control the release of bioactive compounds. Oleogel and emulsion-based encapsulation technologies may possibly be useful for this purpose.

The rambutan seed fat can be used for plant-based foods. Plant-based foods are gaining popularity leading to an increased need for non-animal fats. Rambutan seed fat may be used in goods like plant-based spreads, meat substitutes, and dairy substitutes since it is both solid and plastic at room temperature. To assess its effectiveness in various applications, further research is required.

The production of food products is increasingly using machine learning (ML) and artificial intelligence (AI). The effects of various ingredients on texture, stability, and sensory quality may be predicted with the use of these technologies. Additionally, they may help choose the best combinations of ingredients and optimize production conditions. Applying AI and ML to rambutan seed fat products might speed up the process of finding the optimal formulations and cut down on the time and expense needed for product development (Gbashi & Njobeh, 2024; Zatsu et al., 2024; Datta et al., 2026)

12. Conclusions

Rambutan seed fat is a potential replacement for cocoa butter since it is derived from a copious agricultural by-product that is often discarded as waste. Because of its fatty acid composition, which is mostly made up of oleic and arachidic acids, it has a solid, plastic consistency at room temperature that is similar to cocoa butter. Rambutan seed fat may replace up to 30% of cocoa butter without substantially changing the final product's physical properties, according to many studies. On the other hand, higher substitution levels could affect melting behavior, hardness, and crystallization.

The extraction procedure has an impact on the quality, price, and sustainability of rambutan seed fat production. Despite producing a lot of oil, traditional solvent extraction is not as suitable for large-scale production because of safety and environmental concerns. Green extraction methods that are better for the environment include supercritical CO2, enzyme-assisted extraction, ultrasound-assisted extraction, and microwave-assisted extraction. However, these methods must be further refined and economically evaluated before they are generally used. Due to its complicated crystal structure and thermal behavior, rambutan seed fat may be partly replaced for cocoa butter, according to research utilizing techniques including DSC, XRD, and FTIR.

The circular economy's tenets are further supported by the utilization of rambutan seed fat, which transforms an agricultural waste product into a useful food component. Besides being able to reduce waste, such an approach might decrease the need for cocoa butter. Yet there are many questions that remain to be answered concerning the cost of extraction, industrial production, approval, shelf life, and consumer acceptance.

The enhancement of the economic value of rambutan seed fat should be the focus of future work. Many promising directions may include oleogels, structured lipids, nanotechnology, use in plant foods, and development using artificial intelligence (AI). Further investigations in these areas will definitely help in the development of rambutan seed fat as a valuable and sustainable food ingredient and help extend its application beyond confections.

References

Afzaal, M., Saeed, F., Bibi, M., Ejaz, A., Shah, Y. A., Faisal, Z., Ateeq, H., Akram, N., Asghar, A., & Shah, M. A. (2023). Nutritional, pharmaceutical, and functional aspects of rambutan in industrial perspective: An updated review. *Food Science & Nutrition*, *11*, 3675-3685. https://doi.org/10.1002/fsn3.3379

Beckett, S. T. (2008). *Industrial chocolate manufacture and use* (4th ed.). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781444301588

Bhat, R. S., & Al-Daihan, S. (2014). Antimicrobial activity of Litchi chinensis and Nephelium lappaceum aqueous seed extracts against some pathogenic bacterial strains. *Journal of King Saud University - Science*, *26*, 79-82. https://doi.org/10.1016/j.jksus.2013.05.007

Chai, K. F., Adzahan, N. M., Karim, R., Rukayadi, Y., & Ghazali, H. M. (2019). Fat properties and antinutrient content of rambutan (Nephelium lappaceum L.) seed during solid-state fermentation of rambutan fruit. *Food Chemistry, 274,* 808–815. https://doi.org/10.1016/j.foodchem.2018.09.065

Datta, B., Buehler, M. J., Chow, Y., Gligorić, K., Jurafsky, D., Kaplan, D. L., Ledesma-Amaro, R., Del Missier, G., Neidhardt, L., Pichara, K., Sanchez-Lengeling, B., Schlangen, M., St. Pierre, S. R., Tagkopoulos, I., Thomas, A., Watson, N. J., & Kuhl, E. (2026). Artificial intelligence for food innovation. *Nature Food, 7,* 644–654. https://doi.org/10.1038/s43016-026-01380-7

Declerck, A., Nelis, V., Danthine, S., Dewettinck, K., & Van der Meeren, P. (2021). Characterisation of fat crystal polymorphism in cocoa butter by time-domain NMR and DSC deconvolution. *Foods*, *10*, 520. https://doi.org/10.3390/foods10030520

Gbashi, S., & Njobeh, P. B. (2024). Enhancing food integrity through artificial intelligence and machine learning: A comprehensive review. *Applied Sciences*, *14*, 3421. https://doi.org/10.3390/app14083421

Hernandez-Hernandez, C., Aguilar, C. N., Rodriguez-Herrera, R., Flores-Gallegos, A. C., Morlett-Chavez, J., Govea-Salas, M., & Ascacio-Valdes, J. A. (2019). Rambutan (Nephelium lappaceum L.): Nutritional and functional properties. *Trends in Food Science & Technology*, *85*, 201-210. https://doi.org/10.1016/j.tifs.2019.01.018

Issara, U., Zzaman, W., & Yang, T. A. (2014). Rambutan seed fat as a potential source of cocoa butter substitute in confectionary product. *International Food Research Journal*, *21*, 25-31.

Jahurul, M. H. A., Azzatul, F. S., Sharifudin, M. S., Norliza, M. J., Hasmadi, M., Lee, J. S., Patricia, M., Jinap, S., George, M. R., Khan, M. F., & Zaidul, I. S. M. (2020). Functional and nutritional properties of rambutan (Nephelium lappaceum L.) seed and its industrial application: A review. *Trends in Food Science & Technology*, *99*, 367-374. https://doi.org/10.1016/j.tifs.2020.03.016

Kaushik, R., Morya, S., Bashir, O., Bhadha, J. H., & Kasankala, L. M. (2025). Valorization of fruit waste through reutilization approach: A comprehensive review. *eFood*, *6*, e70073. https://doi.org/10.1002/efd2.70073

Khairy, H. L., Saadoon, A. F., Zzaman, W., Yang, T. A., & Mat Easa, A. (2018). Identification of flavor compounds in rambutan seed fat and its mixture with cocoa butter determined by SPME-GCMS. *Journal of King Saud University - Science*, *30*, 316–323. https://doi.org/10.1016/j.jksus.2017.03.001

Kumar, H., Kimta, N., Guleria, S., Cimler, R., Sethi, N., Dhanjal, D. S., Singh, R., Duggal, S., Verma, R., Prerna, Pathera, A. K., Alomar, S. Y., & Kuca, K. (2024). Valorization of non-edible fruit seeds into valuable products: A sustainable approach towards circular bioeconomy. *Science of the Total Environment*, *922*, 171142. https://doi.org/10.1016/j.scitotenv.2024.171142

Kumar, M., Sharma, K., & Bangar, S. P. (Eds.). (2024). *Valorization of fruit seed waste from food processing industry: Insights on nutritional profile, biological functions, and applications*. Elsevier.

Le, Q., Fang, Z., Chen, H., & Wu, J. (2025). Comprehensive review on oleogels structured by lipid-based compounds: From structure mechanisms to nutritional functionalities and applications in food industry. *Comprehensive Reviews in Food Science and Food Safety*, *24*, e70214. https://doi.org/10.1111/1541-4337.70214

Mahisanunt, B., Jom, K. N., Matsukawa, S., & Klinkesorn, U. (2017). Solvent fractionation of rambutan (Nephelium lappaceum L.) kernel fat for production of non-hydrogenated solid fat: Influence of time and solvent type. *Journal of King Saud University-Science*, *29*, 32-46. https://doi.org/10.1016/j.jksus.2016.08.004

Nastić, N., Mazumder, J. A., & Banat, F. (2025). Supercritical CO_2 extraction of oil from fruit seed by-product: Advances, challenges, and pathways to commercial viability. *Critical Reviews in Food Science and Nutrition*, *66*, 589–606. https://doi.org/10.1080/10408398.2025.2527946

Ray, J., Smith, K. W., Bhaggan, K., & Stapley, A. G. F. (2022). Crystallization and polymorphism of cocoa butter equivalents from blends of palm mid fraction and hard stearins produced by enzymatic acidolysis of high oleic sunflower oil. *European Journal of Lipid Science and Technology*, *124*, 2100228. https://doi.org/10.1002/ejlt.202100228

Rodríguez-Blázquez, S., Gómez-Mejía, E., Rosales-Conrado, N., & León-González, M. E. (2025). Recent insights into eco-friendly extraction techniques for obtaining bioactive compounds from fruit seed oils. *Foods*, *14*, 2271. https://doi.org/10.3390/foods14132271

Sirisompong, W., Jirapakkul, W., & Klinkesorn, U. (2011). Response surface optimization and characteristics of rambutan (Nephelium lappaceum L.) kernel fat by hexane extraction. *LWT - Food Science and Technology*, *44*, 1946-1951. https://doi.org/10.1016/j.lwt.2011.04.011

Solis-Fuentes, J. A., Camey-Ortiz, G., Hernandez-Medel, M. R., Perez-Mendoza, F., & Duran-de-Bazua, C. (2010). Composition, phase behavior and thermal stability of natural edible fat from rambutan (Nephelium lappaceum L.) seed. *Bioresource Technology*, *101*, 799-803. https://doi.org/10.1016/j.biortech.2009.08.031

Sonwai, S., Kaphueakngam, P., & Flood, A. (2014). Blending of mango kernel fat and palm oil mid-fraction to obtain cocoa butter equivalent. *Journal of Food Science and Technology*, *51*, 2357-2369. https://doi.org/10.1007/s13197-012-0808-7

Thilakarathna, R. C. N., Siow, L. F., Tang, T. K., & Lee, Y. Y. (2023). A review on application of ultrasound and ultrasound assisted technology for seed oil extraction. *Journal of Food Science and Technology*, *60*, 1222–1236. https://doi.org/10.1007/s13197-022-05359-7

Thitilertdecha, N., Teerawutgulrag, A., & Rakariyatham, N. (2008). Antioxidant and antibacterial activities of Nephelium lappaceum L. extracts. *LWT - Food Science and Technology*, *41*, 2029-2035. https://doi.org/10.1016/j.lwt.2008.01.017

Tripathi, P., & Karunakaran, G. (2013). Rambutan cultivation. In W. S. Dhillon (Ed.), *Fruit production in India*. Narendra Publishing House, Delhi.

Wall, M. M., Sivakumar, D., & Korsten, L. (2011). Rambutan (Nephelium lappaceum L.). In E. M. Yahia (Ed.), *Postharvest biology and technology of tropical and subtropical fruits: Mangosteen to white sapote*, 312–335. Woodhead Publishing. https://doi.org/10.1533/9780857092618.312

Wahid, P. A., Chopra, R., Kumar, N., Chand, M., Dhiman, A., & Singh, R. (2026). Fibers as oleogelators: Innovations, applications, and future prospects in structured lipid systems. *Journal of the American Oil Chemists' Society*, *103*, 197–224. https://doi.org/10.1002/aocs.70040

Yoswathana, N. (2013). Optimization of $ScCO_2$ extraction of rambutan seed oil using response surface methodology. *International Journal of Chemical Engineering and Applications*, *4*, 187–190. https://doi.org/10.7763/IJCEA.2013.V4.291

Zatsu, V., Shine, A. E., Tharakan, J. M., Peter, D., Ranganathan, T. V., Alotaibi, S. S., Mugabi, R., Bin Muhsinah, A., Waseem, M., & Nayik, G. A. (2024). Revolutionizing the food industry: The transformative power of artificial intelligence—a review. *Food Chemistry: X*, *24*, 101867. https://doi.org/10.1016/j.fochx.2024.101867

Zzaman, W., Issara, U., Easa, A. M., & Yang, T. A. (2017). Exploration on the thermal behavior, solid fat content and hardness of rambutan fat extracted from rambutan seeds as cocoa butter replacer. *International Food Research Journal*, *24*, 2408–2413.