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Functional and nutritional properties of rambutan (*Nephelium lappaceum* L.) seed and its industrial application: A review

M.H.A. Jahurul^{a,*}, F.S. Azzatul^a, M.S. Sharifudin^a, M.J. Norliza^a, M. Hasmadi^a, J.S. Lee^a,
M. Patricia^a, S. Jinap^{b,c}, M.R. Ramlah George^a, M. Firoz Khan^d, I.S.M. Zaidul^f

^a Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, 88400, Kota Kinabalu, Sabah, Malaysia

^b Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400, UPM, Serdang, Selangor, Malaysia

^c Food Safety and Food Integrity (FOSFI), Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, 43400, UPM, Serdang, Selangor, Malaysia

^d Department Chemistry, Faculty of Science, University of Malaya, 50603, Kuala Lumpur, Malaysia

^f Faculty of Pharmacy, International Islamic University Malaysia, Kuantan Campus, 25200, Pahang, Malaysia

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ABSTRACT

Background: Rambutan (*Nephelium lappaceum* L.) is an important commercial fruit in southeast Asia and is gaining more attention in recent years because it is juicy and sweet and has a refreshing flavour and an exotic appearance. It is commercialized for fresh consumption and is industrially processed as canned fruit, juices, jams, jellies, marmalades, and spreads. The seed is a major co-product of this industry and is worthy of attention for industrial applications and their feasibility.

Scope and approach: This review describes the composition of the rambutan seed, which is examined from a critical interpretation regarding the suitable use of this co-product. This review also compares the total yield, physicochemical and thermal properties of its fat for the purpose of evaluating the potential of this fruit co-product as a source of natural edible fat with potential industrial uses.

Key findings and conclusions: Rambutan seed is a major co-product of the industry that has high premium-grade fat, protein, carbohydrate, fibre, antioxidants, and phenolic content and that can be used in several segments of the food, pharmaceutical, and cosmetic industries. Rambutan seed powders are also used as local medicine (they contain antidiabetic compounds) in Malaysia. To determine the effectiveness of raw rambutan seeds in treating diseases, in vivo and human clinical studies should be performed. Research should also continue to determine if rambutan seed fat can be fractionated, chemical and enzymatic interesterified, and blended with other fats to make cocoa butter alternatives. Comprehensive studies are needed on rambutan seed to explore more potential industrial applications.

1. Introduction

Rambutan (*Nephelium lappaceum* L.) is one of the most important tropical commercial fruits widely cultivated in southeast Asia, Australia, South America, and African countries. It is closely related to the subtropical fruits lychee (*Litchi chinensis* Sonn.), longan (*Euphoria longan* Steud.), and pulasan (*Nephelium mutabile* Blume) in the same family Sapindaceae. Thailand, Malaysia, and Indonesia are the leading producers and exporters of the rambutan fruit (Ahmad & Chua, 2013; Tindall, 1994, 1994). Recently, Mahisanunt, Jom, Matsukawa, and Klinkesorn (2017) reported that Thailand produced 318,000 tons of rambutan from 2014 to 2015. It is rich in sugars (glucose and sucrose), proteins, vitamins, minerals, and antioxidants, and is valued for its

refreshing flavour, pleasant aroma, and exotic appearance (Li, Zeng, & Shao, 2018; Ong, Acree, & Lavin, 1998; Zhuang, Ma, Guo, & Sun, 2017). Generally, rambutan is freshly consumed. Rambutan juice, jam, jelly, chips, marmalades, spreads, and canned in syrup are its main industrial products in Malaysia and Thailand (Chai, Adzahan, Karim, Rukayadi, & Ghazali, 2019a; Morton, 1987). After direct consumption or industrial processing, the residues are mainly seeds and peels that are discarded as co-products (Solís-Fuentes, Camey-Ortiz, Hernández-Medel, Pérez-Mendoza, & Durán-de-Bazúa, 2010). Recently, Mahisanunt et al. (2017) reported that a yearly average 1900 tons of rambutan seeds are discarded as a co-product in Thailand. The huge quantity of this industrial co-product causes serious environmental problems and results in economic losses if not utilized effectively (Chai, Adzahan, Karim,

* Corresponding author.

E-mail addresses: jahurul@ums.edu.my, jahurulhaque@yahoo.com (M.H.A. Jahurul).

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Rukayadi, & Ghazali, 2018).

The rambutan seeds are bitter in taste but are consumed after roasting in some Asian countries (Mehdizadeh, Lasekan, Muhammad, & Baharin, 2015; Morton, 1987; Solís-Fuentes et al., 2010). They are a promising source of nutrients for the human diet and for food product applications since they contain considerable amounts of crude fat (33.4–39.13%), protein (7.8–12.4%), carbohydrate (46–48.10%), fibre (11.6%), and ash (1.22%) (Chai et al., 2018; Harahap, Ramli, Vafaei, & Said, 2012; Sirisompong, Jirapakkul, & Klinkesorn, 2011; Solís-Fuentes et al., 2010). Rambutan seed is not only a good source of fat, but it also has an attractive fatty acid profile, in particular, oleic, arachidic, and stearic acids (Adzahan, Karim, Rukayadi, & Ghazali, 2018). Rambutan seeds have also attracted special scientific interest because of their bioactive compounds (antioxidants, phenolic compounds, and dietary fibre) (Thitilertdecha, Teerawutgulrag, & Rakariyatham, 2008). They have been reported to have antimicrobial activity against gram-positive and gram-negative bacteria, which is attributed to its antioxidant capacity (Bhat & Al-daihan, 2014; Soeng, Evacuasiyany, Widowati, & Fauziah, 2015; Thitilertdecha et al., 2008). Evaristus, Abdullah, and Gan (2018) reported that rambutan seed also contains antidiabetic compounds. Moreover, the authors reported that the rambutan seed powders are used to control blood sugar levels by the local people in Malaysia. Meanwhile, the dried rambutan rind has been used in local medicine in Malaysia (Palanisamy et al., 2008).

Although the rambutan seeds are a potential functional ingredient in food processing (Harahap et al., 2012; Vuong, Tran, Tran, Ton, & Le, 2016), the majority of this co-product is considered industrial waste and then becomes a source of pollution (Chai et al., 2018; Evaristus et al., 2018). In developed countries, food industries produced approximately 39% of food wastes and these wastes are being used as raw materials for making various food products (Mirabella, Castellani, & Sala, 2014). These co-products are not only a growing problem but are also economically limiting factors for their disposal (costs to dry, store and ship) (Schieber, Stintzing, & Carle, 2001; Jahurul et al., 2015). Shalini and Gupta (2010) reported that annually \$10 million is spent on the disposal of apple pomace in the USA. The proper use of rambutan seed might produce financial gains for industry, contributing a potential protein ingredient to reduce nutritional deficiencies, promoting health (as α -amylase inhibitory peptides), reducing disposal costs, and reducing the environmental problems. This review examines the nutritional and functional potential of rambutan seeds and the mainstream sectors for their possible applications in the food, pharmaceutical, and cosmetic industries through scientifically proven information.

2. Rambutan seed and its valuation

Rambutan has an oval single seed enclosed with a white basal scar, which represents 4–9% of the whole fruit depending on the variety. The seed is brown in colour with a length of approximately 1–1.3 cm (Akhtar, Ismail, & Shaari, 2018; Li et al., 2018; Mahisanun et al., 2017; Wong, Wong, Loi, & Lim, 1996). Rambutan seed is somewhat bitter and has narcotic properties (Harahap et al., 2012). It is rich in fat, carbohydrate, and protein. In Malaysia and Thailand, this seed is treated as a co-product of rambutan fruit industrially processed into can, juice, jam, jelly, marmalades, and spreads (Chai et al., 2019, 2019; Lourith, Kanlayavattanukul, Mongkonpaibool, Butsaratrakool, & Chinmuang, 2016; Morton, 1987). There is growing concern about the huge number of such kinds of industrial co-products that are highly nutritional and contain bioactive compounds (Torres-León et al., 2016). Various phenolic compounds, such as corilagin, geraniin, and ellagic acid are found in rambutan seed, which could be beneficial health constituents (Akhtar et al., 2018). Rambutan seeds are also a valuable source of minerals such as calcium, zinc, iron, magnesium, and manganese (Olaniyi & Mehdizadeh, 2013). From a nutritional and functional point of view, rambutan seed can be used for food product applications or as part of the human diet.

3. Antioxidant activity of rambutan seed

The degradation of food products during storage and processing is mostly caused by lipid oxidation that results from free radicals. These free radicals have been found to be one of the causes of liver damage and carcinogenesis and have ignited the interests of researchers to prevent them with natural antioxidants from plant materials (Barlow, 1990; Thitilertdecha et al., 2008). As one of the secondary metabolites in plants, phenolic compounds or polyphenols act as plant defence mechanisms to fight against many types of stresses resulting from pathogens, catastrophic states of the environment and wounding (Bennett & Wallsgrove, 1994; Dixon & Paiva, 1995). Recently, the interest in phenolic compounds from fruit has risen because of their function as free radical scavengers (Thitilertdecha & Rakariyatham, 2011). These phenolic compounds may be the main factors causing the strong antioxidant properties possessed by higher plant extracts as they have good potential to scavenge radicals due to their ability to donate a hydrogen atom from their phenolic hydroxyl groups (Larson, 1998; Sawa, Nakao, Akaike, Ono, & Maeda, 1999; Thitilertdecha et al., 2008; Yu et al., 2005).

It has been reported that the existence of phytochemicals such as flavonoids, phenolics and carotenoids can because of the antioxidant activities exhibited by rambutan (Javanmardi, Stushnoff, Locke, & Vivanco, 2003; Mehdizadeh et al., 2015; Rohman, 2017; Rohman, Riyanto, & Utari, 2006; Thitilertdecha et al., 2008). The effects of various polarity ranges of solvents used in seed bioactive extraction have been evaluated by many studies. These studies have used solvents such as water, methanol, butanol, ethanol, ethyl acetate, and ether to establish the antioxidants found in rambutan seeds (Chunglok, Utaipan, Somchit, Lertcanawanichakul, & Sudjaroen, 2014; Fidrianny, Fikayuniar, & Insanu, 2015; Mahmood, Kamilah, Alias, & Ariffin, 2018; Soeng et al., 2015; Thitilertdecha et al., 2008). Meanwhile, Thitilertdecha et al. (2008) reported the antioxidant potential of ether, methanol, and water extracts of rambutan seed by performing reductions in power, linoleic peroxidation, free radical scavenging, and β -carotene bleaching assays. In addition, the authors also found that the highest phenolic content (58.6 mg/g) was from the methanolic fraction of rambutan seed extracts, regardless of the total amount of phenolic contents in the rambutan seed. Their results were in line with Soeng et al. (2015) who had determined the antioxidant properties exhibited by ethanolic extracts of rambutan seed by adapting a superoxide-dismutase (SOD) assay. The authors also found that the most active fraction was ethyl acetate followed by, water after the fractionation of ethanolic extracts into water, butanol, ethyl acetate, and *n*-hexane. The antioxidant activities of various rambutan seed varieties have been determined by ABTS and DPPH assays. A very strong antioxidant potential was exhibited by all four types of ethanolic and ethyl acetate solvent extracts (Fidrianny et al., 2015; Mahmood et al., 2018).

Polyphenols have significant roles in food quality as they affect its bitterness, colour, and taste or smell (Alonso-Salces et al., 2004). Maisuthisakul, Pasuk, and Ritthiruangdej (2008) found a significant amount of flavonoids (13.3 mg/g RE) in rambutan seed when ethanol was used as an extraction solvent. Mehdizadeh et al. (2015) quantified the phenolic constituents in rambutan seed using HPLC and found 98, 423, 94.5, and 461 mg of gallic, geraniin, corilagin, and ellagic acids were acquired from 1 g of water extract. The authors also studied the variability of the polyphenols and amino acids during the fermentation of rambutan seed and found that fermentation significantly reduced the concentration of polyphenols by more than 59%, and by 60% for tannin and 33% for saponin contents of rambutan seed extracts. The same pattern was observed in fermented cocoa beans by Nazaruddin, Seng, Hassan, and Said (2006). The variation of total phenolics in rambutan seed has been reported to be 3.05–124.14 mg GAE g⁻¹ depending on the extraction solvents (Chunglok et al., 2014; Fidrianny et al., 2015; Maisuthisakul et al., 2008). Further studies on bioavailability and health effects of rambutan seeds should be continued and also identified

the phytochemicals in different varieties.

4. Antibacterial, anti-nociceptive, CNS, and antifungal activities of rambutan seed

Rambutan seed extracts are reported to possess antibacterial, anti-nociceptive, CNS, and antifungal activities (Bhat & Al-daihan, 2014; Ragasa, de Luna, Cruz, & Rideout, 2005; Rajasekaran et al., 2013; Thitilertdecha et al., 2008). Monoterpene lactones, 1 and 2, as well as kaempferol 3-O- β -D-glucopyranoside-7-O- α -L-rhamnopyranoside were isolated from the rambutan seed (dichloromethane extracts) and their structures were elucidated by Ragasa et al. (2005). The authors have also tested the antimicrobial potential of 1 and 2 against a panel of bacteria and fungi. The results of their study showed that they were active against *Candida albicans* with an activity index of 0.3 at 30 μ g, while the standard antibiotic canesten at 0.2 g (1% clotrimazole) gave an activity index of 0.8. The authors also reported that 1 and 2 were inactive against bacteria (*E. coli*, *P. aeruginosa*, *S. aureus*, *B. subtilis*) and fungi (*C. albicans*, *T. mentagrophytes*, *A. niger*) compared to the standard antibiotics. Anti-nociceptive, CNS, antibacterial and antifungal activities of raw, boiled, and roasted rambutan seed extracts (methanol) were determined by Rajasekaran et al. (2013). Their results showed that raw and boiled seed extracts exhibited antibacterial, anti-nociceptive, and CNS depressant activities. The possible explanation for these activities exhibited by the seed extracts could be because of the presence of phenolics, tannins, and saponin contents in the seed extracts. The authors suggested that rambutan seed can be a potential source of natural antibacterial agents. Recently, the antibacterial activity of aqueous rambutan seed extract against human pathogens (*S. aureus*, *S. pyogenes*, *B. subtilis*, *E. coli*, and *P. aeruginosa*) has been investigated by Bhat and Al-daihan (2014). They reported that aqueous rambutan seed extract shows moderate inhibition against pathogenic gram-positive (*S. aureus*, *S. pyogenes*, and *B. subtilis*) and gram-negative (*E. coli* and *P. aeruginosa*) bacteria. Research should continue to identify the phenolic compounds, tannins, and saponins responsible for the antinociceptive activity, CNS depressant, and antimicrobial activities from different rambutan varieties.

5. Antinutrient contents in rambutan seed

Rambutan seeds are slightly bitter in taste and are therefore usually discarded as agricultural or industrial waste. It has been reported that the bitterness of rambutan seeds is due to the presence of alkaloids, tannins, saponins, hydrocyanine, oxalate, phytates, and phenolic contents (ellagic acid, corilagin and geraniin) at various tolerable levels (Akhtar et al., 2018; Kheiri, Nordin, & Som, 1987; Morton, 1987). This result is not surprising as the Sapindaceae is a well-known saponin-rich family. Moreover, most of the antinutrients are found at lower levels than the FAO/WHO suggested limits in rambutan seed (Fila et al., 2012). Recently, the saponin and tannin contents in various rambutan seed varieties have been determined by Chai et al. (2018). They reported that saponin and tannin range from 14.27 to 18.96 mg soya saponin/100 g and 4.40–26.68 mg catechin/100 g. Mehdizadeh et al. (2015) found that rambutan seed contains 40 mg/100 g of soya saponin and 1380 mg/100 g of tannin, while Bullangpoti, Visetson, Milne, and Pornbanlualap (2004) reported ~5000 mg/100 g saponin. In another study, Fila et al. (2012) reported that rambutan seed contains 0.98 mg/100 g of saponin and 0.15 mg/100 g of tannin. Variations of saponin and tannin contents in rambutan seed can be because of the studied fruit being grown in different regions and climatic conditions as well as the maturity of the fruit seed. Another possible reason for variations could be due to the analytical method used for quantification of the saponin and tannin contents (Chai et al., 2018).

To develop food products from rambutan seed, there is a need to find a way to reduce the bitterness of this seed. Fermentation could be a good method to reduce undesirable and toxic elements in foodstuffs

(Akhtar et al., 2018; Chai et al., 2019a; Mehdizadeh et al., 2015). The amino acids responsible for the bitter taste of the rambutan seed could be significantly reduced by fermentation (Olaniyi & Mehdizadeh, 2013; Mehdizadeh et al., 2015). Mehdizadeh et al. (2015) reported that the amino acid contents such as leucine, tyrosine, and phenylalanine reduced by 40, 30, and 20% after 10 days of rambutan seed fermentation. They also reported that saponins (33%), polyphenols (59%), and tannin (60%) were reduced significantly by fermentation. In another study, Chai et al. (2019a) found that the saponin and tannin contents of rambutan seed decreased significantly by 67 and 47% after 10 days of fermentation. This significant reduction of antinutrient contents in rambutan seed could be due to the hydrolysis of polyphenolic compounds or tannin complexes during fermentation. Hence, rambutan seed should be industrially processed to reduce antinutrient contents that are responsible for its bitter taste.

6. Protein content in rambutan seed

Depending on the varieties, rambutan seed contains 7.8–14.10% protein on a dry weight basis (Augustin & Chua, 1988; Bhat & Al-daihan, 2014; Harahap et al., 2012; Sirisompong et al., 2011; Solís-Fuentes et al., 2010). However, there is a lack of evidence on its amino acid profiles compared with reports on its chemical and physical properties (in particular, fatty acids and triglycerides). The composition of the essential amino acids lysine (5.07–7.13), leucine (5.48–5.78), valine (4.21–5.11), isoleucine (3.29–3.34), phenylalanine (2.49–3.32), histidine (1.29–1.68), and methionine (1.35–1.63) (g amino acid per 100 g protein) shows that the protein is of good quality (Augustin & Chua, 1988). The non-essential amino acids, such as glutamic acid (10.85–14.95%), glycine (8.51–9.92%), and aspartic acid (7.24–9.80%) are the dominant amino acids, followed by alanine (4.65–4.83%), arginine (4.63–5.75%), serine (4.44–5.56%), threonine (3.59–5.41%), and tyrosine (2.58–3.29%). Essential amino acids such as leucine, lysine, phenylalanine, and valine are at higher levels in rambutan seed than those in the FAO/WHO reference protein (Augustin & Chua, 1988).

A rambutan seed albumin concentrate (RSAC) with a protein content of 80.8% was isolated from rambutan seed meal by Vuong et al. (2016). The authors examined the effects of pH and sodium chloride concentration on the solubility and functional properties of RSAC. They reported that RSAC shows high surface hydrophobicity and recommended that RSAC could be a potential protein ingredient for the formulation of new food products. Recently, Evaristus et al. (2018) successfully extracted and identified α -amylase inhibitor peptides from rambutan seed protein using gastro-digestive enzymes. They used different gastro-digestive enzymes to extract the peptides and investigated the effects of digestion time and enzyme to substrate ratio on the α -amylase inhibitory activity. Their results showed that chymotrypsin effectively produced the inhibitor peptides from rambutan seed protein at an enzyme to substrate ratio 1:20 for 1 h. The authors identified a total of 20 and 31 novel inhibitor peptides. Therefore, rambutan seed could be a potential source of α -amylase inhibitor peptides that could have a positive impact on our health.

7. Aroma profiles in rambutan seed and its fat

Aroma profiles of rambutan seed and its fat are one of the most crucial properties to impact their quality. The aroma is produced because of the presence of volatile compounds in the seed and fat (Mottram & Elmore, 2003). Recently, Chai et al. (2019b) identified seventeen key volatile compounds in fresh and roasted rambutan seed similar to that of cocoa powder. They reported that 3-methylbutanoic acid, dimethylsilanediol, 2-furanmethanol, furfural, 5-methyl-2-furancarboxaldehyde, trimethylpyrazine, and tetramethylpyrazine were the main contributors to the aroma of the roasted rambutan seed. These compounds are responsible for sweaty, burnt, caramel, cooked, woody,

Table 1
Total rambutan seed fats (%) and their fatty acid profiles from various studies.

Variety	Origin	Total fat (%)	Fatty acids											References		
			C ₁₄	C ₁₆	C _{16:1}	C _{18:0}	C _{18:1}	C _{18:2}	C _{18:3}	C _{20:0}	C _{20:1}	C _{22:0}	C _{22:1}		C _{23:0}	C _{24:0}
Rongrien	Thailand	-	2.2	3.4	-	8.7	33.1	0.03	-	42.5	-	2.6	-	-	0.04	Sonwai and Ponprachanuvut (2012)
Mixed varieties	Thailand	41.3	0.11	8.77	0.96	7.25	55.25	3.72	0.26	22.05	1.34	-	-	-	-	Winayanuwattakun et al. (2008)
11 varieties	Malaysia	36.13–39.13	-	2.40–3.39	0.16–3.27	5.22–8.97	33.35–46.64	1.48–3.52	0.14–9.90	26.03–33.27	1.64–2.41	0.06–0.73	-	0.12–0.30	-	Chai et al. (2018)
-	Thailand	37.35	0.02	4.69	-	7.03	36.79	1.37	6.48	34.32	3.10	0.66	0.03	0.33	-	Sirisompong et al. (2011)
-	Thailand	-	0.02	4.81	0.46	7.55	37.14	0.93	0.08	38.36	3.18	0.53	-	0.35	-	Mahisanunt et al. (2017)
Clone R4	Malaysia	33.03	-	3.82	8.26	3.22	40.99	29.13	1.05	5.13	3.03	1.48	-	3.57	-	Chai et al. (2019)
Clone R99	Malaysia	38.0	0.13	4.60	0.72	7.88	43.09	3.22	0.74	31.53	2.10	0.10	-	-	-	Manaf et al. (2013)
Rongrien	Thailand	32.60	-	5.84	0.86	4.54	31.08	2.40	-	28.65	3.04	-	-	-	-	Lourith et al. (2016)
3 varieties	Malaysia	37.1–38.90	0.02–0.03	4.36–4.86	0.95–1.30	5.93–7.49	37.91–40.15	1.21–1.54	-	36.14–36.77	2.53–2.71	0.63–0.80	-	-	-	Augustin and Chua (1988)
RI-104 variety	Mexico	33.40	-	6.10	1.50	7.10	40.3	-	-	6.3	2.9	-	-	-	-	Solis-Fuentes et al. (2010)
-	South Congo	36.8	-	4.20	7.20	36.6	1.8	-	-	6.8	3.6	-	-	-	-	Romain et al. (2013).

fragrant, almond, nutty, coffee, milk-coffee, and chocolate odours for cocoa (Afoakwa, Paterson, Fowler, & Ryan, 2008, 2009; FEMA, 2018). The authors suggested that roasted rambutan seeds have a unique flavours and can be transformed into cocoa-like powder products. In another study, isocitronellol, 3-hydroxy-2-butanone, pentanal, and 4-tridecyl valerate were the main volatile compounds identified in rambutan fruit by Laohakunjit and Kerdchoechuen (2007). Ong et al. (1998) determined the volatile compounds in rambutan fruit by gas chromatography. They reported that β-damascenone, ethyl 2-methylbutyrate, 2,6-nonadienal, (E)-2-nonenal, and nonanal were the main contributors to the rambutan fruit aroma. Their results also demonstrated that the exotic aroma character of rambutan was due to the interaction of fruity-sweet and fatty-green odours, with the possible contribution of “civet-like”-sweaty, spicy, and woody notes.

Distinct aroma profiles have been reported for rambutan seed fat (RSF) by Manaf, Marikkar, Long, and Ghazali (2013). Recently, Khairy, Saadoon, Zzaman, Yang, and Easa (2018) determined flavour compounds in RSF and its blend with cocoa butter for application in chocolate manufacturing as a cocoa butter equivalent. They have identified seven kinds of flavour compounds in RSF and its mixtures. They found the highest levels of ester, alcohol, hydrocarbon, carboxylic acid, aldehyde, ketone, and pyrazines flavours in the range of 16.49, 23.15, 17.65, 23.14, 14.41, 12.20, and 29.38% in RSF followed by 10.59, 10.03, 6.11, 9.43, 8.96, 11.20, and 25.94%, respectively, in cocoa butter. The authors suggested that up to 20% RSF can be used as a cocoa butter equivalent to improve the quality and aroma of products. The sensorial aspects of chocolate products containing RSF from rambutan seeds should be studied.

8. Fat content in various rambutan seed varieties

Currently, RSF is extracted and fractionated using solvents and their quality has been evaluated by many researchers and reported in the literature. The fat content in rambutan seed varies greatly depending on the varieties and maturity of the seed as well as the agricultural practices. On a dry weight basis, rambutan seed contains high amount of fats with values between 14.7 and 41.3% (Chai et al., 2018; Chai et al., 2019b; Kalayasiri, Jeyashoke, & Krisnangkura, 1996; Lourith et al., 2016; Romain, Ngakegni-Limbili, Mouloungui, & Ouamba, 2013; Sirisompong et al., 2011; Solís-Fuentes et al., 2010; Winayanuwattakun et al., 2008). The fat yield depends on several factors such as, the extraction solvent, temperature, and time, seed particle size and pre-treatment conditions (Becker, 1978; Sirisompong et al., 2011). Dadshani (2002) reported that RSF is rich in vitamin C, zinc, and calcium. It also provides minerals necessary for human nutrition (DRIs, 2001).

RSF has attracted substantial interest from researchers because its physicochemical and thermal characteristics are similar to those of confectionary fats. Moreover, this fat could be used for manufacturing candles, soaps, and fuels (Chai et al., 2018; Sirisompong et al., 2011). The search for new sources of fats and oils is increasing by the day because of their demand for human consumption and for industrial purposes. RSF not only could be used for industrial purposes, it also has the potential to be used as edible fat. However, the organic solvents used for the extraction and fractionation of RSF have adverse effects and are non-selective, toxic, non-environmentally friendly, and require a long extraction time. Therefore, it is essential to develop healthy extraction methods, i.e., supercritical carbon dioxide extraction as no studies have been performed for its application to the extraction of RSF.

8.1. Fatty acid profiles of RSF

The major fatty acids in RSF are palmitic, stearic, oleic, and arachidic acids. The oleic and arachidic acids are the leading fatty acids. Moreover, linoleic, linolenic, gondoic, and behenic acids are also present in RSF. The fatty acid profiles of RSF vary greatly with the

Table 2
Triacylglycerol (TAG) profiles of rambutan seed fat in different studies.

TAG profiles	References				
	Chai et al. (2018)	Chai et al. (2019a)	Manaf et al. (2013)	Harahap et al. (2012)	Chai et al. (2019b)
OOO	0.25–1.26	1.05	0.91	1.43	2.76
POO	0.31–2.34	1.94	1.40	–	1.06
PPO	0.27–0.91	0.52	0.90	–	0.28
SOO	0.32–4.42	1.09	3.0	–	1.21
POS	1.99–6.16	5.05	1.63	–	0.93
PPS	1.54–3.44	1.84	0.26	–	2.03
LLL	–	–	2.18	–	–
PLP	–	–	0.64	–	–
POL + SLL	–	–	0.39	–	–
AAA	–	–	1.40	–	–
ALnO	–	–	–	3.03	–
ALO	–	–	–	0.98	–
ALP	–	–	–	6.33	–
AlnS	–	–	–	1.49	–
AOO	–	–	–	49.84	–
AOP	–	–	–	12.82	–
ASO	–	–	–	15.06	–
ASP	–	–	–	9.03	–
Unknown	83.94–95.33	92.01	87.29	–	–

rambutan variety. Table 1 shows the fatty acid profiles of RSF. The high concentrations of saturated fatty acids (SFAs) typically present in RSF are arachidic, stearic, palmitic, and behenic acids, whereas the unsaturated fatty acids (UFAs) are oleic, linoleic, and gondoic acids. The results showed that the SFAs and UFAs of eleven varieties of RSF were 44.19–62.50% and 37.51–45.18%, respectively (Chai et al., 2018). RSF (37.51–45.18%), sal fat (41.9–45.5%), illipe butter (34–37%), kokum butter (40.8%), bambangan seed fat (44.1%), and mango fat (47%) are the fats that contain a similar level of UFAs as cocoa butter (35.2–40.1%) (Jahurul et al., 2013; 2019). This similarity in the fatty acids of RSF make it a valued fat that is analogous to confectionary fats.

8.2. Triglyceride (TAGs) profiles of RSF

The major constituents of fats and oils are triglycerides that are also complex mixtures of fatty acids. Meanwhile, many researchers have determined TAGs in RSF (Chai et al. 2018, 2019; Harahap et al., 2012; Manaf et al., 2013). Table 2 shows the TAGs of RSF from different studies. It can be seen that only a few TAGs were identified in RSF, namely, 1-palmitoyl-2-oleoyl-3-stearoyl-glycerol (POS), 1,2-dipalmitoyl-3-stearoyl-glycerol (PPS), 1-palmitoyl-2,3-dioleoyl-glycerol (POO), 1-stearoyl-2,3-dioleoyl-glycerol (SOO), 1,2-dipalmitoyl-3-oleoyl-glycerol (PPO), and triolein (OOO). However, the identification of major TAGs in RSF is still in its early stages. Recently, Chai et al. (2018), Chai et al. (2019b) and Chai, Adzahan, Karim, Rukayadi, and Ghazali (2019c) reported that approximately 83.94–95.33%, 87.02–92.01% and 90.67–91.32% of the total TAGs in RSF are unknown. This indicates that the identification of major TAGs in RSF is still an unexplored area of research.

8.2.1. Physicochemical properties of RSF

Table 3 shows the physicochemical properties of RSF. These properties of RSF are essential as raw material for possible application in various industries, from foods to cosmetics. The iodine value (IV) of RSF in different studies varied from 32.31 to 58.13 (g iodine/100 g fat) depending on the varieties and location. This result places RSF in the non-drying group of oils such as palm oil and coconut oil, which are commercially produced as food and cosmetic raw materials by different industries (Lourith et al., 2016; Sirisompong et al., 2011). The saponification values (SV) of RSF ranged from 157.07 to 247.73 (mg KOH/g fat). Manaf et al. (2013) reported that the saponification value of RSF is

similar to that of cocoa butter, illipé, kokum, and shea butter. The free fatty acid (FFA) values of RSF varied from 0.99 to 6.10 in different studies. Recently, Lourith et al. (2016) reported that the FFA values of RSF are similar to that of pomegranate, coconut and avocado fats. From Table 3, it can be seen that RSF possessed comparable peroxide values, melting points and refractive indexes with other vegetable fats and oils. Approximately 0.19% unsaponification matter has been reported in RSF by Sirisompong et al. (2011). This value is lower than that reported by Kheiri et al. (1987), and Manaf et al. (2013) who obtained 0.5% and 0.4–0.8% unsaponification matter in RSF. Although the physicochemical properties of RSF are slightly higher, this could be reduced by hydrogenation or by chemical and physical refining processes.

Meanwhile, the solid fat content (SFC) of RSF has been determined by many researchers (Chai et al., 2019a; Harahap et al., 2012; Manaf et al., 2013; Romain et al., 2013; Solís-Fuentes et al., 2010; Sonwai & Ponprachanuvut, 2012). At 0 °C, more than 70% SFC was found in RSF by Solís-Fuentes et al. (2010), Romain et al. (2013) and Chai et al. (2019a). The SFC of RSF showed greater consistency than lard, tallow and palm oil, but a lower consistency than hydrogenated fats or cocoa butter (Solís-Fuentes et al., 2010). In another study, Sonwai and Ponprachanuvut (2012) found a high SFC (above 20%) in RSF at body temperature. Therefore, RSF should be modified by blending, fractionation and chemical and enzymatic interesterification to that of the desired properties.

8.3. Thermal profiles of RSF

Thermal-analytical techniques such as Differential Scanning Calorimetry (DSC) are widely used to determine the thermal history of fats and oils. The melting and crystallization of fats are important in various prepared food products. These properties of fractionated, hydrogenated, chemical, and enzymatic interesterified fats from different sources such as mango seed fat, bambangan seed fat, rambutan seed fat, kokum butter, sal fat, palm oil, shea butter, and illipe fats, have received much attention because of their widespread use in the food and chemical industries (Reddy & Prabhakar, 1994; Calliauw et al., 2005; Maheshwari & Reddy, 2005; Jahurul et al., 2013, 2014a, 2014b, 2018; Chai et al., 2018, 2019b). Meanwhile, many researchers have determined the melting and crystallization profiles of RSF for the potential of rambutan seeds being used as a source of edible fat with potential industrial application (Table 4).

Sirisompong et al. (2011) and Solís-Fuentes et al. (2010) studied the melting and crystallization profiles of Mexican and Thailand RSF, respectively. They reported that RSF shows simple melting and crystallization behaviours. They also observed a solidification profile with three well-differentiated groups of TAGs with high, middle, and low temperatures of crystallization whereas the melting curve showed three or four overlapped peaks. In another study, Chai et al. (2018) analysed the phase behaviour of 11 Malaysian varieties of RSF and found simple melting and crystallization behaviours with four to nine peaks. Recently, Chai et al. (2019a) determined thermal profiles of fermented RSF and reported three to eight peaks. These results for melting and crystallization from different studies demonstrated the complex nature of TAGs in RSF. Moreover, the RSF exhibited nondistinct peaks in different studies indicating that various TAGs melted and crystallized at different temperatures. It can be seen from Table 4 that the melting and crystallization onset and offset temperatures in the same fruit co-product varied greatly in different studies. These differences in peak temperatures could be due to the variation of fatty acids (Table 1) as well as TAGs (Table 2) in the RSF used in each study. Moreover, this could also be due to tempering history, conditions, and DSC calibration procedure used in each study, which might affect the thermal history of the RSF (Jahurul et al., 2014a).

Table 3
The physicochemical properties of rambutan seed fats from different studies.

Variety	IV (g I ₂ /100 g fat)	SV (mg KOH/g fat)	FFA (%)	MP (°C)	RI	PV	References
11 varieties	38.50–50.61	–	0.99–2.18	–	–	–	Chai et al. (2018)
Clone R4	–	–	18.02	–	–	–	Chai et al. (2019)
Clone R99	50.3	182.1	6.1	39.2	–	–	Manaf et al. (2013)
Anak sekolah	37.64	157.07	0.37	–	–	–	Harahap et al. (2012)
RI-104	47.0	186.0	1.99	–	1.468	–	Solis-Fuentes et al. (2010)
13 clone varieties	41.8–49.6	157–190	0.32–67.3	–	–	–	Kheiri and Som (1987)
–	41.6	166	–	–	1.479	–	Sirisompong (2011)
–	44.2	191.4	–	–	–	–	Azam, Waris, and Nahar (2005).
Rongrien	44.17	247.73	4.35	46.05	–	1.0	Lourith et al. (2016)
Rongrien	32.31	199.38	0.77	38.47	–	–	Sonwai and Ponprachanuvut (2012)
–	58.13	195	–	–	–	–	Winayanuwattakun et al. (2008)

8.4. Phytosterol and tocopherol contents in RSF

Vegetable oils generally consist of various compositions including fatty acids, tocopherols and phytosterols. The presence of tocopherols is crucial to specify the identity of the vegetable oils, especially α -tocopherol, which helps in protecting the polyunsaturated fatty acids against peroxidation and oxidation. Meanwhile, phytosterols are the basic constituent of plant cell membranes, including β -sitosterol, campesterol and stigmasterol, which are reported to be the most dominant in higher plants and can help to reduce the risk of numerous types of cancer and reduce blood cholesterol as well as improving the immune system in the human body (Savage, Dutta, & McNeil, 1999; Phillips, Ruggio, & Ashraf-Khorassani, 2005; Ryan, Galvin, O'Connor, Maguire, & O'Brien, 2006; Stevenson et al., 2007; Kamal-Eldin & Andersson, 2012). Sirisompong et al. (2011) determined α -tocopherol and phytosterols content in RSF. They reported that RSF contains 0.103mg/100 g of α -tocopherol. The authors also found 0.61 mg/g of β -sitosterol and 0.32 mg/g of stigmasterol in RSF, whereas campesterol constituents were undetected. The contents of tocopherols and phytosterols are positively correlated with the fatty acid profiles and can be increased with some modification of fatty acid profiles in rambutan seed (Bruni et al., 2002; Goffman & Böhme, 2001). Comprehensive study is needed to identify the phytochemicals from various rambutan seed varieties.

8.5. Application of rambutan seed and its fat

Although the rambutan seeds are bitter in taste, they are consumed after roasting in some Asian countries (Morton, 1987; Solis-Fuentes et al., 2010; Mehdizadeh et al., 2015). Rambutan seed powders are also used to control blood sugar levels by the local people in Malaysia. Moreover, it is used as a local medicine to prevent diabetes (Palanisamy et al., 2008; Evaristus et al., 2018). Rambutan seed has a relatively high

Table 4
Melting and crystallization temperatures of rambutan seed fats.

Melting			Crystallization			References
T _{onset} (°C)	T _{offset} (°C)	ΔH (J/g)	T _{onset} (°C)	T _{offset} (°C)	ΔH (J/g)	
–14.5	51.8	124.3	33.6	–45.6	89	Solis-Fuentes et al. (2010)
–27.6 to –31.3	24.8–50.6	71.2–141.7	23.9–39.4	–43.7–45.6	60.4–88.9	Chai et al. (2018)
–4.5	58.9	85.4	37.8	–14.8	92.1	Sirisompong et al. (2011)
–0.9	58.2	87.5	52.4	–10.2	76.3	Chai et al. (2019b)
–3.2 to –0.7	58.2–59.7	85.7–90.2	47.4–57.2	–12.6 to –16.3	72.5–78.6	^a Chai et al. (2019b)
–31.2	28.6	89.3	25.6	–41.3	71.3	Chai et al. (2019a)
–5.3 to –1.9	48.5–58.6	84.5–92.1	29.8–53.8	–12.2	76.2–82.6	^b Chai et al. (2019a)
–	> 50.0	–	50.0	–10.0	–	^b Febrianto, Issara, Yang, and Abdullah (2014)
9.42	41.55	97.98	28.13	0.95	83.27	Sonwai and Ponprachanuvut, (2013)
–	40.0	–	–	–43.8	–	Manaf et al. (2013)

^a Roasted rambutan seed fat.

^b Fermented rambutan seed fat.

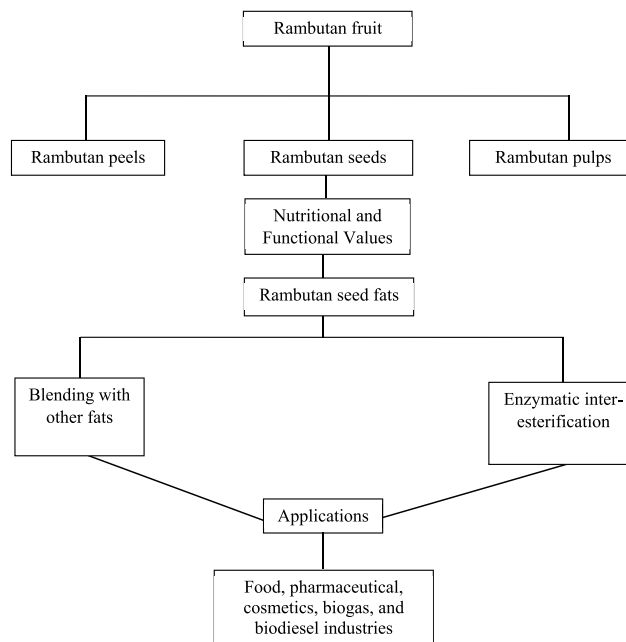


Fig. 1. Application of rambutan seed and its fat in the various industries.

fat content with possible applications in food, cosmetic, and pharmaceutical industries (Fig. 1). It has unique fatty acids and thermal behaviours similar to commercial cocoa butter. This makes RSF a suitable substitute for cocoa butter, which is rather expensive, in confectionary products, which is rather expensive. RSF is highly stable to oxidation due to its high content of arachidic acid. Moreover, RSF can also be used in many applications. First, it can be used as an edible vegetable oil. RSF could also be suitable for candle making (Tindall, 1994, 1994).

RSF can be used in soap manufacturing especially for bar and liquid soaps. Fats and oils are major ingredients of soaps, which are made through the saponification process (Bajpai & Tyagi, 2007; Ghaim & Volz, 2001; Letcavage, 2009, p. 98; Lourith et al., 2016). Stable bar and liquid soaps were formulated using RSF with palm, olive, and castrol oils. The RSF containing bar and liquid soaps were saponified with NaOH and KOH. The alkalinity of the freshly formulated bar and liquid soaps was within the range of values for commercial bar and liquid soaps. The foamability was shown to be superior. Moreover, these soaps are better saponified when stored for 15 days under ambient conditions. A possible explanation for this could be due to its reduction in pH and improved foamability (Lourith et al., 2016). Such applications prove the potential of RSF for use in the cosmetic product and its suitability as a promising raw material for the personal care industry. RSF can be highly converted to biodiesel by transesterification using a catalyst such as Novozyme 435- or Lipozyme RM IM-immobilized lipase. Meanwhile, it is economically considered as a feedstock for biodiesel production by biocatalysts in Thailand (Winayanuwattakun et al., 2008). Comprehensive study can be carried out on RSF to explore its industrial applications.

9. Conclusions

Rambutan fruit is widely accepted around the world and is increasingly industrialized by the day. Rambutan seed is a good source of food ingredients because of its premium fat and compounds that have antimicrobial activity. RSF has arisen as a new source of fat with functional properties that could be used in food, pharmaceutical, and cosmetic fields. The utilization of co-products (rambutan seed) to produce RSF no doubt leads to better waste management and ensures sustainable production. Environmentally friendly recovery techniques such as supercritical carbon dioxide technique should be implemented for RSF extraction. Phytochemicals in the seeds of different varieties of rambutan are still an unexplored area of research. Further studies should be performed on sensory effects of incorporating RSF in different foodstuffs. However, the safety of RSF must be assessed before it is used as an ingredient in the food industry. Moreover, the use of RSF in industries, in particular the food industry, will need to be approved by the regulatory authorities.

Declaration of competing interest

None to declare.

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