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Effects of drying methods on the characteristics of rambutan (*Nephelium lappaceum* L.) seed fat: An optimisation approach

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The pre-treatment of oilseeds prior to extraction process may affect oil yield and quality. The aim of this study was to investigate the effects of two drying methods on rambutan seed fat (RSF) yield and their oxidative stability, physicochemical properties, and crystal morphology. Response surface methodology (RSM) was used in the optimisation and investigation of the effects of three process conditions: seed weight (g), extraction time (min), and solvent volume (ml) on RSF yield. Under optimal conditions, a maximum RSF yield of 44.14% was obtained. The differences between RSF pre-treated with oven-drying and RSF with freeze-drying methods in slip melting point (38.3°C to 39.7°C), free fatty acid (3.13 to 3.50 mg KOH/g fat), peroxide value (1.04 to 1.67 meq of O_2/kg of fat), p-anisidine value (1.10 to 1.56), and total oxidation value (4.21 to 5.67) were significant ($p < 0.05$). Both fats showed needle-like shaped crystals. Our results provide useful information in the pre-treatment of RSF, which has potential to be used as blending component with palm oil for cocoa butter equivalent formulation in chocolate and confectionery industries.

KEYWORDS
characteristics, crystal morphology, freeze and oven drying, rambutan seed fat, RSM

1 | INTRODUCTION

Rambutan (*Nephelium lappaceum* L.) is a seasonal tropical fruit native to Malaysia and Indonesia. The rambutan tree is widely cultivated in Asian countries, that is, Malaysia, Philippines, Thailand, Singapore, Vietnam, India, and Syria, and is also grown in Zaire in Central Africa, Madagascar in South Africa, and even in Australia.[1,2] Rambutan fruits are produced in clusters of 10 to 12 oval or round fruits. Each fruit contains a single seed, which is usually covered with thick and translucent juicy flesh. The flesh gives a refreshing and sweet flavour, whereas the seed is slightly bitter in taste. Rambutan fruits are usually consumed fresh, processed, or canned. Some rambutan fruits are processed into commercial food products such as syrups, jams, jellies, drinks, and candies.[3] The fruit can also be consumed fresh as a salad by mixing it with other tropical fruits.[4] Malaysia, Philippines, and Thailand are the main countries produce and export of canned rambutan in syrup.[5] Rambutan seeds are used in the production of flour and seasoned nuts.[6] Some parts of rambutan, such as fruits, leaves, roots, and barks, have many medicinal uses.

The consumption and processing of rambutan fruit generate large amounts of wastes, which are composed mainly of seeds and peels. The increasing supply of rambutan feedstock for processing in the food industry causes the increase in the problem of rambutan seed wastes.[5,7] Norlia et al[8] reported that approximately 94 500 tonnes of rambutan seeds are discarded by industries in Thailand, Indonesia, and Malaysia per year. Rambutan seed contains approximately 37.1% to 38.9% crude fat, 11.9% to 14.1% protein, 2.8% to 6.6% crude fibre, and 2.6% to 2.9% ash on a dry weight basis.[9] The seed has relatively high fat (approximately, 17% to 39%) depending on the varieties.[10] Hence, it can be a new source of fat, which will be able to fulfil the growing demand for fats and oils. Rambutan seed fat (RSF) is semisolid and white at room temperature. It contains almost equal amounts of saturated (49.1%) and unsaturated (50.9%) fatty acids, where arachidic (34%) and oleic acids (42%) are the main fatty acids.[11] Recently, many researchers reported that the physicochemical properties of RSF from either fermented or nonfermented rambutan seeds are suitable as cocoa butter alternatives.[3,7,12-14] Chai et al[15] produced a cocoa powder-like product from the roasted seeds of fermented rambutan fruit. Thus, optimising the extraction of fat from rambutan seed is crucial in achieving the highest yield. Nowadays, the demand for fats and oils is growing because of human consumption and industrial purposes. Moreover, much effort is required for the development of nutritional and industrial potential wastes into value-added products.[6] For example, the nutritional value and possible use of wastes should be evaluated and valorised in an optimal way.[16] The utilisation of seed wastes in the production of useful products may reduce waste disposal problems in the ecosystem.

The pre-treatment of oilseeds prior to extraction process may affect total oil yield and its quality.[17-20] Pre-treatments can be used to rupture the cell wall structures of oilseeds, enhancing the release of oil from the cellular bodies and increasing extraction yield.[21] Different drying methods may have different effects on the microstructures and quality of the products and may have different yields. For example, Zhang et al,[19] who studied the effects of different drying methods (ie, oven-drying, freeze-drying, vacuum-drying, and microwave-drying) on the extraction rate and qualities of flaxseed oil, reported that microwave-drying and freeze-drying have the highest extraction rates and yields (46.36% and 46.16% vs 33.90%) compared to native flaxseed. Qu et al[18] studied the effects of oven-drying and sun-drying on walnut oil oxidation and reported that oven-drying is a promising method for walnut drying. Freeze-drying has been an attractive method for extending the shelf life of food,[22] whereas oven-drying has been used in the food industry.[18] However, the effect of drying methods on the characteristics of RSF has not been examined. Thus, detailed research on RSF will improve our knowledge and its application to confectionery products, especially in chocolate products. Prior to extraction, the seeds were oven-dried and freeze-dried. Fat extraction methods from oilseeds include mechanical pressing, solvent extraction, and supercritical extraction. Among them, solvent extraction is the most common method used to extract fat from oilseeds. Response surface methodology (RSM) is a collection of mathematical and statistical techniques that is used to optimise the performance of the analytical process in order to obtain the best possible responses. RSM is widely applied in food research studies, for instance, the optimisation of oil extraction from Mahkota Dewa,[23] mango,[24] Feun Kase,[25] and Bambangan.[26] This study hypothesised that there are differences in the extraction of RSF yields and their physicochemical properties due to the difference in the type of drying method used. Therefore, the aim of this study was to optimise the extraction of fat from rambutan seeds using RSM with central composite design (CCD). We investigated the interaction effects of the extraction parameters such as sample weight, solvent volume, and extraction time to obtain maximum fat yields. Moreover, the physicochemical properties such as iodine value (IV), free fatty acid value (FFA), peroxide value (PV), saponification value (SPV), p-anisidine value, total oxidation value (TOTOX), slip melting point (SMP), and crystal morphology of RSF were also determined.

2 | MATERIAL AND METHODS

2.1 | Preparation of rambutan seed powder

Rambutan fruits were purchased from the local market of Kota Kinabalu, Sabah. The skin and flesh of rambutan fruit were peeled off manually with a knife. The seeds were washed to remove any impurities and then dried with two drying methods, namely, freeze-drying and oven-drying. The seeds were then divided into two portions. One portion was freeze-dried at condenser temperature of −40°C for 48 hours while the other another portion was oven-dried at 60°C for 48 hours. The temperature and time for oven-drying and freeze-drying were determined according to the methods reported by Chai et al[14] and Neoh et al[27] with some modifications. After drying, the brown shell of rambutan seed was removed manually. Both freeze-dried and oven-dried seeds were then separately ground into fine powder with a blender and subsequently passed through a sieve to obtain uniform particle size (<200 μm). Both rambutan seed powders were stored at −20°C in plastic containers until fat extraction.

TABLE 1 Rambutan seed fat extraction factors and their levels

Variables	Symbol	Coded factor levels		
		-1	0	+1
Sample weight (g)	X_1	10	15	20
Solvent volume (ml)	X_2	250	300	350
Extraction time (h)	X_3	6	7	8

2.2 | Determination of moisture content

Moisture content of rambutan seed powders was determined according to standard method established by American Oil Chemists' Society.[28]

2.3 | Extraction of RSF using *n*-hexane

The total RSF was extracted by *n*-hexane for 8 hours at 50°C based on the Soxhlet extraction in our previous study.[26] The percentage of the total fat content was determined by the following equation:

$$\text{Total fat yield} = \frac{\text{Mass of extracted rambutan seed fat }(\text{g})}{\text{Mass of rambutan seed powder }(\text{g})} \times 100. \tag{1}$$

2.4 | Experimental design

The RSF with freeze-dried pre-treatment was optimised with the CCD of RSM technique. Three-dimensional surface plot was used to show the functional relationship between independent and response variables and to illustrate the types of interaction between the test variables to determine the optimum conditions. In this study, the fat extraction factors and their levels considered were 10 to 20 g of rambutan seed powder (X_1), 250 to 350 ml of solvent volume (X_2), and 6 to 8 hours of extraction time (X_3) (Table 1). The temperature and solvent (*n*-hexane) were kept constant at 65°C throughout the extraction process. A three-factor CCD was done through a total of 20 experimental runs, including six centre points, eight cube points, and six axial points. These points provide information about the interior experimental region, which makes it possible to evaluate the curvature effect. The coded experimental design and yield (%) of RSF with RSM with CCD is shown in the Appendix. The data was fitted with a second-order polynomial equation after running the experiment. The equation used is expressed in Equation (2)

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x^2{}_i + \sum_{i=1}^{n-1} . \sum_{j=i+1}^{n} \beta_{ij} x_i x_j, \tag{2}$$

where Y = predicted response (yield of RSF in %), β_o = constant, $\beta_{i,}$ = linear coefficient, β_{ii} = quadratic coefficient, β_{ij} = interactive coefficients, and x_i and x_j = independent variables.

2.5 | Determination of physicochemical properties

The physicochemical properties (SMP, IV, SPV, PV, FFA, and p-anisidine values) of pre-dried RSF were determined according to Official method established by American Oil Chemists' Society.[28]

2.6 | Determination of total oxidation value

TOTOX value was calculated from the PV and *p*-anisidine value of pre-dried RSF by using the following Equation (3), adapted from Ng et al[29]:

$$TOTOX = 2 peroxide\, value + P - anisidine\, value. \tag{3}$$

2.7 | Determination of crystal morphology of RSF

The crystal morphology of RSF was studied using a polarised light microscopy (PLM; Olympus BX51, Olympus Optical Co, Ltd, Tokyo, Japan). The fat sample was initially melted at 90°C for 10 minutes. A drop of the melted fat was placed on a glass slide, which is pre-heated to 90°C. The glass slide was then covered with a coverslip, inclined at an angle of 45° and stored at room temperature (25°C) for 48 hours until the formation of crystal occurred. The glass slide was then evaluated under a PLM at a magnification power of 100× to observe the grayscale photographs of the fat crystals.[30]

2.8 | Statistical analysis

The extraction yield and physicochemical properties of each drying methods were carried out in duplicates and the results were expressed as means ± standard deviations. The data obtained from fat extraction of rambutan seed were statistically analysed using Minitab statistical software (Version 18.0). Multiple regressions were applied in order to correlate the response variable to independent variables by fitting the coefficient of the polynomial model of the response. Goodness of fit for the model was evaluated by test of significance and analysis of variance (ANOVA). The significance level of 5% was employed in the analysis; thus, the result was considered significant when p-value is lower than 0.05.

3 | RESULTS AND DISCUSSION

3.1 | Moisture content of rambutan seed powders

The moisture content of oven- and freeze-dried rambutan seed powders were found to be 8.33 and 8.46%, respectively, showing no significant difference between the two drying methods. Our results are in line with the results reported by Sui et al,[31] who investigated the effects of different drying methods on nutritional, functional, and physicochemical properties of sweet potato leaves. Jinap et al[32] studied the effects of moisture contents (1.95%-17.64%) on cocoa butter extraction from ground cocoa nibs. They reported that the content of cocoa butter increased with moisture contents. A moisture contents of 17.64% and 9.79% produced the highest yield (60.73% and 60.36%). In another study, Devittori et al[33] reduced moisture content of ground millet bran from 8% to 1% and found no effect on the oil yield. The moisture contents of 8.33% and 8.46% may not affect the extractability of RSF in this study.

3.2 | Physicochemical properties

3.2.1 | Iodine value

IVs of fat extracted from pre-treated oven- and freeze-dried rambutan seeds are presented in Table 2. The results show that IV of RSF pre-treated with oven-drying was 40.45 g I_2/ 100 g fat, while IV for freeze-dried pre-treated fat was 40.77 g I_2/ 100 g fat. These values are very close to the results of Kheiri and Mohd Som,[34] who reported that IV of RSF has a range of 41.8 to 49.6 g I_2/ 100 g fat. The results were also found to be similar to that reported by Sirisompong et al,[4] who revealed the IV of RSF was 41.6 g I_2/100 g fat. However, IV obtained in this study was lower as compared to 50.27 g I_2/100 g fat, which was obtained by Manaf et al.[11] In another study, Mahisanunt et al[5] reported that RSF pre-treated with oven-drying at 60°C had an IV of 48.69 g I_2/100 g fat. The IVs obtained in this study were not significantly different ($p > 0.05$) from each other. This result indicated that the IVs of fat are not influenced greatly by the oven- and freeze-drying pre-treatment methods.

The low IV indicates that RSF has a low degree of unsaturation, which makes RSF less prone to lipid oxidation than fats with higher degrees of unsaturation. Thus, the risk of undesirable deterioration of fat quality such as off-flavours, rancid odour development and nutritional losses can be reduced. The fat poses no significant risk to consumer health. RSF is a more saturated fat and therefore presents as semisolid in room temperature. The low IV of RSF may be due to the presence of high concentration of saturated fatty acids, primarily arachidic acid. Manaf et al[11] reported that arachidic acid is one of the dominant fatty acid present in RSF. RSF has a potential to be used as a softer chocolate filling in chocolate and confectionery industries. Fats and oils are categorised into drying, semidrying, and nondrying oils according to their IVs as well as their drying capacities. IVs of drying oils are very high, which range from 130 to 190, whereas semidrying

TABLE 2 Physicochemical properties of rambutan seed fat[1] extracted from different drying methods

Properties	Methods	
	Oven-dried seed oil	Freeze-dried seed oil
Iodine value (g iodine/100 g fat)	40.45 ± 1.29^a	40.77 ± 1.33^a
Acid value (mg KOH/g)	3.13 ± 0.11^a	3.50 ± 0.11^b
Peroxide value (meq of O_2/kg of fat)	1.67 ± 0.13^a	1.04 ± 0.20^b
Saponification value (mg KOH/g fat)	187.25 ± 0.41^a	186.93 ± 0.37^a
p-anisidine value	1.56 ± 0.31^a	1.10 ± 0.22^b
TOTOX value	5.67 ± 0.34^a	4.21 ± 0.15^b
Slip melting point (°C)	39.7 ± 0.58^a	38.3 ± 0.58^b

[1]Mean ± standard deviation.

[a-b]Means in the same row with different letters are significantly different ($P < 0.05$) measured by Tukey's test.

oils have IV in the range of 100 to 130.[35] Since IV of RSF is lower than 100, it is placed into the so-called nondrying oil group. Nondrying oils show good resistance to oxidation such that they do not harden due to drying when exposed to air. Therefore, RSF is suitable for production of hard soaps in the industry.

3.2.2 | Peroxide value

RSF from oven-drying and freeze-drying had PVs of 1.67 and 1.04 meq of O_2/kg of fat, respectively, which are comparable with those reported in cocoa butter and vegetable oils.[36,37] However, there was a significant difference ($p < 0.05$) in the PVs between the two different drying methods used. Similar results were observed by Gutiérrez et al,[38] who studied the effects of drying methods on the quality of quebec sea buckthorn (*Hippophaë rhamnoides* L.) seed oils.

3.2.3 | Saponification value

No significant difference ($p > 0.05$) was found in the SPV of RSF when comparing the two drying methods. Similar values were reported for RSF by Solís-Fuentes et al[39] and Manaf et al.[11] Moreover, the SPV obtained in this study were similar to that of cocoa butter and its alternative fats such as illipé, kokum, and shea butter. However, significantly low and high SPVs were also reported in RSF in different studies.[4,40] The possible explanation for the high and low SPVs in RSF may be due to the difference in varieties, weather, and origin.

3.2.4 | TOTOX and p-anisidine values

TOTOX and p-anisidine values of RSF pre-treated with oven-drying were 5.67 and 1.56, respectively, while these values for freeze-dried pre-treated RSF were 4.21 and 1.10. A significant difference ($p < 0.05$) was observed in the p-anisidine and TOTOX values of RSF when comparing the two different drying methods. Fat from the freeze-dried rambutan seed had low p-anisidine value, indicating low levels of carbonyl compounds in the absence of heat. Similar p-anisidine values (7.2 to 9.1) were reported in microwave-drying and air-drying of grape seed oil by Oomah et al.[41]

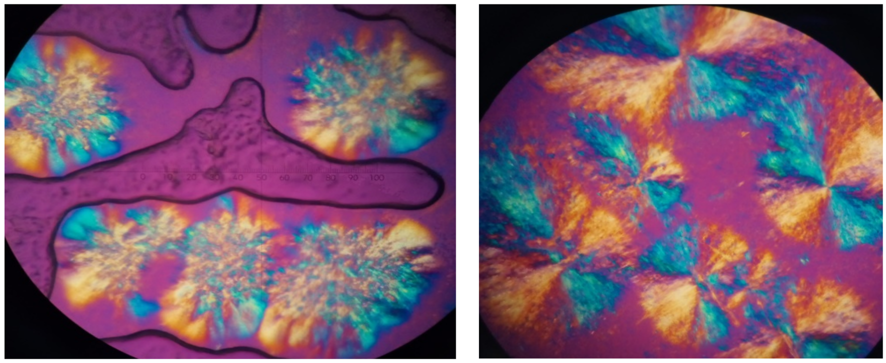
3.2.5 | Free fatty acid value

RSF with oven-drying pre-treatment had an FFA of 3.13 mg KOH/g fat, whereas freeze-drying treated RSF had an FFA of 3.50 mg KOH/g fat (Table 2). This result demonstrated that RSF with freeze-drying pre-treatment contains a higher FFA compared to those treated by oven-drying. There was a significant difference ($p < 0.05$) between the FFA of RSF pre-treated with oven- and freeze-drying methods. The pre-treated freeze-dried sample had high FFA, indicating high enzymatic rancidity (breakdown of RSF by lipases). The lipase enzyme activity, which was still active in the freeze-dried seed, released FFA via decomposition of fats, thereby resulting in high FFA.[21] This result indicated that drying pre-treatment of sample have some impacts on the level of FFA in the fats. Although freeze-drying can preserve the raw quality and bioactive compounds in the seeds, its preservation effect greatly depends on the type of chemical compounds present and the type of sample used.[42]

In this study, the FFAs of RSF were considerably high compared with the results obtained by Hajar et al,[43] who reported that RSF had an FFA of 1.2162 mg KOH/g. The conditions and duration of storage of oilseeds can be the factors that might have influenced the level of FFA. Improper storage of seeds under conditions favouring lipase activity may result in a fat with high FFA; therefore, seeds should not be stored at high humidity condition. Seeds that were stored for a prolonged period of time may also have high FFA. High FFA of RSF was reported by Lourith et al,[40] who mentioned that FFA of RSF was 4.35 mg KOH/g using maceration in *n*-hexane method. FFA of RSF was found to be higher than cocoa butter. This implies that, if RSF is used as cocoa butter alternative, a refining process is required to reduce the FFA to an acceptable level where their deleterious effects on oil stability are the minimum, making the fat obtained to be of high in quality and more suitable for applications in chocolate and confectionery industries.

3.2.6 | Slip melting point

The SMP of RSF was determined using capillary tube method and the results are shown in Table 2. Based on the results, the SMP of RSF extracted from oven-dried seeds was 39.7°C, while it was 38.3°C for freeze-dried seeds. There was a significant difference ($p < 0.05$) between the two SMPs of RSF. These values are found to be very similar to the results obtained by Sonwai and Ponprachanuvut,[30] Manaf et al,[11] and Hajar et al,[43] who reported that the SMP of RSF were 38.5°C, 39.2°C, and 38.0°C to 48.8°C, respectively. The low melting point of RSF makes it a potential fat in the production of chocolate and confectionery products. RSF with oven-drying pre-treatment had high SMP compared to those pre-treated with freeze-drying. The results revealed that the application of high temperature during the drying of seeds may influence



(A) (B)

FIGURE 1 Polarised light microscope image showing crystal morphology of (A) oven-dried and (B) freeze-dried rambutan seed fat, obtained during static isothermal crystallisation at 25°C for 48 hours (100× magnification)

the melting points of fat by increasing their saturation (breakdown of unsaturated fatty acids). Drying at high temperature helps breakdown cell walls and the chemical and bioactive compounds are exposed to air. The reactive C=C present in the fat therefore undergo chemical reaction, making the fat more saturated. This also causes a faster degradation of oilseed due to lipid oxidation process.

Fat that quickly melts under body temperature just like cocoa butter will produce chocolate and chocolate products with desirable melting properties. SMP of cocoa butter ranged from 27°C to 35°C, which is lower than the SMP of RSF.[1,30,44] This result indicated that RSF contains a higher amount of saturated fatty acids than cocoa butter. The high level of long chain saturated fatty acids, especially arachidic acid in RSF contributes to its high SMP.[30] When RSF is used as an alternative to cocoa butter, the unique melting profile of RSF shall result in a different flavour release of the chocolate products. The high melting point of RSF may produce chocolate products with a waxy mouth-feel. RSF may be particularly suitable as alternative to cocoa butter in the production of chocolate in tropical climates due to its relatively high SMP.

3.3 | Morphology

PLM was used to observe the crystal structure of RSF. The crystal formation in RSF are shown in Figures 1A and 1B. The PLM images showed that fat crystals in RSF were small in size and appeared scattered throughout the field. Many crystals were formed due to the presence of different triglycerides in terms of fatty acids.[45] The fat crystals formed in RSF treated by oven-drying and freeze-drying appeared in similar shape and size. There was no essential difference in the fat crystals formed in both oven-dried and freeze-dried RSF. RSF crystals were densely packed, needle-like in shape, and approximately 20 to 30 μm. A higher amount of fat crystal was observed in oven-dried RSF than in freeze-dried RSF. This phenomenon may be caused by different crystallisation rate of fat. The rate of crystallisation would affect the number, size and distribution of fat crystals, thereby affecting the properties of products, such as flavour release, appearance and texture.[46] Zzaman et al[47] reported that the crystal of cocoa butter was slightly bigger than that of RSF; however, cocoa butter also showed needle-like fat crystals after crystallisation. Mahmood et al[16] reported that RSF had a similar crystal morphology as cocoa butter when it was observed under PLM. Hence, the crystal network microstructures of RSF were considered very similar to cocoa butter. The small crystals of RSF may contribute to a smoother and better texture of chocolate products than cocoa butter.

3.4 | Optimisation and validation of RSF

The outcomes of the experimental design in percentage yield of RSF are presented in Tables 3 and 4. Results show that RSF yields ranged from 34.38% to 44.44%. The highest yield was 44.44% at sample weight of 20 g, solvent volume of 350 g, and extraction time of 8 hours, making this condition the optimum for high RSF yield. In contrast, the lowest yield was 34.38% at two conditions: (1) at sample weight of 20 g, solvent volume of 250 g, and extraction time of 8 hours; and (2) at sample weight of 20 g, solvent volume of 300 g, and extraction time of 7 hours. This indicates that sample weight, solvent volume and extraction time are closely related to the fat yields in which different levels of extraction give different fat yields. Under the optimum condition, the predicted fat yield was 44.14%. Composite desirability (D) was 0.97, which was very close to 1.00, indicating that the optimum condition was an ideal setting that achieves favourable results. Based on a response regression equation, the experimental and predicted values were compared for the validation of the adequacy of the response surface model. The multiple response prediction, ie, 95% confidence interval (CI) was 41.99 and 46.29 which indicates 95% of the results fall within this interval when the test was conducted for an infinite time. A 95% prediction

TABLE 3 Experimental design and yield (%) of freeze-dried rambutan seed fat using response surface methodology with central composite design

Run	Sample weight	Solvent volume	Extraction time	Fat yield
1	10	250	6	43.03
2	20	250	6	36.06
3	10	350	6	38.06
4	20	350	6	40.74
5	10	250	8	38.92
6	20	250	8	34.38
7	10	350	8	42.65
8	20	350	8	44.44
9	10	300	7	39.54
10	20	300	7	34.38
11	15	250	7	39.40
12	15	350	7	41.92
13	15	300	6	39.45
14	15	300	8	37.34
15	15	300	7	35.98
16	15	300	7	35.98
17	15	300	7	35.98
18	15	300	7	35.98
19	15	300	7	35.98
20	15	300	7	35.98

TABLE 4 Optimisation and validation results

	Experimental		Predicted
	Minimum	Maximum	Maximum
Sample weight (g)	10	20	20
Solvent volume (ml)	250	350	350
Extraction time (h)	6	8	8
Maximum fat yield (%)	34.38	44.44	44.14

interval (PI) was 40.72 and 47.56, which indicates that there is a 95% probability that the results will fall within this interval when a single test was carried out. The low standard error of the fit (SE fit) (0.995) indicates there is less variation in predicted fat yield to experimental fat yield. These verified that the response surface models were adequate in this study. The optimised mathematical relationship between fat yield (Y) and the coded values of independent variables, ie, sample weight (X_1), solvent volume (X_2), and extraction time (X_3), and their respective interactions, is expressed in Equation (4). The final equation of the optimisation in terms of coded factors is expressed in Equation (5)

$$Y\ (\%) = 294.0 - 2.22\,X_1 - 1.085\,X_2 - 23.2\,X_3 - 0.0229\,X_1X_1 + 0.001251\,X_2X_2 + 0.862\,X_3X_3 + 0.00799\,X_1X_2 + 0.0385\,X_1X_3 + 0.03520\,X_2X_3 \tag{4}$$

$$Y\ (\%) = 259.1 - 2.641\,X_1 - 1.126\,X_2 - 10.52\,X_3 + 0.001320\,X_2X_2 + 0.00799\,X_1X_2 + 0.03520\,X_2X_3. \tag{5}$$

Table 5 shows the result of the test of significance for every regression coefficient. There is a statistically significant difference between model terms and response variable if p-value is less than or equal to significance level of 0.05. In this case, the single effect of linear term X_1 and X_2 were found significant ($p < 0.05$), whereas X_3 did not have a strong effect on RSF yield. This implies that at significance level of 5%, sample weight and solvent volume have significant effect on the fat yield but extraction time has less effect. Table 5 also shows that the quadratic term X_2X_2 and the interaction effects of X_1X_2 and X_2X_3 have significant effect ($p < 0.05$) on RSF yield. However, the quadratic term X_2X_2 with F-value of 35.80 and p-value of 0.000 showed the most significant effect on the fat yields.

F-value of 16.62 with low p-value of 0.000 implied the regression model was highly significant (Table 5). For a good fit of a model, R^2 should be at least 80%.[48] In this study, the coefficient of determination was 88.47%. This value indicates that 88.47% of variation in fat yield is explained by the independent variables. The value of adjusted R^2 was very high (83.14%), which provides a strong support that the model was highly significant. Moreover, the high values of both R^2 and adjusted R^2 indicate that this model is workable and can be used in theoretical prediction of the fat extraction and optimisation process.[4] The variance inflation factor of quadratic terms showed that the variables are moderately correlated. Hence, the model is suitable to represent the real relationship among the selected independent variables.

TABLE 5 Significant[a] probability (p-value and F-ratio) of the sample weight, solvent volume, and extraction time (independent variables), regression coefficients, R^2, P-value, and lack of fit for the reduced response surface model

Regression coefficients	Fat yield
β0	36.659
Bi	−1.220
Bj	1.602
Bc	0.039
Bij	1.997
Bjc	1.760
Bic	-
βi^2	-
βj^2	3.301
βc^2	-

	Main effects			Interaction effects			Quadratic effects		
Variables	βi	βj	βc	βij	βjc	βic	βi^2	βj^2	βc^2
p-value	0.008	0.001	0.922	0.001	0.001	-	-	0.000	-
F-ratio	9.78	16.86	0.01	20.98	16.28	-	-	35.80	-

Regression	R^2	p-value	Lack of fit (F-value)	Lack of fit (p-value)
Fat yield	0.8847	0.000	*	*

[a]Only the terms with statistical significance are included.

3.5 | Effects of sample weight and solvent volume on RSF yields

Figure 2A shows the surface plot representing the effects of sample weight, solvent volume and their reciprocal interaction on fat yields while extraction time was kept constant at 7 hours. The results showed that the yields decreased as the sample weight increased. For example, the yields decreased from 39.54% to 34.38% as the sample weight increased from 10 to 20 g. Similar trend was observed by Ajala et al,[49] who demonstrated that the yields of shea butter decreased with shea kernel. Moreover, the results also showed that the yields increased with increasing solvent volume. For instance, the yields increased from 39.40% to 41.92% as the solvent increased from 250 to 350 ml. Similar trends were observed by Jahurul et al,[26] who demonstrated that the bambangan kernel fat increased with solvent volume.

When the effects of sample weight and solvent volume were considered simultaneously, high sample weight and solvent volume favoured RSF yield. The highest yield (41.92%) was obtained at the highest sample weight of 15 g and solvent volume of 350 ml. However, low sample weight and high solvent volume may lead to a high yield. At 15 g sample weight, the yield decreased to 39.40% when the solvent volume decreased to 250 ml because the fat from the sample was not fully extracted by solvent. The highest yield was obtained when 350 ml of solvent was used. These results indicated that sample weight and solvent volume and their interaction have significant effect on RSF yield.

3.6 | Effects of sample weight and extraction time on RSF yields

Figure 2B shows the effect of sample weight, extraction time, and their reciprocal interaction on RSF yields while keeping solvent volume constant at 300 ml. The results showed that the yield decreased when the sample weight increased. The highest yield (43%) was obtained when 10 g of sample was extracted for 6 hours. The yield decreased to 39.45%, when the sample was increased to 15 g. RSF yield decreased to 36.06% as the sample was further increased to 20 g. This is because 6 hours was sufficient for 300 ml of solvent to fully extract fat from 10 g sample and thus fat yield was high. It can be seen from Figure 2B, the yields changed slightly when the extraction time changed. The yield decreased to 36% when the extraction time increased to 7 hours and increased again to 37.54% at extraction time of 8 hours. This indicated that extraction time did not have significant effect on the yield.

High yields were obtained at low sample weight and low and high extraction times. No significant yield was observed at low and high extraction time and high sample weight. RSF yields decreased as sample weight and extraction time increased. When the sample weight and extraction time increased to 15 g and 7 hours, respectively, the yield decreased slightly to 35.98%. At sample weight of 20 g and extraction time to 8 hours, the yield decreased to 34.38%. Moreover, high sample weight and extraction time resulted in low fat yields. Hence, the interactions of sample weight and extraction time have less significant effect on the yield.

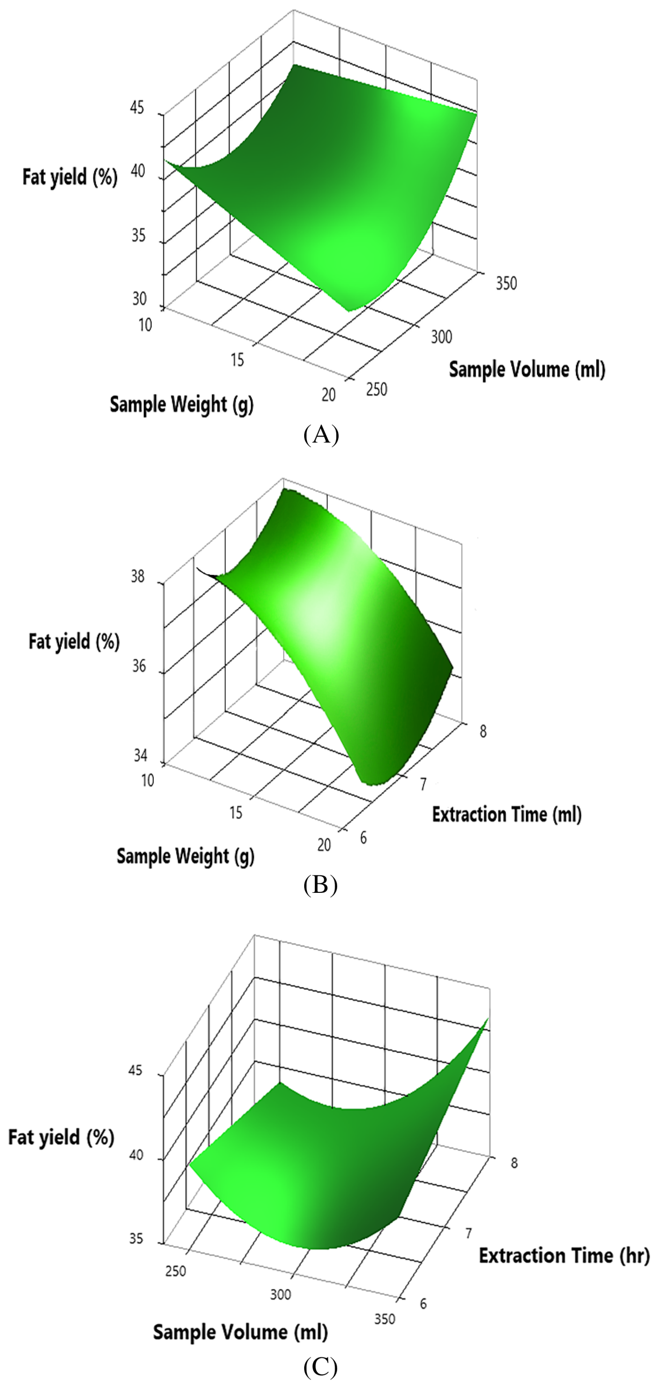


FIGURE 2 Surface plot of fat yield as function of sample weight, solvent volume, and extraction time at a fixed (A) time of 7 hours, (B) weight of 15 g, and (C) solvent volume of 300 ml

3.7 | Effects of solvent volume and extraction time on RSF yields

Figure 2C shows the effects of solvent volume, extraction time and their reciprocal interaction on RSF yield at a constant sample weight 15 g. The yields increased with solvent volume. At extraction time of 8 hours, the yields showed a significant increment from 34.38% to 44.44% as the solvent volume increased from 250 to 350 ml. At a fixed amount of sample, the increased solvent volume increases the concentration gradient between the solid and liquid phases, and the extraction yields increased because of good mass transfer. The yields increased gradually with extraction time. When 15 g of sample was extracted with 300 ml of solvent, the yield was 39.45% at 6 hours extraction time. When the extraction time was extended to 7 hours, the yield was 41.92%. The yield increased to 44.44% at 8 hours extraction time. Ajala et al[49] studied the solvent extraction of shea butter and showed that yields of shea butter increased with extraction time. Increasing the extraction time facilitates the penetration of solvents into sample and fat extraction, thereby resulting in high fat yield.

The results revealed that high solvent volume and extraction time favoured the fat yields. When the sample was extracted with 250 ml of solvent for 6 hours, the yield obtained was approximately 36.06%. The yield increased to 44.44% as the solvent increased to 350 ml and extraction time was extended to 8 hours. This result is similar to a previous study performed by Jahurul et al,[26] who reported that the yields of bambangan kernel fat increased as solvent volume and extraction time increased. However, the lowest yield was obtained at low solvent volume and high extraction time. Hence, this indicated that RSF yield is significantly influenced by the interaction effect of solvent volume and extraction time.

4 | CONCLUSION

The present work improves understanding of the relationship between the drying processes and quality of RSF and provides useful information for the application of RSF in food industry. For the first time, the effects of different drying methods, ie, oven-drying and freeze-drying on the extraction yields and quality of fat extracted from rambutan seeds, were investigated. The highest yield of RSF was 44.44% and the lowest was 34.38%. Sample weight and solvent volume were the most significant parameters that influencing RSF yield. The fat yields increased with decreasing sample weight and increasing solvent volume. However, high extraction time (8 hours) favours fat yield (42.65%) at high solvent volume and low sample weight. Physicochemical properties, such as IV (40.45-40.77 g I_2/100g fat), FFA (3.13-3.50 mg KOH/g fat), PV (1.04-1.67 meq of O_2/kg of fat), SPV (186.93-187.25 mg KOH/g fat), p-anisidine value (1.10-1.56), TOTOX value (4.21-5.67), and SMP (38.3°C-39.7°C) were obtained for oven- and freeze-dried RSF. The results indicated that RSF is a promising alternative source of food that can be used as a blending component for cocoa butter equivalent formulation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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APPENDIX

TABLE A1 Coded experimental design and yield (%) of rambutan seed fat using response surface methodology with central composite design

Run	X_1	X_2	X_3	Fat yield (%)
1	−1	−1	−1	43.03
2	+1	−1	−1	36.06
3	−1	+1	−1	38.06
4	+1	+1	−1	40.74
5	−1	−1	+1	38.92
6	+1	−1	+1	34.38
7	−1	+1	+1	42.65
8	+1	+1	+1	44.44
9	−1	0	0	39.54
10	+1	0	0	34.38
11	0	−1	0	39.40
12	0	+1	0	41.92
13	0	0	−1	39.45
14	0	0	+1	37.34
15	0	0	0	35.98
16	0	0	0	35.98
17	0	0	0	35.98
18	0	0	0	35.98
19	0	0	0	35.98
20	0	0	0	35.98