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Physicochemical Properties of Pili (*Canarium ovatum*) Nut Oils Extracted Using Different Extraction Solvents

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ABSTRACT

There is still lack of information on pili (*Canarium ovatum*) nut oil from Sabah, Malaysia. Therefore, the objective of this research was to investigate the physicochemical properties of pili nut oils obtained from Soxhlet extraction by using different extraction solvents such as petroleum ether, hexane, acetone and ethanol. The extracted pili nut oils were assessed for colour, refractive index, slip melting, and cloud point; iodine, free fatty acid, peroxide, p-anisidine, totox values; carotene content, thermal behaviour, fatty acid composition, and triacylglycerol profile. The highest oil yields were obtained by extraction using petroleum ether and hexane. The physical and chemical properties of oil are found to be significantly differed with different extraction solvents. The major triacylglycerols of pili nut oils were palmitoyl–di–oleoyl glycerol (PPO) and di-palmitoyl–oleoyl glycerol (PPO) with oleic and palmitic were the most predominant fatty acids. All extracted pili nut oils were below than the permitted range of free fatty acid content, peroxide and totox values (maximum 10 meq O_2/kg) for cooking oils. The pili nut oil extracted with petroleum ether contained the highest (~ 110 ppm) β-carotene. Among the extraction solvents, petroleum ether was the best in terms of oil yield, quality, and β-carotene content.

Keywords: Pili nut oil, properties, solvent extraction

INTRODUCTION

Pili (*Canarium ovatum*) is a member of the Burseraceae family. Many of the literatures focused on pili nut oil from the Philippines. Kakuda *et al.* (2000) extracted pili nut oil using Soxhlet method which petroleum ether as a solvent. They found that the pili nut contained higher amount of saturated fatty acids than unsaturated fatty acids. The polyunsaturated fatty acids were less than 11%. Other researches using Soxhlet extraction with petroleum ether as solvent also found that pili nut was light yellowish in colour with oleic stearic, palmitic, linoleic, and linolenic acids as the major fatty acids (Pham & Dumandan, 2015; Millena *et al.,* 2018; Millena *et al.,* 2023). Other study conducted by Zarinah *et al.,* (2014) extracted pili nut oil using cold press method and the physicochemical properties were determined for roasted and unroasted pili nut. The percentage of oil yield and iodine value were not significantly different between roasted and unroasted pili nuts. However, the percentage of free fatty acid and peroxide value showed a significant different. Both samples had a high proportion of

oleic acid and fully melted at 25 ℃ and were claimed to be free of trisaturated triacylglycerols.

Extraction of oil using Soxhlet technique could produces a higher oil yield than most other extraction techniques, albeit taking longer to complete (López-Bascón & Luque de Castro, 2020). This method also can use different extraction solvents such as hexane, acetone, etc. The sample is dried before the extraction process because it can increase the oil yield, decrease the moisture content, and deactivate enzymes that encourage the lipid oxidation. Additionally, it promotes the breakdown of cell tissue, which facilitates the solvent's easy penetration of flake (Keneni *et al.,* 2020). The aim of this study was to extract the pili nut oil using Soxhlet technique with different extraction solvents to assess the pili nut oil's physical, chemical, and quality properties.

Researching the physicochemical properties of pili nut oil is crucial for assessing its quality, stability, and potential for diverse applications. Detailed characterization of parameters such as refractive index, melting behaviour, oxidative stability, and fatty acid profile provides essential insights into its functional and nutritional value. Such knowledge not only guides the optimization of processing, storage, and utilization practices but also strengthens the positioning of pili nut oil as a unique and value-added specialty oil for the food, nutraceutical, and cosmetic industries.

MATERIALS & METHODS

Materials

The dried pili nut was gifted by the Lagud Sebrang Agriculture Research Centre, Sabah Agriculture Department in Tenom, Sabah, Malaysia. Analytical and general grade chemicals were used in this research. All physicochemical analysis was carried in triplicate.

Oil Extraction

Oil was extracted using Soxhlet method (AOAC, 2023). A 150 g of dried and crushed pili nuts were put in cellulose thimble, and the oil was extracted for 8 hr using petroleum ether (60 °C) in a Soxhlet extractor. A rotary evaporator (Tokyo Rakakikal Co., Ltd., Tokyo, Japan) was used to recover the oil. After an hour at 60 °C in the oven, the extracted oil was put into an air tight bottle and kept at -20 ℃. The similar method was repeated using different solvents (hexane, acetone and ethanol). Prior to analysis, the oil was left at room temperature (25 °C) for 1 hour before heated at 60 °C until it was totally molten.

Determination of Oil Yield

The oil yield was determined according to AOAC (2023) using specific equation, Eq. (1):

$$\text{Percentage of oil yield (w/w)} = W_{Oil}/W_{Sample} \times 100\% \quad \text{Eq.(1)}$$

W_{Oil} is the weight of extracted oil and W_{Sample} is the weight of the pili nut powder.

Determination of Colour

The colour of the oil samples was measured using a colorimeter using the Hunter Lab system, where a* value ranges from negative (green) to positive (red), and L* value is the lightness of colour from 0 (black) to 100 (white) in the tristimulus colour coordinate system. It can be either positive (yellow) or negative (blue) for b* value (PORIM, 1995).

Determination of Refractive Index (RI), Slip Melting Point (SMP), Cloud Point (CP), Totox Value, Carotene Content, Iodine Value (IV), Free Fatty Acid (FFA), Peroxide Value (PV), and p-Anisidine Value (p-AV)

The refractive index (RI), slip melting point (SMP), cloud point (CP), Totox value, carotene content, iodine value (IV), free fatty acid (FFA), peroxide value (PV), and p-anisidine value (p-AV) of the extracted oil samples were determined according to the official methods of the American Oil Chemists' Society (AOCS, 2000).

Determination of Fatty Acid (FA) Composition

Fatty acid composition was determined by esterifying the oil into methyl esters (FAME) by dissolving 50 mg of oil in 0.8 ml of hexane and 0.2 ml of a 1 M solution of sodium methoxide (AOCS, 2000). The FAME subsequently analysed using a gas chromatograph (GC) with a

flame ionization (FID) was used as a detector. The polar capillary column (RTX-5; 0.32 mm × 30 m length x 0.25 µm thickness) was used. The temperature of the oven was set at 50 °C (for 1 min) and increased to 200 °C at a flow rate of 8 °C/min. The temperatures of the injector and detector were kept at 200 °C throughout the analysis. With a split ratio of 58:1, the flow rate of the helium as a carrier gas was maintained at 1.0/min. The peaks were identified using a FAME standard (Supelco, Bellefonte, PA). The partial area divided by the entire peak area was used to determine the percentage of FA (Yanty *et al.,* 2018).

Determination of Triacylglycerol (TAG) Composition

A high-performance liquid chromatography with a refractive index as a detector was used to determine TAG composition. A column (RP-18; 5 µm × 12.5 cm length × 4 mm i.d.; Merck, Darmstadt, Germany) and the mobile phase of acetone/acetonitrile (63.5:36.5 v/v) was used. The flow rate was maintained at 1.5 ml/min with the oven temperature was maintained at 30 °C. A 1 ml of 5% (w/w) oil in chloroform were used as an injector volume. The individual peaks were identified by comparing their retention time TAG standards, and the relative percentage of individual TAGs was reported as the relative proportion of the TAGs (Yanty *et al.,* 2013).

Determination of Thermal Behaviour

The differential scanning calorimeter was used to measure thermal behaviour of extracted oil samples using a method of Yanty *et al.* (2014). Nitrogen gas (purity: 99.99%) was used as the purge gas at a pressure of 20 psi and a flow rate of 100 ml/min. An empty aluminium sample pan was used as a reference. A sample pan containing 3 to 5 mg of oil was sealed and put inside the sample chamber of the device. An oil sample was heated from -60 – 60 °C at a rate of 5 °C/min, kept at 60 °C isothermally for 2 min, and then cooled from 60 – -60 °C at a rate of 5 °C/min. The onset, peak, and offset (end) temperatures were recorded for heating and cooling thermograms. The temperature at which the melting and crystallisation process begins, the temperature at which the majority of the TAG has melted and crystallised, and the temperature at which the oil has completely melted and crystallised were all indicated by these values from the heating and cooling thermograms.

Statistical Analysis

A Statistical Package for Social Sciences (SPSS) software (Version 28) using one-way analysis of variance (ANOVA) with a confidence level of 95% was used to determine the significant difference among mean scores of the data.

RESULTS & DISCUSSION

Oil Yield

The oil yield of pili nut oils extracted using different extraction solvents are shown in Table 1. Pili nut oil extracted using petroleum ether (69.60%) and hexane (68.85%) as the extraction solvents showed the highest oil yield. However, there was no significant difference ($p<0.05$) in oil yield between the two extraction solvents. The lowest oil yield obtained through extraction of oil using acetone (60.27%) as extraction solvent. The differences in oil yield obtained using different extraction solvents may be attributed to their polarity. Petroleum ether and hexane are non-polar solvents, whereas acetone and ethanol are polar solvents. Generally, non-polar solvents produce higher oil yields because lipids are largely non-polar, and their solubility decreases in highly polar solvents, where excessive polarity may lead to solvolysis and reduced lipid recovery (Isaac *et al*., 2023). However, in some cases, polar solvents can promote oil release by interacting with ester groups of triglycerides through hydrogen bonding and by facilitating cell membrane disruption, which enhances the release of intracellular oil (Wang *et al*., 2023). In addition, polar solvents may lower surface tension at the phase boundary, thereby improving phase separation. Overall, the present results are consistent with the principle of “like dissolves like,” whereby non-polar solvents exhibit stronger hydrophobic interactions with lipids, leading to higher extraction yields (Wang *et al*., 2023).

Table 1. Oil yield of pili nut oils using different extraction solvents.

Extraction Solvent	Oil Yield (%)
Petroleum Ether	69.60±0.94[a]
Hexane	68.85±1.25[a]
Acetone	60.27±0.70[c]
Ethanol	64.86±0.10[b]

Each values represent average of triplicates ± standard deviation. Different superscripted letters in the column indicate significant difference ($p<0.05$) between the samples.

Physical Properties of Oils

The colour, refractive index, slip melting point, and cloud point of extracted pili nut oil using different extraction solvents are shown in Table 2. Based on the results, the colour of the oil showed a significant difference between the solvents used. The pili nut oil extracted with ethanol showed a higher value for all colour parameters [lightness (L*), redness (a*) and yellowness (b*)]. The oil had a value of 25.92 (L*), -1.91 (a*) and 28.68 (b*). On the other hand, hexane as an extraction solvent showed the lowest value for colour parameter among all solvents. The oil had L*, a* and b* of 9.51, -1.14 and 9.38, respectively. The redness (a*) showed a negative value which indicated greenness of colour. The differences of the intensity of the colour of extracted oils were due to the concentration of pigments such as carotenoids, etc. Visually, all extracted pili nut oils in this study were yellow in colour.

Refractive index (RI) is to analyse light rays traversing through materials medium (Sarkar *et al.,* 2015). RI is usually used to identify the possible chances of rancidity development in oil. A higher value of RI can increase the chance of the oxidation of oil that can cause rancidity. It is the basic value for the degree of unsaturation, chain length of fatty acids and degree of conjugation (Awuchi *et al.,* 2018). According to Table 2, there were significant different of RI values of extracted oils. The highest (1.47) RI value is oil extracted with hexane and ethanol while lowest (1.45) is extracted with acetone.

Due to the large number of different triglycerides, oils and fats do not have exact melting points (Shin & Lee, 2022). Particularly in baked goods, the slip melting point of fats and oils affects the incorporation of air, mouthfeel, rheology, shelf life and other quality criteria. Based on Table 2, the slip melting point (SMP) of extracted oil using acetone as an extraction solvent showed a significant higher compared to those of other extracted oils. SMP could be affected with the differences in carbon number or length of fatty acid (Tian *et al.,* 2024). Therefore, saturated fatty acid with high carbon number will result in a higher melting point which need more heat energy to break the bond between fatty acids (Shin & Lee, 2022). Since saturated fatty acid tend to solidify at higher temperatures, a high SMP indicates a larger percentage of saturated fatty acid in the oil (Sarkar *et al.,* 2015). The cloud point is the temperature when the oils start to become cloudy as the temperature reduce. However, there were not much different between all extracted pili nut oils.

Table 2. Physical properties of pili nut oil using different extraction solvents.

Parameter		Petroleum ether	Hexane	Acetone	Ethanol
Colour	L*	13.27 ± 0.16[c]	9.51 ± 0.03[d]	14.50 ± 0.02[b]	25.92 ± 0.12[a]
	a*	-1.63 ± 0.12[c]	-1.14 ± 0.04[b]	-1.34 ± 0.19[a]	-1.91 ± 0.19[c]
	b*	16.52 ± 0.14[c]	9.38 ± 0.08[d]	18.14 ± 0.12[b]	28.68 ± 0.77[a]
Refractive index		1.46 ± 0.00[b]	1.47 ± 0.00[a]	1.45 ± 0.00[c]	1.47 ± 0.00[a]
Slip melting point (°C)		18.50 ± 0.50[b]	19.17 ± 0.29[b]	24.33 ± 0.58[a]	18.67 ± 1.15[b]
Cloud point (°C)		23.17 ± 0.29[c]	24.27 ± 0.25[bc]	24.27 ± 0.25[ab]	24.83 ± 1.04[a]

Each value in the table represents the mean ± standard deviation of three replicates. Different superscripted letters in the row indicate significant difference ($p<0.05$) between the samples.

Thermal Behaviour Profiles

The heating and cooling thermograms of extracted pili nut oil using different extraction solvents are shown in Figure 1 and Figure 2, respectively. Based on Figure 1, the extracted oil had similar trend in term of heating profiles especially for oil extracted using petroleum ether, hexane and acetone as a solvent. There were two major peaks which were 0.80 ℃ and 5.33 ℃ (petroleum ether), 2.41 ℃ and 6.25 ℃ (hexane), 0.14 ℃ and 4.40 ℃ (acetone) and 1.16 ℃ and 5.74 ℃ (ethanol) with a shoulder peak at 11.77 ℃, 11.35 ℃, 10.50 ℃ and 10.09 ℃, respectively. The end-set of melting point for each solvent was 26.70 ℃ (petroleum ether), 23.50 ℃ (hexane), 26.27 ℃ (acetone) and 24.77 ℃ (ethanol). The trend and temperature in the heating profile of this pili nut oils extracted with different solvent could be affected by the degree of unsaturation of fatty acids (Yanty *et al.,* 2018).

The cooling thermograms of pili nut oils extracted using different extraction solvents are shown in Figure 2. All of oils extracted using different extraction solvents showed similar cooling profiles. The oil samples extracted with hexane had a major peak (at around 2.66 – -0.02 °C) with a shoulder peak at around -0.58 – -11.80 °C. In addition, all oil samples had two minor peaks at around -26.49 – -33.49 °C and -45.18 – -55.45 °C. The oil extracted using hexane had the highest (4.49 °C) and acetone had the lowest (3.81 °C) onset temperatures. The oil extracted using hexane had the highest (-55.45 °C) and acetone had the lowest (-45.16 °C) endset temperatures. These findings could be caused by the concentration of the triacylglycerol molecules which crystallise at higher temperature regions and thus show a slightly different at the onset point of crystallisation. In addition, the major peak in the cooling curve associated with solidification of major triacylglycerol (Van Wetten *et al.,* 2014).

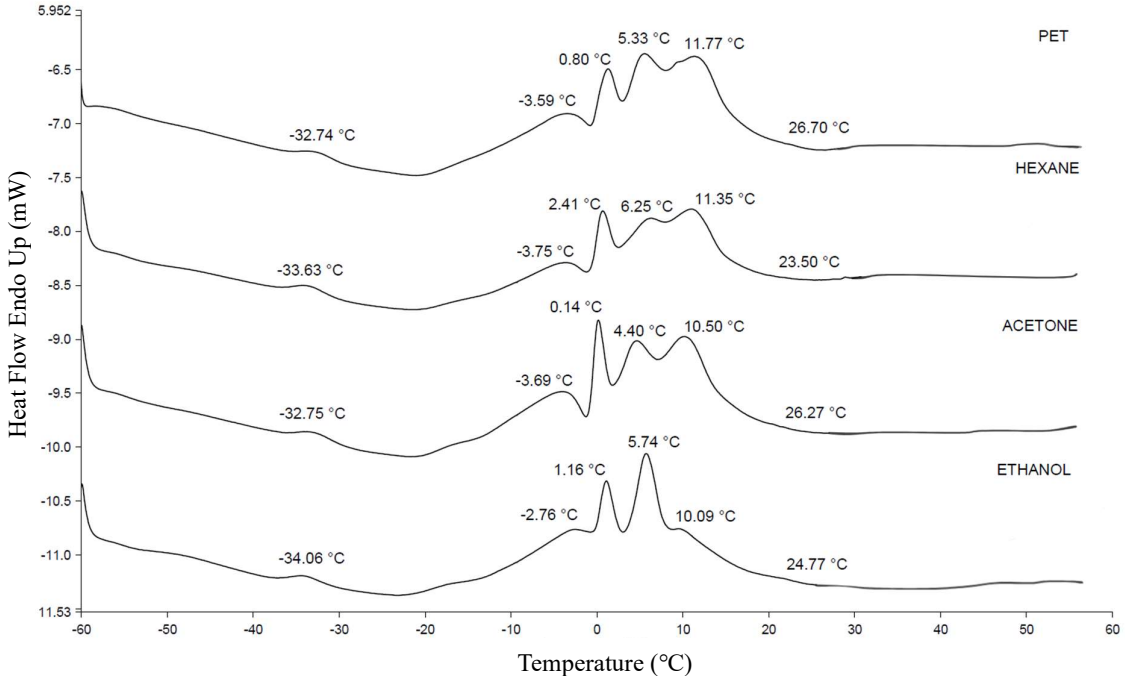

Figure 1. Heating thermogram of pili nut oils extracted with different extraction solvents PET: Petroleum ether.

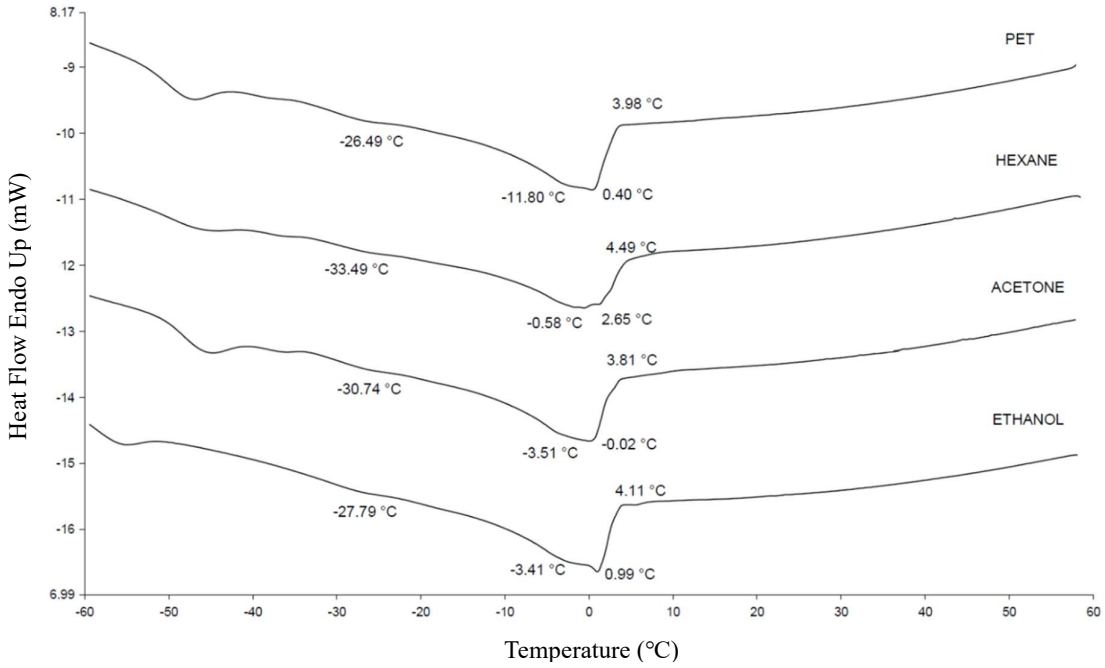

Figure 2. Cooling thermogram of pili nut oils extracted with different extraction solvents PET: Petroleum ether

Chemical Properties of Oils

The chemical properties of pili nut oil extracted using different solvents are shown in Table 3. Iodine value (IV) is the measurement of the total unsaturated fatty acid present in edible oils. This analysis is important to predict whether the oils have high unsaturated or saturated lipids which is important to human health (Pulassery *et al.,* 2022).

The IV of extracted pili nut oils showed a significant different between all extraction solvents which petroleum ether had the highest IV. It might be due to higher unsaturated fatty acid content obtained through extraction using petroleum ether as compared to other oil samples. It is reported that oils with high iodine value was more prone to oxidation (Norazlina *et al.,* 2021).

Free fatty acid (FFA) is widely recognized as a highly important component and is associated with both the commercial value and quality of edible oils. In general, oils and fats are hydrolysed in order to produce free fatty acids (Mahesar *et al.,* 2014). The pili nut oil extracted using petroleum ether had the highest FFA (1.46%) than those of other oil samples. However, there was no significant different between pili nut oil extracted using acetone, hexane and ethanol. In the food industry, frying oil with FFA more than 2% are either thrown away or replace with fresh oil to reduce the content of FFA (Dunford, 2016). Therefore, FFA of all extracted oils were in the range.

Table 3 shows the peroxide value (PV) of pili nut oil using different extraction solvents. PV is an indicator to oxidation of oil. The result showed that the PV of pili nut oil extracted using ethanol (0.91 meq O_2/kg) had the lowest value as compared to other extraction solvents. Peroxide value less than 10 meq O_2/kg indicate that the oil is in a good quality while the value between 30 and 40 meq O_2/kg indicates that the oil is rancid. In this study, all oil samples were in a good quality (below 10 meq O_2/kg).

p-Anisidine value (p-AV) measures the secondary oxidation of the oils by determining the amount of aldehyde in animal fats and vegetable oils. PV is highly related to p-AV to assess the rancidity of the oil (Abdulkarim *et al.,* 2007). Extracted pili nut oil using ethanol as extracted solvent (4.00 meq O_2/kg) showed the highest p-AV while petroleum ether (1.24 meq O_2/kg) showed the lowest p-AV among all

extraction solvents (Table 3). The p-AV should be less than 10 meq O_2/kg for indication of good quality oil (Tesfaye *et al.,* 2017). All samples of the pili nut oil in this study showed lower values than 10 meq O_2/kg which indicate it is a good quality of oil. Totox value is directly related to the PV and p-AV, indicating the lipid's primary and secondary oxidation. Totox value of pili nut oils showed no significant different between extraction solvents used.

Carotene content (expressed as β-carotene) is an important source of pro-vitamin A and it is a micronutrient antioxidant regulating vital metabolism in our body (Tesfaye *et al.,* 2017). According to Table 3, the oil sample extracted using petroleum ether (109.51 ppm) showed the highest value of carotene content while oil samples extracted using acetone showed the lowest value (61.25 ppm) of carotene content. Manaf *et al.* (2024) reported that the carotene content of pili nut oil extracted using petroleum ether had a lower value (66.22 ppm) as compared to this study. According to Ignaczak *et al.* (2023), polyunsaturated fatty acid is positively related to the concentration of carotene. However, the present research showed a higher carotene value than the past research reported by Manaf *et al.* (2024), even though the same method and extraction solvent used. This may be due to the increased susceptibility of the oil to lipid peroxidation, as the conjugated double bonds of polyunsaturated fatty acids readily undergo reactions with free radicals, particularly peroxyl radicals, resulting in a higher oxidation rate compared to oils extracted with other solvents (Mordi *et al.,* 2020).

Table 3. Chemical properties of pili nut oil using different extraction solvents.

Parameter	Petroleum Ether	Hexane	Acetone	Ethanol
Iodine value (g I_2/100 g)	96.44 ± 0.00^{a}	59.48 ± 0.96^{c}	67.91 ± 0.62^{b}	61.74 ± 1.33^{c}
Free fatty acid (%)	1.46 ± 0.29^{a}	0.69 ± 0.03^{b}	0.52 ± 0.26^{b}	0.66 ± 0.04^{b}
Peroxide value (meq O_2/kg)	2.53 ± 0.23^{a}	2.24 ± 0.43^{a}	2.07 ± 0.23^{a}	0.91 ± 0.15^{b}
p-Anisidine value (meq O_2/kg)	1.24 ± 0.22^{d}	2.88 ± 0.02^{c}	2.38 ± 0.02^{b}	4.00 ± 0.29^{a}
Totox value	6.31 ± 0.53^{ab}	7.37 ± 0.87^{a}	6.51 ± 0.44^{ab}	5.83 ± 0.15^{b}
Carotene (ppm as β-carotene)	109.51 ± 0.00^{a}	101.18 ± 0.00^{b}	61.25 ± 0.00^{d}	96.64 ± 0.00^{c}

Each value in the table represents the mean ± standard deviation of three replicates. Different superscripted letters in the row indicate significant difference ($p<0.05$) between the samples.

Fatty Acid Composition

The fatty acid composition of pili nut oil extracted using different extraction solvents are shown in Table 4. According to Table 4, all extracted oils had eleven fatty acids from C12 to C20. The fatty acids of pili nut oils were lauric (ranging from 0.03 – 0.05 %), myristic (ranging from 0.03 – 0.04%), followed by palmitic (ranging from 30.10 – 30.87%), palmitoleic (ranging from 0.39 – 0.43%), margaric (ranging from 0.12 – 0.13%), stearic (ranging from 7.92 – 9.13%), oleic (ranging from 51.18 – 51.44%), linoleic (ranging from 7.85 – 8.63%), linolenic (ranging from 0.54 – 0.69%), arachidic (ranging from 0.22 – 0.23%) and eicosenoic (ranging from 0.11 – 0.15%) acids. The oil with the highest (40.25%) saturated content was obtained through acetone extraction.

The result was agreeable with the highest SMP (Table 2) value of this oil. The ratio of saturated and unsaturated fatty acids among all oil samples were approximately 1:1. Therefore, these oils were a semi-solid state at room temperature (25 °C). This result was comparable to fatty acid composition of pili nut oil extracted with petroleum ether and palm oil which had a

ratio of 1:1 on its saturated and unsaturated fatty acids (Marikkar *et al.,* 2018; Manaf *et al.,* 2024). Therefore, the pili nut oil has the potential to become a palm oil substitute for commercial uses. In addition, pili nut oil also has the potential to undergo fractionation process due to ratio of saturated and unsaturated (1:1) fatty acids. The olein part can be used for liquid or cooking purposes and the stearin part can be used for shortening production.

Triacylglycerol Composition

The triacylglycerol composition of pili nut oil extracted using different extraction solvents is shown in Table 5. According to Table 5, the dominant triacylglycerol compositions of pili nut oil extracted using different extraction solvents were POO (ranging from 29.42 – 28.54%), PPO (ranging from 18.65 – 17.62%) and OOO (ranging from (11.99 – 9.00%). According to Adin *et al.* (2024), pili nut oil extracted from mechanical press extraction also contained POO (28.01%) and PPO (20.58%) as the major triacylglycerol molecules. Among all extraction solvent used, pili nut oil extracted using acetone contained the highest amount of PPO (18.65%) and the lowest amount of PPO (12.57%) was found in the oil extracted using hexane. The triacylglycerol composition is mainly related to fatty acid composition as the triacylglycerol is formed from several fatty acids. Therefore, the predominant TAG in pili nut oil was formed from the major fatty acids which were oleic and palmitic acid (Table 4). As mentioned earlier, the oil extracted using acetone contained more saturated fatty acid which was palmitic acids (Table 4) as the most dominant and higher SMP (Table 2) compared to those of other extraction solvents.

Table 4. The fatty acid composition of pili nut oil extracted using different solvents.

Fatty acid	Petroleum Ether	Hexane	Acetone	Ethanol
Lauric acid (C12:0)	0.04±0.00^{c}	0.05±0.00^{a}	0.03±0.00^{d}	0.04±0.00^{b}
Myristic acid (C14:0)	0.03±0.00^{c}	0.04±0.00^{b}	0.04±0.00^{a}	0.04±0.00^{a}
Palmitic acid (C16:0)	30.10±0.00^{d}	30.37±0.00^{b}	30.87±0.01^{a}	30.19±0.05^{c}
Palmitoleic acid (C16:1)	0.39±0.00^{c}	0.39±0.00^{c}	0.40±0.00^{b}	0.43±0.00^{a}
Margaric acid (C17:0)	0.13±0.00^{a}	0.12±0.00^{b}	0.12±0.00^{b}	0.13±0.00^{ab}
Stearic acid (C18:0	9.13±0.00^{a}	9.05±0.00^{b}	8.95±0.01^{c}	7.92±0.01^{d}
Oleic acid (C18:1)	51.40±0.00^{b}	51.18±0.00^{c}	50.20±0.02^{d}	51.44±0.00^{a}
Linoleic acid (C18:2)	7.85±0.00^{d}	7.96±0.00^{c}	8.49±0.01^{b}	8.63±0.00^{a}
Linolenic acid(C18:3)	0.55±0.00^{c}	0.56±0.00^{b}	0.54±0.00^{d}	0.69±0.00^{a}
Arachidic acid (C20:0)	0.23±0.00^{a}	0.23±0.00^{a}	0.22±0.00^{b}	0.22±0.00^{b}
Eicosenoic acid (C20:1)	0.14±0.00^{b}	0.15±0.00^{a}	0.13±0.00^{c}	0.11±0.00^{d}
Saturated fatty acid	39.67±0.00^{c}	39.86±0.00^{b}	40.25±0.02^{a}	38.54±0.05^{d}
Unsaturated fatty acid	60.34±0.00^{b}	60.24±0.00^{c}	59.76±0.02^{d}	61.30±0.00^{a}

Each value in the table represents the mean ± standard deviation of three replicates. Different superscripted letters in the row indicate significant difference ($p<0.05$) between the samples.

Table 5. Triacylglycerol (TAG) composition of pili nut oil extracted using different extraction solvents.

	Percentage (%)			
TAG	Petroleum Ether	Hexane	Acetone	Ethanol
LnLnL	1.20±0.56^{a}	2.87±2.00^{a}	1.90±0.03^{a}	1.40±0.66^{a}
LnLL	0.93±0.09^{a}	2.24±1.67^{a}	0.57±0.16^{a}	0.61±0.19^{a}
LLL	0.74±0.00 ^{a}	4.40±3.93^{a}	0.65±0.04^{a}	1.32±0.30^{a}
PLnL	0.46±0.00^{a}	2.80±3.10^{a}	0.43±0.03^{a}	0.83±0.33^{a}
OLL	1.29±0.01^{a}	3.82±2.34^{a}	0.79±0.21^{a}	1.39±0.28^{a}
PLL	2.53±0.01^{a}	4.52±2.28^{a}	2.43±0.18^{a}	2.82±0.30^{a}
OOL	3.36±0.07^{ab}	4.90±1.57^{a}	2.73±0.06^{b}	3.27±0.41^{ab}
POL	7.59±0.12^{a}	6.33±0.29^{b}	6.44±0.07^{b}	6.31±0.20^{b}
PPL	4.48±0.02^{ab}	6.07±1.24^{a}	4.11±0.01^{b}	4.32±0.13^{b}
OOO	11.29±0.21^{ab}	9.00±2.09^{b}	11.65±0.11^{ab}	11.99±0.45^{a}
POO	28.54±0.32^{a}	14.66±9.20^{b}	29.42±0.30^{a}	26.01±2.08^{ab}
PPO	17.62±0.02^{b}	12.57±4.19^{c}	18.65±0.12^{a}	17.52±1.31^{b}
PPP	0.47±0.03^{a}	0.91±0.70^{a}	0.47±0.02^{a}	0.29±0.13^{a}
OOS	7.73±0.06^{a}	8.31±1.29^{a}	7.75±0.01^{a}	8.17±0.46^{a}
POS	8.75±0.08^{a}	9.77±2.42^{a}	8.90±0.01^{a}	9.55±0.64^{a}
PPS	0.38±0.01^{a}	0.58±0.23^{a}	0.40±0.06^{a}	0.45±0.56^{a}
SSO	1.61±0.01^{b}	3.28±0.57^{a}	1.60±0.08^{b}	1.59±0.52^{b}
Unknown	1.03±0.00^{b}	4.94±2.84^{a}	1.10±0.08^{b}	1.84±1.19^{ab}

O: oleic; P: palmitic; S: stearic; L: linoleic; Ln: linolenic. Each value in the table represents the mean ± standard deviation of three replicates. Different superscripted letters in the row indicate significant difference ($p<0.05$) between the samples.

CONCLUSION

Pili nut oil (*Canarium ovatum*) may become a new potential source of edible oil that is rich in oleic and palmitic acids. Petroleum ether and hexane were the most suitable extraction solvents due to high oil yield (~70%) obtained from this study. The extracted oils were semisolid form in room temperature (25 °C) but they had different SMP values. The oil extracted using petroleum ether had the lowest SMP value, which contained the lowest amount of saturated fatty acid (palmitic acid) and the highest source of β-carotene. Therefore, this study concluded that extraction of pili nut oil using a petroleum ether as an extraction solvent was the best in terms of the quality.

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REFERENCES

Abdulkarim, S.M., Long, K., Lai, O.M., Muhammad, S.K.S. & Ghazali, H.M. (2007). Frying quality and stability of high-oleic *Moringa oleifera* seed oil in comparison with other vegetable oils. *Food Chemistry*, 105(4): 1382–1389. DOI: 10.1016/j.foodchem.2007.05.013.

Adin, A., Gawai, A.A., Josli, I.C., Nakolas, L., Amin, A.A., Linton, J., Azmi, N.H., Yin, F.H., Arshad, S., Nusantoro, B.P., Wasoh, H. & Manaf, Y.N.A. (2024). Physicochemical and quality characteristics of pili (*Canarium ovatum*) nut oil obtained from mechanical press extraction. *Transactions on Science and Technology*, 11(4-2): 1–6.

Association of Official Analytical Chemists (AOAC). (2023). *Official Methods of Analysis*. 22nd Edition. Rockville, United State of America.

The American Oil Chemists' Society (AOCS). (2000). *Official Methods and Recommended Practices of the American Oil Chemists' Society.* Champaign, United State of America.

Awuchi, C.G., Ikechukwu, A.O. & Gonzaga, A. (2018). Effects of repeated deep frying on refractive index and peroxide value of selected vegetable oils. *International Journal of Advanced Academic Research*, 4(4): 106–116.

Dunford, N.T. (2016). *Edible Oil Quality. Robert M. Kerr Food & Agricultural Products Center Food Technology Fact Sheet 405-744-6071*.

https://extension.okstate.edu/factsheets/edible-oil-quality.html. Downloaded on 1 May 2025.

Ignaczak, A., Salamon, A., Kowalska, J., Marzec, A. & Kowalska, H. (2023). Influence of pre-treatment and drying methods on the quality of dried carrot properties as snacks. *Molecules,* 28(17): 6407. DOI: 10.3390/molecules28176407.

Isaac, I.O., Enengedi, I.S. & Abdulazeez, I.A. (2023). Quality assessment of *Vitellaria paradoxa* seed oil obtained under different extraction conditions and solvents. *Sustainable Chemistry and Pharmacy,* 35: 101–176. DOI: 10.2139/ssrn.4446435.

Kakuda, Y., Jahaniaval, F., Marcone, M.F., Montevirgen, L., Montevirgen, Q. & Umali, J. (2000). Characterization of pili nut *(Canarium ovatum)* oil: Fatty acid and triacylglycerol composition and physicochemical properties. *Journal of The American Oil Chemists' Society,* 77(9): 991–997. DOI: 10.1007/s11746-000-0156-8.

Keneni, Y.G., Bahiru, L.A. & Marchetti, J.M. (2020). Effects of different extraction solvents on oil extracted from jatropha seeds and the potential of seed residues as a heat provider. *Bioenergy Research,* 14: 1207–1222. DOI: 10.1007/s12155-020-10217-5.

López-Bascón, M.A. & Luque De Castro, M.D. (2020). *Soxhlet Extraction.* In Poole, C.F. (eds.) *Liquid-Phase Extraction*. Spain, Elsevier. pp. 327–354).

Mahesar, S.A., Sherazi, S.T.H., Khaskheli, A.R., Kandhro, A.A. & Uddin, S. (2014). Analytical approaches for the assessment of free fatty acids in oils and fats. *Analytics Methods,* 6(14): 4956–4963. DOI: 10.1039/c4ay00344f.

Manaf, A., Lin, C.Y., Josli, I.C., Tananak, J., Adin, A., Amin, A.A., Kadir, A., Siew, C.K., Lee, J.S., Muhamad, H.R. & Nusantoro, B.P. (2024). Physicochemical properties of pili *(Canarium ovatum)* nut oil from Sabah, Malaysia. *Transactions on Science and Technology,* 11(4): 228–234.

Marikkar, J.M.M., Yanty, N.A.M., Paciulli, M., Miskandar, M.S. & Chiavaro, E. (2018). Composition and thermal properties of quaternary mixtures of palm oil:palm stearin:soybean oil:cocoa butter. *Italian Journal of Food Science,* 30(4): 740–751.

Millena, C.G. & Sagum, R.S. (2018). Physicochemical characterization and fatty acid profiling of different Philippine pili nut (*Canarium ovatum*) varieties. *Journal of American Oil Chemist Society,* 95: 325–336. DOI: 10.1002/aocs.12028.

Millena, C.G., Baloloy, K.A., Doma, N.G. & Hernan, P.B. (2023). Effect of maturity on physicochemical and fatty acid profile of Philippine pili (*Canarium ovatum*). *Philippine Journal of Science*, 152(1): 159–171. DOI:10.56899/152.01.11.

Mordi, R.C., Ademosun, O.T., Ajanaku, C.O., Olanrewaju, I.O. & Walton, J.C. (2020). Free radical mediated oxidative degradation of carotenes and xanthophylls. *Molecules*, 25(5): 1038. DOI: 10.3390/molecules25051038.

Norazlina, M.R., Tan, Y.S., Hasmadi, M. & Jahurul, M.H.A. (2021). Effect of solvent pre-treatment on the physicochemical, thermal profiles and morphological behavior of *Mangifera pajang* seed fat. *Heliyon*, 7(9): 1–6. DOI: 10.1016/j.heliyon.2021.e08073.

Palm Oil Research Institute of Malaysia (PORIM). (1995). *Methods of Test for Palm Oil and Palm Oil Product.* Bangi, Malaysia.

Pham, L.J. & Dumandan, N.G. (2015). Philippine Pili: Composition of the lipid molecular species. *Journal of Ethnic Foods,* 2(4): 147–153. DOI: 10.1016/j.jef.2015.11.001.

Pulassery, S., Abraham, B., Ajikumar, N., Munnilath, A. & Yoosaf, K. (2022). Rapid iodine value estimation using a handheld Raman spectrometer for on-site, reagent-free authentication of edible oils. *ACS Omega,* 7(11): 9164–9171. DOI: 10.1021/acsomega.1c05123.

Sarkar, A., Pandey, J.P., Singh, A., Tiwari, L. & Kumar, A. (2015). Novel method of using refractive index as a tool for finding the quality of aqueous enzymatic extracted algae oil. *Advances in Applied Science Research,* 6(4): 50–60.

Shin, K.S. & Lee, J.H. (2022). Melting, crystallization, and in vitro digestion properties of fats containing stearoyl-rich triacylglycerols. *Molecules,* 27(1), 191. DOI: 10.3390/molecules27010191.

Tesfaye, B., Abebaw, A. & Reddy, M.U. (2017). Determination of cholesterol and β- carotene content in some selected edible oils. *International Journal of Innovative Science and Research Technology*, 2(7): 14–17.

Tian, W., Yan, X., Zeng, Z., Xia, J., Zhao, J., Zeng, G., Yu, P, Wen, X. & Gong, D. (2024). Enzymatic interesterification improves the lipid composition, physicochemical properties and rheological behavior of *Cinnamomum camphora* seed oil, *Pangasius bocourti* stearin and perilla seed oil blends. *Food Chemistry,* 430: 137026. DOI: 10.1016/j.foodchem.2023.137026.

Van Wetten, I. A., Van Herwaarden, A. W., Splinter, R., & Van Ruth, S. M. (2014). Oil Analysis by FastDSC. *Procedia Engineering*, 87: 280–283. DOI: 10.1016/j.proeng.2014.11.662.

Wang, Y., Su, Y., Shehzad, Q., Yu, L., Tian, A., Wang, S., Ma, L., Zheng, L. & Xu, L. (2023). Comparative study on quality characteristics of *Bischofia olycarpa* seed oil by different solvents: Lipid composition, phytochemicals, and antioxidant activity. *Food Chemistry,* 202(17): 100588. DOI: 10.1016/j.fochx.2023.100588.

Yanty, N.A.M., Dollah, S., Marikkar, J.M.N., Miskandar, M.S., Desa, M.N.M. & Nusantoro, B.P. (2018). Physicochemical properties and thermal behavior of binary blends of *Madhuca longifolia* seed fat and palm oil as a lard substitute. *Journal of Advanced Agricultural Technologies,* 5(3): 202–208. DOI: 10.18178/joaat.5.3.202-208.

Yanty, N.A.M., Marikkar, J.M.N. & Shuhaimi, M. (2013). Effect of fractional crystallization on the composition and thermal properties of engkabang *(Shorea macrophylla)* seed fat and cocoa butter. *Grasas Y Aceites,* 64(5): 546–553. DOI: 10.3989/gya.023213.

Yanty, N.A.M., Marikkar, J.M.N., Nusantoro, B.P., Long, K. & Ghazali H.M. (2014) Physicochemical characteristics of papaya (*Carica papaya* L.) seed oil of the Hong Kong/Sekaki variety. *Journal of Oleo Science,* 63(9): 885–892. DOI: .5650/jos.ess13221.

Zarinah, Z., Maaruf, A.G., Nazaruddin, Wong, W.W.W. & Xuebing. (2014). Extraction and determination of physico-chemical characteristics of pili nut oil. *International Food Research Journal*, 21(1): 297-301.