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Characteristics of Mango Seed Kernels and Their Impact on Yield and Quality of Oil from Soxhlet Extraction Process

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ABSTRACT

Mango seed kernels (MSKs), a significant source of food waste, contain beneficial constituents such as oil and bioactive compounds. Due to this, their valorization has been explored as a method of waste management through resource recovery. However, research on the potential of Harumanis MSK as feedstock to produce oil remains underexplored. Hence, this study aims to evaluate the characteristics of the Harumanis MSK and its impact on yield and quality of oil produced, in comparison with other type of MSK, the Thai Milk MSK. Proximate analysis showed that Harumanis MSK contains higher moisture, volatile matter and ash content whereas Thai Milk MSK contains higher fixed carbon. Soxhlet extraction of both MSKs using *n*-hexane as solvent at various time of 60 – 180 min revealed that oil yield obtained for both MSKs is within 5 – 14 wt.%, with 180 min as the most suitable extraction duration, to yield Harumanis and Thai Milk MSKs oil of 11.03 and 14.48 wt.%, respectively. Fourier-Transform Infrared (FTIR) analysis confirmed the presence of saturated triglycerides in both oils with Harumanis MSK oil exhibiting a higher concentration. Further analysis suggested that minimal thermal degradation occurred during extraction, indicating the oils produced are of good quality and thermally stable. This study highlights that both MSKs serve as viable sources for oil production, with Thai Milk MSK presents a better feedstock for higher oil yield while Harumanis MSK offers superior oil quality due to its higher content of saturated triglyceride. These findings underscore the potential of mango seed valorization as an effective strategy for sustainable waste management.

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INTRODUCTION

Statistically, 15 – 20% of 931 million tonnes of food waste is from fruit and vegetables, including their peels, seeds, rinds, etc. (FAO, 2023). According to Chew et al. (2017), these fruit wastes contain a variety of renewable and sustainable resources, such as oil and bioactive compounds. Utilizing this waste as a beneficial substance will help in managing uncontrollable amounts of food waste. Mango (*Mangifera indica* L.) is one of a high nutritional valued fruit that is commercially available, with India supplying approximately 55% of the total global crop (Lebaka et al., 2021). In Malaysia, Harumanis mango is considered one of the most profit-oriented cultivars among the mango varieties grown (Muhamad Hassan et al., 2019). As a significant tropical fruit, it was forecasted that mango processing could reach USD 1.8 billion in 2029 (Swetha et al., 2026). As the fruit is processed, a huge amount of mango peel and seed kernels are generated (Choudhary et al., 2026), with Baruah et al. (2026) reported that more than a million tons of mango seeds produced yearly. However, Mohamad et al. (2022) reported that these peel and kernels are usually discarded, contributing to environmental pollution. Chemical composition of MSK highlighted its high carbohydrate content (Anggraini et al., 2023). Lebaka et al. (2021) emphasized that MSK contains high amounts of carbohydrates (58 – 80% starch with 21% in pure form), protein, and lipids (8.15 – 13.16% oil), while Abdelaziz (2018) reported that MSKs and their oil are composed of carbohydrates, lipids, and protein. With beneficial content of bioactive compounds such as phenolic compounds, vitamin C and carotenoids in MSK extract, this low-cost mango by product has continued exhibiting its significance in pharmaceutical and cosmeceutical field (Baruah et al., 2026).

Several methods have been applied to extract oil from the MSK with Soxhlet extraction being one of the most widely used. Recent work by Labbassi et al. (2026) also highlights that Soxhlet extraction is better than ultra-assisted extraction (UAE) to recover oil from *Moringa oleifera* seeds. With its simplicity, this technique has been proven to perform better than other traditional extraction methods, yielding higher oil recovery for MSK oil (Kittiphoom & Sutasinee, 2013; Agu et al., 2021). Studies by Fahimdanesh and Bahrami (2013) and Sani (2013) utilized the Soxhlet extraction method to extract oil from MSK and obtained 12.5% and 8.27% of oil, respectively, with Mokbul et al. (2022) reported oil yields ranging from 6.59 - 9.65%. Optimized condition by Ohale et al. (2022) produced 13.62 – 16.1% oil from Soxhlet extraction of Nigerian MSK while that of Fajriyati et al (2025) yielded MSKO of 14.52% from Indonesian MSK.

Several studies have reported that hexane is the most effective solvent for Soxhlet extraction, followed by petroleum ether and ethanol to extract oil from MSK. Nwaokobia et al. (2018) found that hexane produced a greater yield than ethanol at various extraction periods, with an average of 4 – 13.06% and 1.99 – 8.22%, respectively. This is because hexane is a relatively non-polar solvent that readily extracts the non-polar mango oil. On the contrary, ethanol, which contains both polar and non-polar components, does not extract as much oil, since it does not mix well with non-polar solutes. A work by Jinoni et al. (2023) highlighted that hexane may have superior solubility for the target chemicals in *Phaleria macrocarpa* seeds, resulting in increased extraction efficiency. Recently, Assaf et al. (2025) reported the highest oil yield (30.6%) from papaya seed using n-hexane, while Ndoye et al. (2026) used n-hexane to macerate four varieties of MSK to yield 7.1 – 7.5% of oil. Additionally, oil extracted using hexane also has a higher overall quality, as observed by Hrushikesh and Diamond (2022), who reported that oil extracted with n-hexane has higher quality than petroleum ether by using the cold extraction method. Similarly, Awolu and Monahar (2019) emphasized that n-hexane-derived oil exhibited superior quality, with Benchawan et al. (2025) added that n-hexane oil from MSK is found to be not rancid and of good quality to be used as natural antioxidant in cosmetic products.

Regarding extraction duration, Awolu and Monahar (2019) reported that the process typically takes 3, 4, and 5 hours, with Awolu et al. (2013) observing that oil yield begins to reduce after 2 hours. Although this method requires prolonged operational time, consuming large solvent volumes, and demands time and

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energy during solvent evaporation, it remains a preferred method due to its cost-effectiveness and ability to yield higher amounts of lipids compared to alternative extraction techniques (Hirondart et al., 2020; Scherer et al., 2024)

Based on the literature, there is a lack of studies focusing on the valorization of Harumanis MSK. Thus, this study could explain a conventional and economical method to reduce agricultural waste by turning Harumanis mango by-products into a useful product like oil. In this study, the characteristics of Harumanis MSK and its impact on the quantity and quality of the oil produced were investigated. The results obtained were then compared with another type of MSK, the Thai Milk MSK.

METHODOLOGY

Chemicals and instrumentation

Table 1 shows the chemicals, apparatus, and instruments that were used in this study.

Table 1. List of chemicals, apparatus, and instruments used in this study

Chemical/apparatus/instrument	Usage
n-hexane	Solvent for Soxhlet extraction
Soxhlet extraction set up	Extraction apparatus to extract oil from MSKs
FTIR spectrophotometer	Functional group analysis of MSK oil

Sample collection and preparation

The dried Harumanis MSKs were provided by local cultivators of Athanliz Innovations Sdn. Bhd., while Thai Milk MSKs were obtained from a local market in UiTM Perlis, Arau. The collected sample of MSKs was thoroughly cleaned to remove any dirt, dried in the oven at 65 °C (Aremu et al., 2022) for 48 hours to remove moisture, and manually crushed before being ground using a blender into a powder form. The powdered kernel seeds were kept in air-tight containers before further analysis. Figure 1 shows the powdered Harumanis and Thai Milk MSKs.

a) b)

Fig. 1. Powdered a) Harumanis MSK and b) Thai Milk MSK.

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Proximate analysis of MSK

Moisture content refers to the amount of water present in the MSKs (Efthymiopoulos et al., 2019) and was calculated based on the initial and final weights of the sample, assuming that all weight loss is due to the removal of water and ignoring the loss of other volatiles (Zambrano et al., 2019). To determine the moisture content, the petri dish was washed and dried in the oven at 105 °C for 30 minutes. It was then cooled in a desiccator and weighed empty. The powdered MSKs were individually weighed into the petri dish and dried in the oven at 105 °C for 24 hours. Following that, the petri dish was then placed into a desiccator to be cooled and weighed (Ogbuagu et al., 2021). The percentage of moisture content was calculated using Equation 1:

$$\text{Moisture content (wt. \%)} = \frac{W_1\text{-}W_2}{W_3} \times 100 \tag{1}$$

Where,

W_1= weight of petri dish and sample before drying.

W_2= weight of petri dish and sample after drying.

W_3= weight of sample.

Volatile matter is defined as all substances that can be vaporized at high temperature, such as water and gases. To determine the volatile matter, 1.5 g of moisture-free MSKs powder was weighed, transferred to a crucible, and placed in the muffle furnace for 8 minutes at a temperature of 550 °C (Inegbedion, 2022). The sample was then weighed again after cooling in a desiccator. The percentage of volatile matter was calculated using Equation 2:

$$\text{Volatile matter (wt. \%)} = \frac{W_1 - W_2}{W_1} \times 100 \tag{2}$$

Where,

W_1 = weight of oven-dried sample.

W_2 = weight of sample after 8 minutes in the furnace.

Ash content represents the inorganic residue remaining after combustion of MSKs (Inegbedion, 2022). To determine the ash content, the powdered MSKs were individually placed in a crucible and weighed. It was then placed in a muffle furnace at 500 °C for 3 hours or until a whitish grey ash is obtained. Finally, the crucible was stored in a desiccator until cooled and weighed again (Ogbuagu et al., 2021). The percentage of ash content was calculated using Equation 3:

$$\text{Ash content (wt. \%)} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \tag{3}$$

Where,

W_1 = weight of empty crucible.

W_2 = weight of crucible and sample before drying.

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W_3 = weight of crucible and ash.

Fixed carbon is the portion of the material that remains in MSKs after subtracting moisture, volatile matter, and ash content from total mass (Inegbedion, 2022). It represents the solid carbon content, which is a primary source of energy in combustion processes. The value of fixed carbon was calculated using Equation 4 (Nwaokobia et al., 2018):

$$\text{Fixed carbon (wt. \%)} = 100 - (\text{wt.\% moisture} + \text{wt.\% volatile matter} + \text{wt.\% ash}) \tag{4}$$

Extraction of oil from MSK

Figure 2 shows the Soxhlet extraction setup for this study. First, the known weight of MSKs was placed into a thimble and then inserted into the extraction chamber of the Soxhlet extractor. A 20:1 ratio of *n*-hexane (mL) to weight of kernel (g) was used for the extraction process. Extraction durations were carried out for 60, 90, 120, 150, and 180 minutes. The maximum extraction time in this study was set to 180 minutes due to a study by Awolu et al. (2013) that reported that the oil yield began to decline after 2 hours.

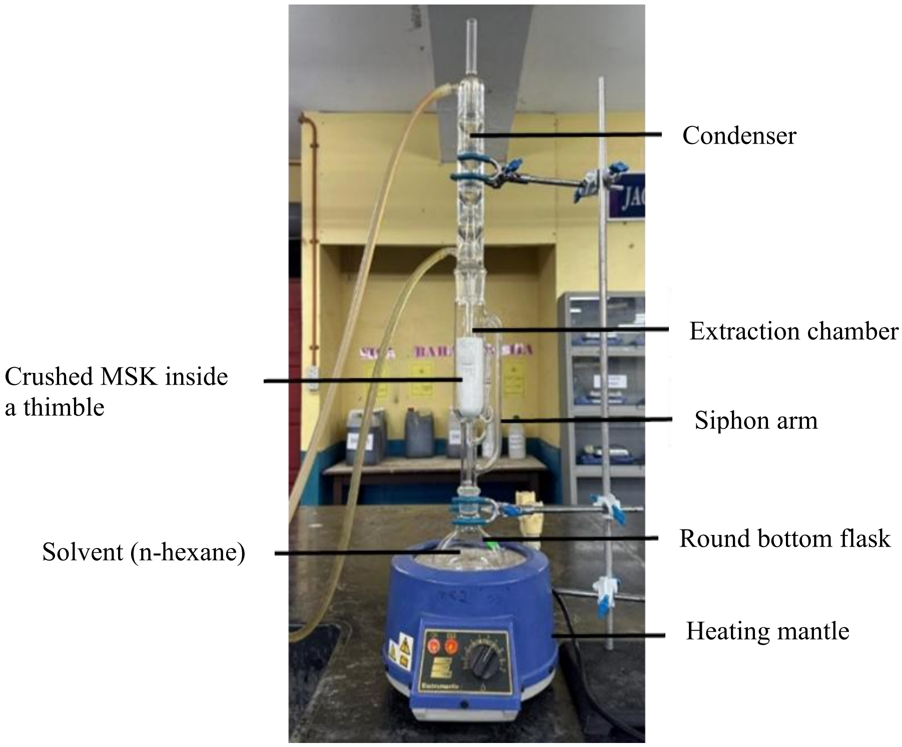

Fig. 2. Soxhlet extraction setup.

Following the extraction process, the residue was dried and weighed. N-hexane was separated from the oil via a rotary evaporator, and the mass of collected oil was weighed (Rashd et al., 2024). The percentage of oil yield was calculated by using Equation 5:

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$$\text{Oil yield (wt. \%)} = \frac{\text{Mass of oil (g)}}{\text{Mass of seed kernel (g)}} \times 100 \tag{5}$$

The highest oil yield obtained from Harumanis and Thai Milk MSKs was used for further analysis. All experimental procedures were carried out in duplicate, and the results are reported as mean values.

Functional group analysis of MSK oil using FTIR spectroscopy

The primary functional groups of Harumanis and Thai Milk MSKs oil were determined by Fourier-Transform Infrared (FTIR) Spectroscopy. The FTIR Spectra were obtained by the attenuated total reflection (ATR) approach using the Perkin Elmer Spectrum model. For this purpose, a drop of MSK oil was placed on top of the diamond ATR crystal plate, which had been disinfected with ethanol solution to remove contaminants (de la Mata et al., 2012). The spectra obtained for all oil samples were then scanned in absorbance mode from 4000 to 600 cm^{-1}.

RESULTS AND DISCUSSION

Proximate analysis of MSK

Table 2 shows the proximate analysis of Harumanis MSK and Thai Milk MSK.

Table 2. Proximate analysis of Harumanis MSK and Thai Milk MSK

Type of MSK	Moisture content (wt.%)	Ash content (wt. %)	Volatile matter (wt. %)	Fixed carbon (wt. %)
Harumanis	8.26	3.36	2.59	84.61
Thai Milk	5.36	2.71	2.87	89.04

Based on Table 2, it was found that both MSKs have good moisture content, which is less than 10%, with Harumanis MSK having a higher moisture content compared to Thai Milk MSK. Martinez et al. (2015) reported that seeds with high moisture content above 10% promotes the hydrolysis of triglycerides, potentially lowering the quality of oil. In addition, low moisture levels in seed kernels indicate that they are stable and less hygroscopic in nature, which may increase their shelf life (Halaldeen et al., 2024). This finding highlights the potential of these MSKs to produce high-quality oil. Previous work by Aremu et al. (2016) found that high moisture content in seeds lowers oil production and expression efficiency. With another similar finding reported by Singh et al. (2019), which stated that as the moisture content in seeds increased, the efficiency of oil extraction decreased, it is expected that Harumanis MSK, with higher moisture content, will produce less oil yield.

In terms of ash content, Harumanis MSK is found to have higher ash than Thai Milk MSK. Umeagukwu et al. (2023) mentioned that a high ash content in seeds reduces the efficiency of oil extraction. Thus, it is expected that Harumanis MSK will have a lower oil yield. Likewise, Supriyanto et al. (2022) also mentioned that low ash in seeds improves the possibility of producing oil yield.

For the analysis of volatile matter, Harumanis MSK was found to have a higher content of volatile components than Thai Milk MSK. According to Hasan et al. (2020), excessive volatile matter in seeds might reduce oil extraction efficiency due to high water content, which acts as a primary volatile compound

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that evaporates during the extraction process. As a result, it is expected that Harumanis MSK will produce less oil yield compared with Thai Milk MSK.

In addition, Harumanis MSK has a lower fixed carbon content compared to Thai Milk MSK. Low fixed carbon in seeds allows solvents to penetrate more easily, thus enhancing oil extraction efficiency (Kumar et al., 2018). Based on the fixed carbon content, Harumanis MSK could yield a higher oil yield than Thai Milk MSK.

Soxhlet extraction of MSK

This section evaluates the oil yield of two types of MSKs in relation to extraction duration. The impact of different extraction durations on oil output from Harumanis and Thai Milk MSKs using Soxhlet extraction is presented in Figure 3.

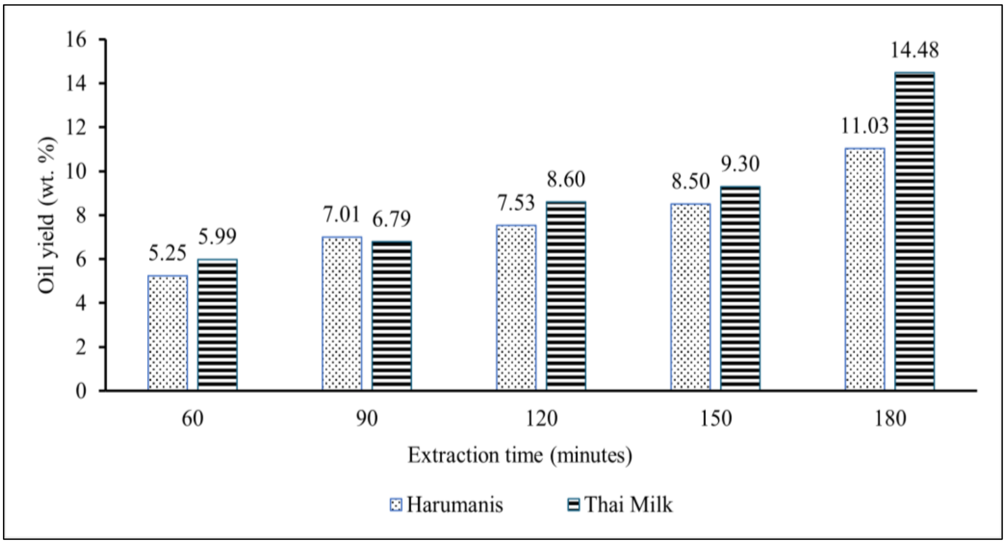

Fig. 3. Effect of extraction time on oil yield from Soxhlet extraction of different MSKs.

Based on the bar graph, the oil yield range extracted from Harumanis MSK was from 5.25 - 11.03 wt.%, while the Thai Milk MSK oil yield obtained was from 5.99 - 14.48 wt.%. These results align with Nwaokobia et al. (2018) findings, noting an average of 4 – 13.06 wt.% of oil yield from the extraction of MSKs. A more recent work by Benchawan et al. (2025) reveals 8.71% oil yield following reflux extraction of Mun Duean Kao MSK using hexane as solvent, indicating good potential for recovering oil from Harumanis and Thai Milk MSKs.

On average, Thai Milk MSK produced a higher oil yield compared to Harumanis MSK. This is anticipated since Thai Milk MSK contains lower moisture, volatile matter, and ash content, which leads to better characteristics for a feedstock to produce high oil yield. On the contrary, Harumanis MSK's high moisture content likely contributes to the formation of emulsions during solvent extraction (Adelola Orhevba & Precious, 2020), while its high ash content leads to more impurities introduced into the oil extraction process, thus lowering oil yield (Zubairu et al., 2024). However, based on the high value of fixed carbon of Thai Milk MSK, it is expected that the oil yield to be lower (Mariyam et al., 2024). Nonetheless,

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in this study, higher fixed carbon in Thai Milk MSK leads to higher oil yield, suggesting that the possibility of oil yield is not directly affected by fixed carbon content. According to Criado et al. (2003), fixed carbon is relatively inert in the context of Soxhlet extraction, causing it to interact less with the solvent. As a result, its presence has no noticeable effect on the efficiency of the oil extraction process.

In terms of extraction duration, the finding showed that Harumanis MSK oil yield increased with an increase in time from 5.25 wt.% at 60 min to 11.03 wt.% at 180 min. Meanwhile, the oil yield from Thai Milk MSKs also showed a positive increment from 5.99 wt.% at 60 min to 14.48 wt.% at 180 min. These results suggest that prolonged extraction duration increased the oil yield of both MSKs, which could be due to the increased solvent exposure of n-hexane to the MSKs (Pichai & Krit, 2015). The most suitable extraction time to obtain the highest oil yield from both MSKs was found to be at 180 min. The oil yield did not decrease after 2 hours of extraction time, as reported previously by Awolu et al. (2013). This suggests that even at prolonged extraction, the oil extracted from Harumanis and Thai Milk MSKs did not undergo thermal degradation that could lead to the formation of various volatile compounds such as aldehydes, ketones, and alcohols (Shahidi & Hossain, 2022).

Functional group analysis of MSK oil

The Fourier-transform infrared spectroscopy (FTIR) analysis was performed on the oil samples of the highest yield obtained from Harumanis MSK (HMSKO) and Thai Milk MSK (TMMSKO). FTIR spectra analysis in Figures 4 and 5 illustrates the chemical profile of oils extracted, offering insights into the structural components, such as triglycerides, which correlate with the quality and possible applications of the oil. The functional groups identified are tabulated in Table 3.

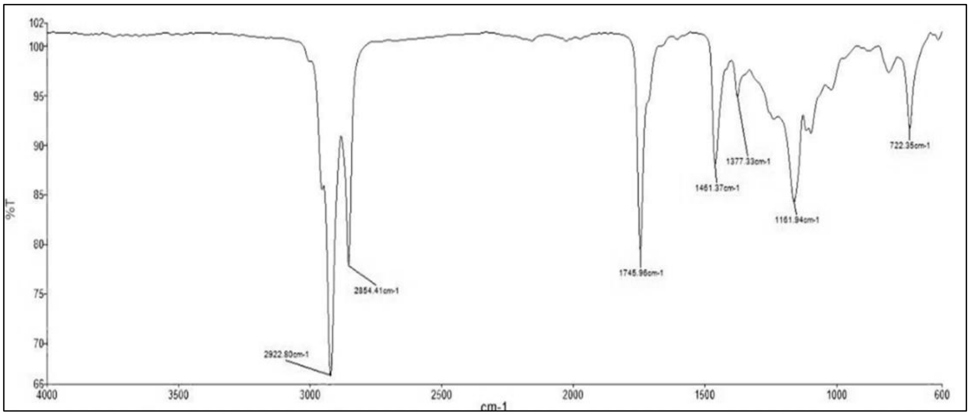

Fig. 4. FTIR spectrum of HMSKO.

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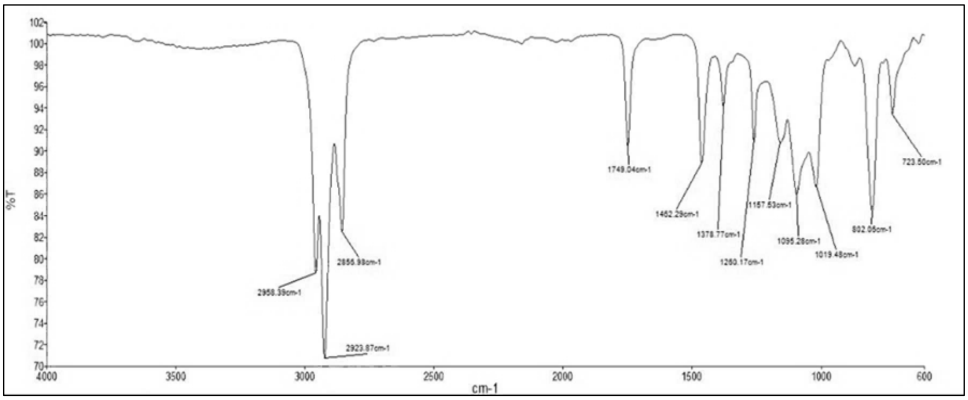

Fig. 5. FTIR spectrum of TMMSKO.

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Table 3. Functional group analysis of MSK oil

Wavenumber (cm^{-1})	Bond	Functional group
2854.7 – 2925.8	C – H (sp^3) stretching	Alkyl
1745 – 1747.5	C = O stretching	Ester
1163.0 – 1236.3	C – O stretching	Ester

The FTIR spectra of the two oil samples extracted with n-hexane using Soxhlet extraction display almost similar patterns. This similarity is anticipated, considering both samples were extracted using the same solvent, likely yielding analogous compositions. The medium peak in HMSKO and TMMSKO that showcases a C–H (sp^3) asymmetric and symmetric stretching vibration of aliphatic CH_2 and CH_3 (Zahir et al., 2014), aligning with the fact that triglyceride is predominantly composed of long-chain hydrocarbons. Other than that, there is a visible peak in HMSKO and TMMSKO, indicating the C=O ester carbonyl of triglycerides. It is noticeable that the peak in TMMSKO is less intense compared to that in HMSKO describing that Harumanis MSK may contain a higher concentration of triglycerides. According to Ekin (2019), a high content of triglyceride could result in superior conversion of biodiesel. In addition, the C–O stretching in both MSK oils further evaluates the composition of triglycerides. Other notable peaks identified in the fingerprint regions like 1461.37, 1377.33, and 722.35 cm^{-1} in HMSKO, and 1462.29, 1260.17, and 723.50 cm^{-1} in TMMSKO could be associated with the C–H bond or specific aromatic ring, similar to findings by Rahman et al. (2024).

Furthermore, the absence of a broad peak of O–H stretching vibration and any significant peak around 1710 cm^{-1} in HMSKO and TMMSKO related to C=O stretching indicates that free fatty acid content in HMSK and TMMSKO is negligible which suggests that no thermal degradation of oil occurred during the extraction process (Zahir, 2014). This finding correlates with the moisture content for both MSKs which are less than 10 wt.%, thereby hydrolysis of triglycerides into free fatty acids is unlikely to happen (Martínez et al., 2015). The absence of free fatty acids in oil is important to maintain the quality by preventing deterioration (Tan et al., 2023). Apart from that, the lack of peak C–H (sp^2) stretching in the 3000 – 3100 cm^{-1} region and C=C stretching of alkene functional groups in the 1640 – 1680 cm^{-1} region illustrates that the oil sample is dominantly composed of saturated triglycerides instead of unsaturated triglycerides (Martín-Cabrejas & Goicoechea-Oses, 2024). It was reported that saturated triglycerides are less prone to oxidation, unlike unsaturated triglycerides which can react easily with oxygen in the presence of heat or light, leading to the formation of various compounds such as hydroperoxides, ketones, aldehydes, and carboxylic acid (Sakaino et al., 2022). This, in turn, results in an increase in acid value that influences the rancidity and off-flavours in oil. Based on these findings, both MSK oil samples indicate excellent quality as it is thermally stable, ideal for prolonged high-heat cooking and could have longer shelf life in terms of tolerance to rancidity (Kittiphoom & Sutasinee, 2013).

CONCLUSIONS

This study analysed the characteristics of MSKs from two mango species, Harumanis and Thai Milk mangoes, focusing on their proximate composition, oil extraction efficiency, and functional group analysis of the extracted oil. Proximate analysis revealed significant differences between the two MSK samples. Harumanis MSK exhibited higher moisture, volatile matter, and ash, whereas Thai Milk MSK had lower moisture but a higher fixed carbon content, suggesting a greater potential for oil extraction. This was confirmed through Soxhlet extraction where the highest oil yields obtained after 180 min were 14.48 wt.% for Thai Milk MSK and 11.03 wt.% for Harumanis MSK. The results indicate that longer extraction duration contributes to the increase of oil yield and the patterns observed underscore the necessity of increasing the extraction length to further determine the maximum oil that could be produced from the

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MSKs. Analysis of functional groups by FTIR spectroscopy identified essential attributes of the extracted oils. Both samples displayed peaks corresponding to triglycerides and aliphatic hydrocarbons, confirming the presence of long-chain fatty acids. Besides, HMSKO displayed an intense peak of C=O ester carbonyl peaks, suggesting triglyceride structures. The absence of peaks corresponding to free fatty acids and unsaturation suggests that both oil samples are predominantly composed of saturated triglycerides, making them suitable for applications such as biodiesel conversion with high oxidative resistance, food, and cosmetics. Future work should include analysis of the oils using Thermogravimetric Analysis (TGA) or Differential Scanning Calorimeter (DSC) to confirm their thermal stability.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts, and declare the absence of conflicting interests with the funders.

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