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RESEARCH ARTICLE

Synergistic ultrasonic-microwave assisted extraction (UMAE) for enhanced fat extraction from nutmeg seeds

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OBJECTIVES Nutmeg seeds contain essential oils and fats, are widely used in the cosmetic and pharmaceutical industries. This research aims to determine the yield, physicochemical characteristics and fat composition of nutmeg seeds extracted from Ultrasonic-Microwave Extraction (UMAE). METHODS The research used a factorial completely randomized design (CRD) method with the independent variables, length of extraction time (45, 90, 135 min) and microwave power (300 and 450 watts). The dependent variables in this research are yield, melting point, specific gravity, acid number and saponification number. RESULTS The results showed that the highest fat yield of nutmeg was 30.48% at 300 Watts and 135 min. The physicochemical characteristic of nutmeg fat was yellow with specific gravity, melting point, acid number and saponification number were 0.96, 52.4 °C, 16.69 mg KOH/g fat and 254.96 mg KOH/gram fat. CONCLUSIONS Gas Chromatography-Mass Spectrometry (GC-MS) results show that the fat composition is trichloromethyl, isopropyl phosphoranidothioic acid and lauric acid triglyceride which have potential as cosmetic raw materials.

KEYWORDS cosmetic ingredients; extraction; fat; nutmeg seeds; UMAE

1. INTRODUCTION

The nutmeg tree (Myristica fragrans) is a plant native to Indonesia that has a lush structure and fruits with high economic value (Jose et al. 2016; Budiastra et al. 2021). Beyond its flavorful seeds, the cultivation of nutmeg plays a crucial role in the local economy, providing livelihoods for many farmers and supporting various related industries. For instance, the nutmeg shell has been utilized as a precursor for activated carbon production due to its high carbon content and porous structure (Elisa et al. 2024). However, our study will explore other functions, such as utilizing nutmeg seeds, which are rich in nutritional and medicinal properties (Okiki et al. 2023), and they have been traditionally used as a spice, serving both as a preservative and an aromatic agent in food preparation (Loizzo et al. 2016). Beyond their culinary uses, nutmeg seeds also play a vital role in traditional medicine, where they are believed to possess various health benefits, including anti-inflammatory and analgesic properties. This wide range of applications underscores the importance of nutmeg in both cultural practices and modern industries.

Nutmeg seeds contain volatile essential oils (±10%) and fixed oils (±25-30%) (Jose et al. 2016), which are widely applied in the cosmetics industry (Aćimović et al. 2022). The high oil content in nutmeg seeds not only enhances their flavor but also makes them a valuable source of natural ingredients in cosmetics and personal care products. These oils contribute to the moisturizing, soothing, and aromatic qualities that are sought after in beauty formulations. As consumers increasingly demand natural and organic products, the cosmetic industry has turned to nutmeg extracts as a sustainable alternative to synthetic ingredients. The versatility of nutmeg seeds highlights the need for effective extraction methods that can maximize the yield of beneficial compounds while preserving their integrity. Traditional methods of nutmeg fat extraction, such as the Soxhlet method, have been widely used, but they have limitations in terms of time efficiency and potential degradation of sensitive compounds due to prolonged heat exposure (Kozłowska et al. 2016). Another established method, the Folch extraction, utilizes chloroform and methanol as solvents, but the use of chloroform is increasingly restricted due to its carcinogenic nature and associated health risks (Ivetich and Gorelkina 2020). These challenges have led to a growing interest in alternative extraction methods that are not only more efficient but also en-

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vironmentally friendly.

Recent advancements in extraction technologies have introduced techniques such as ultrasonic extraction, microwave-assisted extraction (MAE), and their combined form, ultrasonic-microwave-assisted extraction (UMAE). The ultrasonic method improves mass transfer by breaking down plant cell walls and enhancing solvent penetration, leading to increased extraction efficiency (Samaram et al. 2014). Studies have shown that ultrasonic extraction can produce higher yields compared to traditional methods, making it an attractive alternative for industrial applications, especially in the cosmetic and pharmaceutical industries (Morsy 2016). Microwave-assisted extraction (MAE) offers the advantage of low energy consumption and short extraction times while effectively increasing the yield of active compounds, such as phenolic substances (Aćimović et al. 2022; Hossain et al. 2023; Shintawati et al. 2022). Furthermore, the UMAE technique, which combines ultrasonic pretreatment with microwave-assisted extraction, has demonstrated the highest yield of non-volatile oil (29%) from nutmeg seeds, aligning with "Green Chemistry" principles by reducing extraction time and the need for harmful solvents (Savic Gajic and Savic 2023; Ramandani et al. 2022).

Choosing the appropriate extraction method is critical, as it impacts both the efficiency of the process and the quality of the extracted compounds. This research aims to explore the UMAE method for extracting nutmeg fat, followed by purification with 96% ethanol, to optimize yield while maintaining the integrity of the beneficial compounds present in nutmeg seeds.

2. RESEARCH METHODS

This research used a factorial completely randomized design (CRD) method with independent variables, such as extraction time (45, 90, 135 min) and extraction power (300 and 450 watts), as presented in Table 1. The physicochemical properties observed are colour, acid number, saponification number, specific gravity and melting point.

2.1 Equipments and materials

The equipment used is an ultrasonic batch (BRANSON, USA), microwave oven (SHARP, Japan), glassware (Pyrex, USA), analytical balance (Sartorius, Germany), hot plate (Corning, USA), oven (Memmert, Germany), blender (Philips, Netherlands), a set of simple distillation equipment (Labtech, UK), melting point apparatus (Stuart, UK), 60 mesh sieve (Retsch, Germany) and GC-MS (Shimadzu QP 2010 SE). The nutmeg seeds used come from Sinar Harapan Village, Kedongdong District, Pesawaran Regency, Lampung Province, Indonesia. Other materials used are n-hexane, 96% ethanol, PP indicator, 0.1N KOH, 0.5N HCl and 0.5N KOH-alcohol, were purchased from Merck, Germany, ensuring high quality and consistency in the experimental procedures.

2.2 Preparation of nutmeg seeds

Nutmeg seeds were dried in an oven at 50 °C for 24 hours until constant weight (Ananingsiha et al. 2020). The dried nutmeg seeds are ground with a blender, and sieved with a 60 mesh (Baihaqi et al. 2018). Ninety grams of nutmeg powder was added with 375 mL of n-hexane solvent then sonicated using an ultrasonic batch at a temperature of 45 °C, frequency of 40 KHz, for 40 min.

2.3 Extraction and purification of nutmeg seeds through UMAE

The sonicated mixture of nutmeg seeds was put into a round flask and then extracted in a microwave using power and time according to research variations. After completion of extraction, the solids are separated from the fat extract using filter paper. The nutmeg fat was separated from the n-hexane solvent using a simple distillation. Purification of nutmeg fat is carried out by adding 100 mL of 96% ethanol solution then heated to a maximum temperature of 65 °C. The mixture is cooled in an ice bath until crystallization occurs for 2 hours. The nutmeg fat precipitate is filtered using filter paper, then dried at room temperature for 16 hours. The yield of fat from purification is calculated using the Equation 1 (Ananingsiha et al. 2020).

$$\text{Yield (\%w/w)} = \frac{Mass\ of\ fat\ (g)}{Mass\ of\ nutmeg\ seed} \times 100 \quad (1)$$

2.4 Specific gravity analysis

Specific gravity analysis of nutmeg fat was carried out using the AOCS method Cc 10a-25, 1993 (Nagre et al. 2011) at modified. The test was carried out at a temperature of 25°C. Specific gravity calculated using the with Equation 2.

$$\text{Specific gravity} = \frac{Mass\ of\ fat\ (g)}{Mass\ of\ water\ [1 + 0.000025\ (t - 25)]} \quad (2)$$

2.5 Acid number analysis

A total of 1.5 g of nutmeg fat were added to 50 mL of 95% alcohol. Then the sample was heated on a hot plate for 15 min, then titrated with 0.1N KOH with 3 drops of PP indicator [14]. Titration is carried out until the solution changes color to pink. The acid number are calculated with Equation 3. To ensure reliability, all measurements were performed in triplicate, and the standard deviation of the results was calculated.

$$\text{Acid number (mg KOH/g fat)} = \frac{V \times N \times 56.1}{Mass\ of\ sample} \quad (3)$$

Where, V is the volume of KOH used in titration (mL), N is the normality of KOH (0.1N), and 56.1 is the molecular weight of KOH (g/mol).

2.6 Saponification number analysis

A total of 1.5 g of fat was dissolved in 50 ml of 0.5N KOH alcohol then refluxed. After completion, the sample was titrated with 0.5N HCl and 3 drops of PP indicator. The saponification number are calculated with Equation 4 (Ananingsiha et al. 2020). As with the acid number analysis, saponification measurements were performed in triplicate to validate repeatability, and standard deviations were calculated to evaluate precision.

$$SN\ (mgKOH/gfat) = \frac{(V_0 - V_1) \times N \times 56.1}{Mass\ of\ sample} \quad (4)$$

TABLE 1. Experimental design for synergistic ultrasonic-microwave assisted extraction (UMAE) of nutmeg seed fat.

Extraction power (watt) (A)	Extraction time (min) (B)	Replicates		
		1	2	3
300	45	A1.B1	A1.B1	A1.B1
	90	A1.B2	A1.B2	A1.B2
	135	A1.B3	A1.B3	A1.B3
450	45	A2.B1	A2.B1	A2.B1
	90	A2.B2	A2.B2	A2.B2
	135	A2.B3	A2.B3	A2.B3

Where, the saponification number (SN) is calculated using the volumes of blank HCl (V_0) and sample HCl (V_1), with HCl normality (N) being 0.5N, where SN, V_0, V_1, and N represent the saponification number, volume of blank HCl, volume of sample HCl, and normality of HCl, respectively.

2.7 Intrumental analysis

The fat with the highest yield was analyzed for its chemical composition using Gas Chromatography-Mass Spectrometry (GC-MS) (Shimadzu QP 2010 SE). The GC-MS was operated under the following conditions: an injector temperature of 250°C. The samples for GC-MS analysis were sent to the Instrumentation Lab, Basic Physics and Chemistry Department, Universitas Islam Indonesia.

The melting point of the fat was determined using a melting point apparatus. A sample of fat was inserted into a capillary tube, and the melting point was measured once the fat had completely melted(Nagre et al. 2011). The melting point testing was conducted at the Chemistry Lab, Institute of Technology Sumatera (ITERA).

3. RESULTS AND DISCUSSION

3.1 Effect of extraction power and time on fat yield

The results of the research showed that the nutmeg fat yield ranged between 27.92% - 30.48% at 300 watts of power, while at 450 watts the nutmeg fat yield was 22.27% - 28.46%. This trend can be attributed to excessive solvent evaporation at higher power levels, which reduces the effective contact time between the raw material and the solvent, limiting fat extraction efficiency. Figure 1(a) shows that both extraction at 300 watts and 450 watts, the longer extraction time, the higher fat yield. However, at 450 watts and an extraction time 135 min, the yield decreased. This decline may be due to significant solvent loss from prolonged high heating, leading to inefficient fat solubilization and potential thermal degradation of extractable compounds. The yield of this research is higher than the extraction of nutmeg fat using the ultrasonic-assisted extraction (UAE) method, 23.86% (Ananingsiha et al. 2020) and the Soxhlet method with extraction time 6 hours 30, 36% (Hartanto and Silitonga 2018). This research shows that heating using microwaves shortens time and increases yield compared to heating using a heating mantle which is in line with research (Silmi et al. 2022; Shintawati et al. 2022).

3.2 Effect of extraction power and time on acid number

The results showed that the acid value ranged from 6.08 to 20.99 mg KOH/g fat. The number of nutmeg fatty acids extracted with 300 Watt increased with increasing time, this shows the increase in free fatty acids contained in the fat. A higher acid number is often associated with lower fat quality (Widyaningsih et al. 2014). Additionally, the acid number reflects the presence of organic acids in the fat, particularly oleic and linoleic acids, which are readily extracted by the hexane solvent (Saranaung et al. 2018). Figure 1(b) shows that 450 watts and short extraction times, the acid number is higher compared to extraction at 300 watts, suggesting that higher microwave power enhances the release of free fatty acids due to the increased breakdown of triglycerides. However, with prolonged extraction at 450 watts, the acid number decreases, which may indicate further reactions involving free fatty acids, such as oxidation or esterification, leading to the formation of other lipid-derived compounds. The possible conversion of free fatty acids into volatile compounds or secondary oxidation products at higher power and extended heating times may also contribute to this trend. In comparison, Ananingsiha et al. (2020) has reported acid numbers of 13.83–19.82 mg KOH/g fat using the UAE method, which is generally higher than the values observed in this study. This suggests that UMAE can produce better-quality fat in terms of lower acid numbers, likely due to its ability to extract lipids with minimal exposure to excessive heat, reducing the likelihood of hydrolysis or oxidative degradation. These findings highlight the influence of microwave power on fat quality, where excessive heating may trigger complex reactions such as oxidation, polymerization, or isomerization, ultimately affecting the acid number and overall stability of the extracted fat.

3.3 Effect of extraction power and time on saponification number

The saponification number represents the milligrams of KOH required to saponify 1 gram of fat or oil (Widyaningsih et al. 2014), indicating the average molecular weight of fatty acids within the fat. In this study, the saponification number ranged from 219.45 -254.96 mg KOH/g fat, suggesting the presence of medium to short-chain fatty acids. A higher saponification number typically correlates with lower molecular weight fatty acids and glycerides (Widyaningsih et al. 2014). Figure 1(c) illustrates an increasing trend in the saponification number with extended extraction times, particularly at 300 watts, which suggests the breakdown of larger lipid molecules into smaller fatty acid fragments. This correlates with the increase in acid number observed in Figure 1(b), reinforcing the idea that prolonged microwave exposure pro-

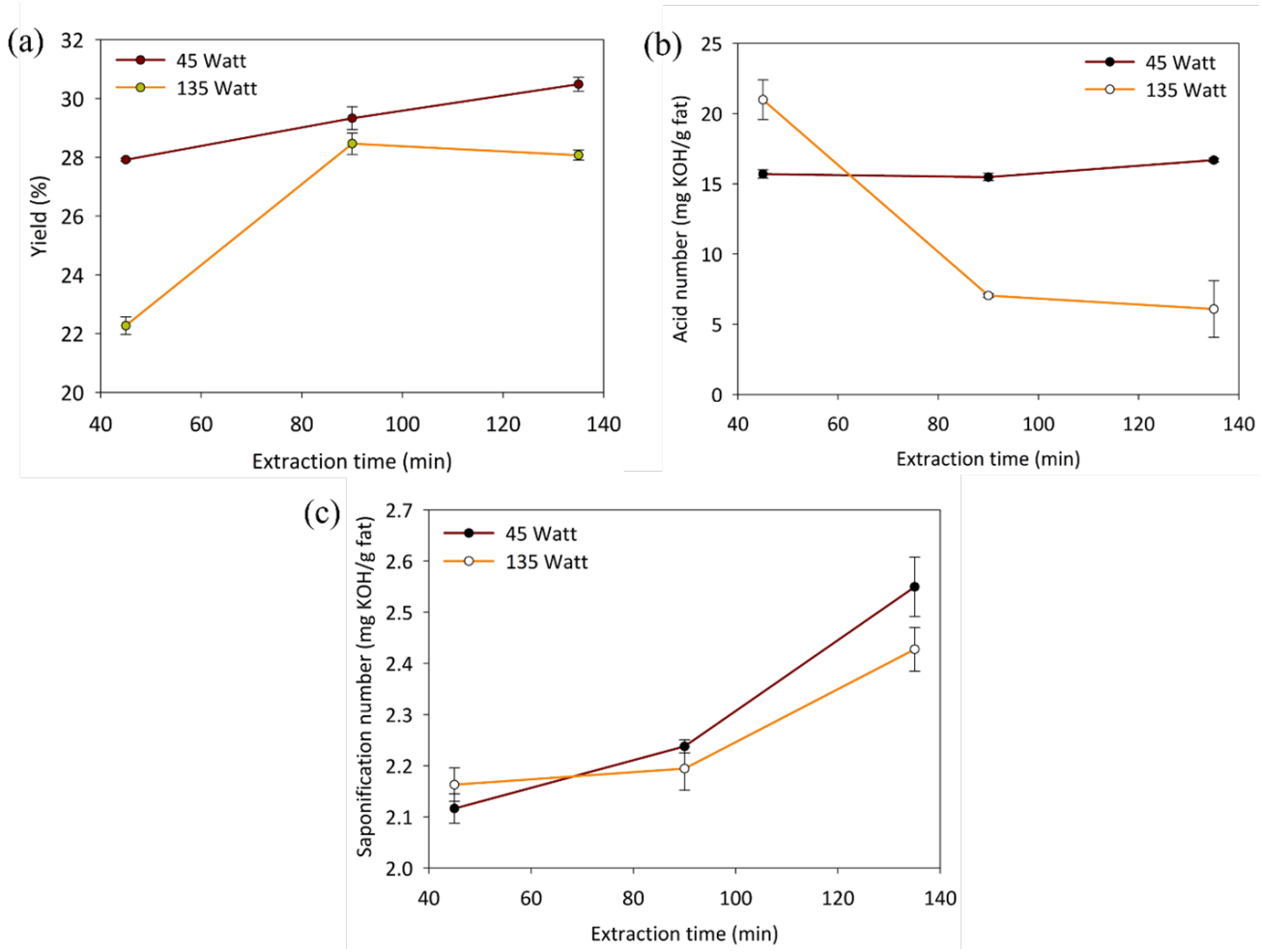

FIGURE 1. Effect of extraction power and time on (a) yields (%), (b) acid number (mg KOH/g fat), and (c) saponification number (mg KOH/g fat).

motes lipid hydrolysis. The saponification number at 450 watts also increases with time, accompanied by a decrease in specific gravity (Table 2). This trend implies that some of the free fatty acids formed during high-power extraction may undergo further reactions, such as oxidation or polymerization, leading to the formation of lower-density compounds. The high saponification number observed in this study aligns with previous findings on African nutmeg fat (234–249 mg KOH/g fat) obtained through pressing, Soxhlet extraction, and NaOH-ethanol purification methods (Nagre et al. 2011) as well as enzymatic pretreatment (236 mg KOH/g fat) (Chiwetalu et al. 2022). The high saponification value also suggests good emulsification properties, meaning the extracted fat could be suitable for soap production and other applications requiring strong emulsifying power. Potential degradation or transformation mechanisms contributing to saponification number variations includes of triglyceride hydrolysis, thermal degradation of fatty acids, oxidation or polymerization. These findings emphasize the role of microwave power and extraction duration in modifying fat composition, influencing its suitability for industrial applications such as cosmetics, soap production, and emulsifiers.

3.4 Color of nutmeg fat

The color of nutmeg fat produced by UMAE method followed by purification using 96% ethanol varies from white to yellow, as in Figure 2. The color of nutmeg fat is influenced by the extraction power and time used. 300 watts and 135 min produced a yellow color. High power, 450 watts and 135 min produced a whiter fat color. This variation in color indicates that extraction power and time significantly impact the composition and characteristics of the extracted fat. Longer extraction times at 300 watts resulted in a yellow color, likely due to the presence of certain compounds such as triglycerides. In contrast, 450 watts of extraction power produced a whiter fat, possibly indicating the decomposition or volatilization of yellow compounds at higher temperatures.

The yellow compound is thought to be a triglyceride compound such as trimyristin. Trimyristin is yellowish white, formed from the esterification reaction of glycerol and myristate acid and is solid at room temperature (YILDIRIM et al. 2020). Trimyristin is used in the cosmetics industry as an emollient, skin conditioner, vitamin solvent and viscosity regulator. It is important to note that the presence of trimyristin and other triglycerides contributes to the color of the fat and its potential utility in cosmetic applications. It is suspected that increasing the power and extraction time will decompose the yellow compounds contained in nutmeg fat and evaporate with the solvent at high heating so that the color of the fat changes to white. In terms of product quality, the whiter nutmeg fat produced at 450 watts and 135 min is likely to have fewer yellowish compounds and may be considered of higher purity, making it suitable for applications requiring a more neutral fat. On the other hand, the yellow

FIGURE 2. Color of nutmeg fat extracted at (a) 300 Watts for 45 min, (b) 300 Watts for 90 min, (c) 300 Watts for 135 min, (d). 450 Watts for 45 min, (e) 450 Watts for 90 min, (f) 450 Watts for 135 min.

fat produced at 300 watts and 135 min may contain more triglyceride compounds like trimyristin, which could be beneficial for specific cosmetic formulations. The operating conditions, such as extraction power and time, clearly influence both the color and the composition of the fat, affecting its suitability for various industrial uses. The color of nutmeg fat in this study is in accordance with Ananingsiha et al. (2020) research which is pale yellow in color.

3.5 Melting point

The nutmeg fat melting point as the results of this research range from 52.4°C - 53.0°C and the specific gravity of the nutmeg fat produced ranges from 0.96-0.98 as shown in Table 2. The results indicate that microwave power and extraction time have minimal effects on the melting point. At the lower power level of 300 watts, the melting points measured were consistently around 52.4°C to 52.5°C across all time intervals, with slight variations as the heating time increased from 45 to 135 min. This stability suggests that prolonged heating at moderate power does not significantly alter the thermal properties of nutmeg fat, implying a consistent crystalline structure under these conditions. Conversely, at the higher power level of 450 watts, the melting points showed a slight increase, ranging from 52.5°C to 53.0°C. This small but noticeable elevation suggests that higher power levels may induce subtle modifications in the fat's crystalline structure, possibly due to localized overheating or minor compositional changes. However, the overall variation remains small, reinforcing that nutmeg fat retains its thermal stability even under different UMAE conditions. Furthermore, the melting point of nutmeg fat purified using ethanol in this study aligns closely with that reported by Hossain et al. (2023), where nutmeg fat recrystallized with acetone exhibited a melting point of 53.0°C–54.0°C. This similarity suggests that the UMAE method with ethanol purification yields nutmeg fat with comparable thermal properties to conventional recrystallization techniques, making it a viable alternative for extraction and purification.

TABLE 2. Effect of extraction power and time on the melting point and specific gravity of extracted nutmeg seed fat.

No.	Extraction power (watt)	Extraction time (min)	Melting Point (°C)	Specific Gravity 35/25
1	300	45	52.5	0.96
2	300	90	52.4	0.96
3	300	135	52.4	0.96
4	450	45	52.9	0.98
5	450	90	52.5	0.97
6	450	135	53.0	0.97

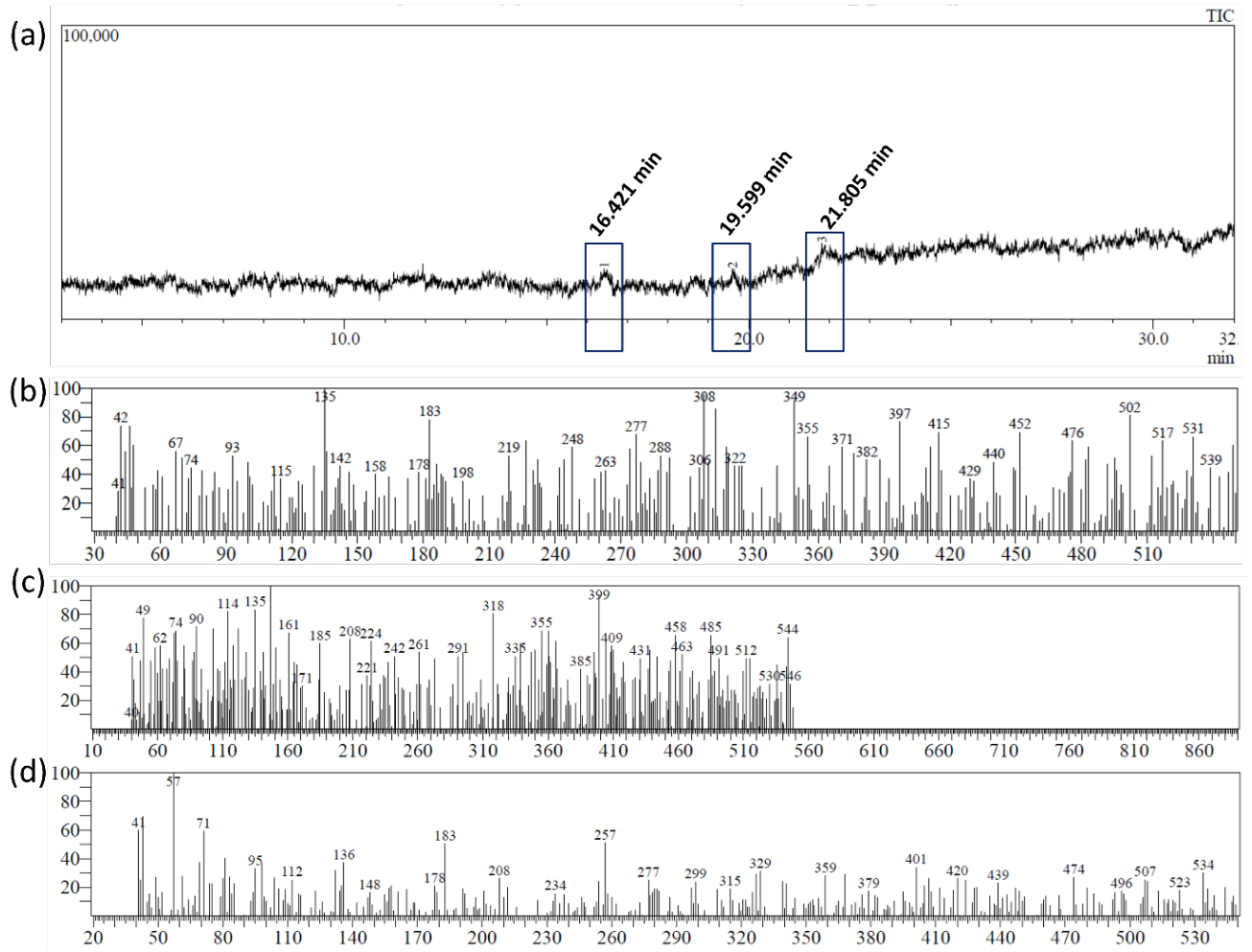

FIGURE 3. GC-MS results for (a) Chromatogram nutmeg fat (b) retention time 16.420 (c) retention time 19.600, and (d) retention time 21.805.

On the other hand, the specific gravity at a power level of 300 watts remained consistent at 0.96 across all extraction times of 45, 90, and 135 min. This stability indicates that the extraction conditions at this lower power level do not significantly influence the density of the fat produced. In contrast, at the higher power level of 450 watts, the specific gravity values exhibit slight variations, ranging from 0.97 to 0.98. Specifically, a specific gravity of 0.98 is recorded at 45 min, while it slightly decreases to 0.97 for both the 90-minute and 135-minute extraction periods. The increase in specific gravity at 450 watts, particularly at shorter extraction times, may be attributed to the selective extraction of denser lipid fractions or a higher concentration of minor components such as phospholipids, sterols, and other unsaponifiable matter. As the extraction progresses, prolonged exposure to elevated temperatures may lead to slight degradation or volatilization of lighter fractions, resulting in a slight decrease in specific gravity over time. Additionally, higher microwave power could induce thermal effects that alter the molecular interactions within the extracted fat, influencing its overall density. Overall, these findings imply that while the specific gravity of nutmeg fat is relatively stable at lower power levels, higher power conditions can lead to slight changes in density, potentially affecting the composition and quality of the extracted fat. Understanding these specific gravity values is essential for assessing the suitability of nutmeg fat for various applications, particularly in industries such as cosmetics and food products, where density and composition can significantly influence product performance. The specific gravity of the research results is higher than African nutmeg (Kombo) fat reaching 0.922 (Nagre et al. 2011). The high specific gravity of nutmeg fat as a result of this research is thought to be because the nutmeg fat content of nutmeg from Indonesia is lower, namely 30.48%, while African nutmeg is 74.13%. The fat content of nutmeg is influenced by plant type, planting location and cultivation techniques.

3.6 Nutmeg fat chemicals composition

The GC-MS analysis confirmed the presence of multiple chemical compounds in the nutmeg fat extracted under optimal conditions. The number of peaks detected in the chromatogram, as shown in Figure 3, reflects the complexity and diversity of the extracted components. Table 3 provides a detailed breakdown of the compositions, highlighting the dominant compounds present in the highest-yield sample.

Table 3 shows that the nutmeg fat contain Benzene, 1,2,4,5-tetrachloro-3,6-bis(trichloromethyl) and O,O-bis(2,4-dichlorophenyl) isopropyl phosphoranidothioic acid, both of them are found in pesticides (BRAHUSHI et al. 2017; Jankuloska et al. 2019). It is suspected both compounds are used to kill pests found in nutmeg during storage. There are some pest in nutmeg seed such as A. fasciculatus (Dharmaputra et al. 2018). Trilaurin or lauric acid triglyceride is a saturated medium chain fatty acid with a 12 carbon chain and lau-

TABLE 3. Identified chemical components in extracted nutmeg seed fat using GC-MS analysis.

Formula	Component	Molecular weight (g/mol)	Retention time (min)	Area %
C_8Cl_{10}	Benzene, 1,2,4,5-tetrachloro-3,6-bis(trichloromethyl)	446	16.421	27.49
$C_{15}H_{14}Cl_4NO_2PS$	O, O-bis(2,4-dichlorophenyl) isopropyl phosphoranidothioic acid	443	19.599	40.85
$C_{39}H_{74}O_6$	Lauric acid triglyceride	639	21.805	31.66

TABLE 4. Comparison study of nutmeg with extraction methods.

Raw materials	Methods	Results	References
Nutmeg oleoresins	UAE 40% output power; 10 min extraction	Yield of 8.26 ± 0.01%	(Morsy 2016)
Nutmeg oleoresins	Maceration; 4320 min	Yield of 9.63 ± 0.01%	(Morsy 2016)
Nutmeg	Ethanol extraction; 1 mm; 41 Hz; 7 days	DPPH of 209.8 ± 0.3 mmol TE/100; ABTS of 619.55 ± 2.8 mmol TE/100 g; TPC of 482.9 ± 3.9 mg GA/100 g	(Poliński et al. 2022)
Nutmeg seed	Soxhlet extraction with methanol and acetone (1:7) solvent	Total phenolic content of 0.6217 mg/mL	(Panggabean et al. 2019)
Nutmeg seed	150 mL methanol	Yield 4.22%; 61x104 CFU/g for 0.1% nutmeg seed	(Panggabean et al. 2019)
Nutmeg seed	UMAE at 300 watts	Yield of 27.92% - 30.48%	This study
Nutmeg seed	UMAE at 450 watts	Yield of 22.27% - 28.46%	This study

ric acid is dodecanoic acid (Spandana 2019). Lauric acid is widely used in soap or cosmetic products and has antimicrobial properties (Su'i et al. 2016). The lauric acid content has high solubility, increases saponification and produces excellent foaming (Widyasanti et al. 2017) such as saponification results of this research. Industry also uses lauric acid as an emulsifier and increases the elasticity of bioplastics (Adorna et al. 2020).

3.7 Comparison and limitations

In this section, a comparative analysis of various extraction methods for nutmeg and its components is presented, focusing on yield, antioxidant activity, and phenolic content. Table 4, summarizes the results of different techniques, including UAE, maceration, ethanol extraction, Soxhlet extraction, and UMAE, highlighting the efficiency and outcomes of each method.

The UMAE method shows clear advantages in both yield and quality compared to traditional methods. Its shorter extraction time and higher efficiency help produce a stronger extract with valuable bioactive compounds, making it ideal for industries like cosmetics and pharmaceuticals. These results confirm that UMAE improves both yield and quality, making it an effective extraction method. However, there are some limitations to this study. For instance, pesticide residues could have been extracted with the nutmeg, and the equipment used may not always provide consistent results. Also, the sample size was small, so larger samples are needed to confirm these findings. The physicochemical properties of the UMAE-extracted nutmeg fat, like its higher yield and quality, make it useful in cosmetics and pharmaceuticals, especially for products like skin conditioners and vitamin solvents. UMAE fast process and low solvent use also make it more cost-effective and sustainable for industrial production, meeting the growing demand for natural ingredients in these industries.

4. CONCLUSIONS

The extraction of nutmeg fat using the UMAE method proves to be an efficient and effective process. The highest yield of 30.48% was achieved at 300 watts of microwave power for 135 min, indicating that the UMAE method significantly enhances the extraction efficiency compared to traditional techniques. Additionally, the extracted nutmeg fat demonstrated desirable quality characteristics, including a melting point of 52.4°C, specific gravity of 0.96, an acid number of 16.69 mg KOH/g fat, and a saponification value of 254.96 mg KOH/g. The chemical composition of the nutmeg fat included key compounds such as 2,4-dichlorophenyl, lauric acid, and trichloromethyl, which contribute to its potential applications. Overall, the UMAE method not only increases yield and quality but also reduces extraction time, making it a promising alternative for large-scale production of nutmeg fat.

REFERENCES

Aćimović M, Šovljanski O, Pezo L, Travičić V, Tomić A, Zheljazkov VD, Ćetković G, Švarc-Gajić J, Brezo-Borjan T, Sofrenić I. 2022. Variability in biological activities of satureja montana subsp. Montana and subsp. Variegata based on different extraction methods. Antibiotics. 11(9):1235. doi:10.3390/antibiotics11091235.

Adorna JA, Aleman CKA, Gonzaga ILE, Pangasinan JN, Sisican KMD, Dang VD, Doong RA, Ventura RLG, Ventura JRS. 2020. Effect of lauric acid on the thermal and mechanical properties of polyhydroxybutyrate (phb)/starch com-

posite biofilms. International Journal of Polymer Science. 2020:1–11. doi:10.1155/2020/7947019.

Ananingsiha VK, Budiantoa V, Soedarini B. 2020. Optimasi suhu, waktu, dan rasio bahan pada ultrasound-assisted extractionbutterbiji pala (Myristica fragrans). Journal of Food Technology and Nutrition. 19(2):126–134. https://jurnal.ukwms.ac.id/index.php/JTPG/article/view/2817/2502.

Baihaqi B, Budiastra IW, Yasni S, Darmawati E. 2018. Improvement of oleoresin extraction effectivenesss in nutmeg by ultrasound assisted method. Jurnal Keteknikan Pertanian. 6(3):249–254. doi:10.19028/jtep.06.3.249-254.

BRAHUSHI F, KENGARA FO, SONG Y, JIANG X, MUNCH JC, WANG F. 2017. Fate processes of chlorobenzenes in soil and potential remediation strategies: A review. Pedosphere. 27(3):407–420. doi:10.1016/s1002-0160(17)60338-2.

Budiastra IW, Zahra AM, Sugiyono, Sutrisno. 2021. Physicochemical properties of nutmeg oleoresin obtained by ultrasound-assisted extraction from different raw material qualities and drying methods. International Journal on Advanced Science, Engineering and Information Technology. 11(1):229–235. doi:10.18517/ijaseit.11.1.7324.

Chiwetalu MO, Ossai EC, Enechi OC, Ugwu CN, Ozogwu VEO, R Okpala CO, Njoku OU. 2022. An enhanced fat extraction from Pycnanthus angolensis (African nutmeg) seeds using cellulase from Aspergillus niger strain BC23. Quality Assurance and Safety of Crops & Foods. 14(3):165–175. doi:10.15586/qas.v14i3.997.

Dharmaputra OS, Sunjaya S, Retnowati I, Nurfadila N. 2018. Keanekaragaman serangga hama pala (Myristica fragrans) dan tingkat kerusakannya di penyimpanan. Jurnal Entomologi Indonesia. 15(2):57. doi:10.5994/jei.15.2.51.

Elisa E, Shintawati S, Afifah DA, Ramandani AA. 2024. Characteristics candlenut shell-based activated Carbon for reduction Iron (Fe) in surface water from Bratasena Tulang Bawang, Lampung. Journal of Natural Sciences and Mathematics Research. 10(1):35–45. doi:10.21580/jnsmr.v10i1.20320.

Hartanto ES, Silitonga RF. 2018. Ekstraksi asam miristat asal biji pala (myristica fragrans houtt) dan limbah industri olahannya. Warta Industri Hasil Pertanian. 35(1):38. doi:10.32765/wartaihp.v35i1.3833.

Hossain T, Spencer D, W Denton R. 2023. Microwave-assisted extraction of trimyristin from nutmeg using ethanol: A greener approach for the undergraduate organic chemistry laboratory. World Journal of Chemical Education. 11(2):17–20. doi:10.12691/wjce-11-2-3.

Ivetich M, Gorelkina A. 2020. Reducing water contamination to ensure the quality and safety of food products. Food Processing: Techniques and Technology. 50(3):515–524. doi:10.21603/2074-9414-2020-3-515-524.

Jankuloska V, Pavlovska G, Kalevska T, Stamatovska V. 2019. Pesticide residues in food : Food safety , nutrition and health pesticide residues in food : food safety , nutrition and health. International Journal of Food Technology and Nutrition. 2(4):4–9. https://www.foodsciencejournal.com.

Jose H, Arya KR, Sindhu TJ, Syamjith P, Vinod K, Sandhya S. 2016. A descriptive review on myristica fragrans houtt. Hygeia.J.D.Med. 8(1):3590. doi:10.15254/H.J.D.Med.8.2016.155.

Kozłowska M, Gruczyńska E, Ścibisz I, Rudzińska M. 2016. Fatty acids and sterols composition, and antioxidant activity of oils extracted from plant seeds. Food Chemistry. 213:450–456. doi:10.1016/j.foodchem.2016.06.102.

Loizzo MR, Sicari V, Tenuta MC, Leporini MR, Falco T, Pellicanò TM, Menichini F, Tundis R. 2016. Phytochemicals content, antioxidant and hypoglycaemic activities of commercial nutmeg mace (Myristica fragrans L.) and pimento (Pimenta dioica (L.) Merr.). International Journal of Food Science & Technology. 51(9):2057–2063. doi:10.1111/ijfs.13178.

Morsy NFS. 2016. A comparative study of nutmeg (Myristica fragrans Houtt.) oleoresins obtained by conventional and green extraction techniques. Journal of Food Science and Technology. 53(10):3770–3777. doi:10.1007/s13197-016-2363-0.

Nagre RD, Oduro I, Ellis WO. 2011. Comparative physicochemical evaluation of kombo kernel fat produced by three different processes. African Journal of Food Science and Technology. 2(4):83–91. https://www.interesjournals.org/articles/comparative-physicochemical-evaluation-of-kombokernel-fat-produced-by-three-different-processes.pdf.

Okiki PA, Nwobi CP, Akpor OB, Adewole E, Agbana RD. 2023. Assessment of nutritional and medicinal properties of nutmeg. Scientific African. 19:e01548. doi:10.1016/j.sciaf.2023.e01548.

Panggabean KA, Rusmarilin H, Suryanto D. 2019. The utilization of nutmeg seed (Myristica fragrans Houtt) extract as an antimicrobial on tempeh sausage. IOP Conference Series: Earth and Environmental Science. 260(1):12087. doi:10.1088/1755-1315/260/1/012087.

Poliński S, Topka P, Tańska M, Kowalska S, Czaplicki S, Szydłowska-Czerniak A. 2022. Effect of grinding process parameters and storage time on extraction of antioxidants from ginger and nutmeg. Molecules. 27(21):7395. doi:10.3390/molecules27217395.

Ramandani AA, Shintawati S, Aji SP, Sunarsi S. 2022. Pemanfaatan lignin serai wangi sebagai lignin resorsinol formaldehida (lrf) menggunakan ultrasonic microwave-assisted extraction (umae). CHEESA: Chemical Engineering Research Articles. 5(1):40. doi:10.25273/cheesa.v5i1.10348.40-48.

Samaram S, Mirhosseini H, Tan CP, Ghazali HM. 2014. Ultrasound-assisted extraction and solvent extraction of papaya seed oil: Crystallization and thermal behavior, saturation degree, color and oxidative stability. Industrial Crops and Products. 52:702–708. doi:10.1016/j.indcrop.2013.11.047.

Saranaung A, Sangi MS, Katja DG. 2018. Pengaruh ukuran bahan terhadap rendemen dan kualitas minyak biji pala (myristica fragrans houtt) dengan metode soxhletasi. Jurnal MIPA. 7(1):39. doi:10.35799/jm.7.1.2018.19282.

Savic Gajic IM, Savic IM. 2023. Optimization of ultrasound procedure for the sustainable production of oil from plum seeds. Carbon Resources Conversion. 6(1):20–26. doi:10.1016/j.crcon.2022.10.003.

Shintawati, Widodo YR, Ermaya D. 2022. Yield and quality improvement of candlenut oil by microwave assisted ex-

traction (mae) methods. IOP Conference Series: Earth and Environmental Science. 1012(1):12024. doi:10.1088/1755-1315/1012/1/012024.

Silmi FF, Variyana Y, Shintawati. 2022. Perbandingan yield ekstraksi piperin piper nigrum l. Dengan menggunakan ekstraksi konvensional dan microwave. JURNAL TEKNOLOGI KIMIA MINERAL. 1(2):52–55. doi:10.61844/jtkm.v1i2.272.

Spandana T. 2019. Analytical method validation of lauric acid present in pure and commercial preparations of coconut oil using gc-fid method. International Journal of Engineering Research and. V8(12). doi:10.17577/ijertv8is120081.

Su'i M, Sumaryati E, Sucahyono DD. 2016. Pemanfaatan fraksi kaya asam laurat hasil hidrolisis dari endosperm kelapa menggunakan lipase endogeneus sebagai pengawet susu kedelai kemasan (utilization of high lauric fraction that produced from coconut endosperm using lipase endogenous as preservatio. Jurnal Agritech. 36(02):154. doi:10.22146/agritech.12859.

Widyaningsih W, IN Budiasih INB, WA Kurniawan WAK, M Chasani MC, VH Nursalim VHN. 2014. Sintesis, pemurnian dan karakterisasi metil ester sulfonat (mes) sebagai bahan inti deterjen dari minyak biji nyamplung (calophyllum inophyllum l). Molekul. 9(1):63. doi:10.20884/1.jm.2014.9.1.151.

Widyasanti A, Qurratu'ain Y, Nurjanah S. 2017. Pembuatan sabun mandi cair berbasis minyak kelapa murni (vco) dengan penambahan minyak biji kelor (moringa oleifera lam). Chimica et Natura Acta. 5(2):77. doi:10.24198/cna.v5.n2.14691.

YILDIRIM A, ÖZTÜRK S, TÜRKDEMİR H, KOLALI A, ATALAY BG, KOCATAŞ H. 2020. An improved isolation of trimyristin from Myristica fragrans as a renewable feedstock with assistance of novel cationic gemini surfactant. Journal of the Turkish Chemical Society Section A: Chemistry. 7(2):545–560. doi:10.18596/jotcsa.605805.