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Research Article

Effect of extraction conditions on the sandalwood seed oil extraction process

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ABSTRACT

Introduction: In recent years, the use of plant-derived natural oils has been increasing in the cosmetics and pharmaceutical industries due to the high demand for green materials. Among these is the sandalwood tree, whose heartwood is widely used in the cosmetics industry. Sandalwood seeds are also a promising raw material, containing bioactive compounds such as ximenynic acid, which have been widely researched and have proven anti-inflammatory and anti-aging effects.

Methods: This study investigated the process of solvent extraction of sandalwood seeds using a Soxhlet extractor, and evaluated the effects of different parameters including solvent type (petroleum ether, ethyl acetate, and *n*-hexane) and seed-to-solvent ratio. Resulting oils were tested for physicochemical properties.

Results: Oil extraction yield decreased with increased mass ratio of sandalwood seed to solvent. Among the tested solvents, petroleum ether exhibited the highest extraction yield compared with ethyl acetate and *n*-hexane. The extraction process yielded 12.68% oil from 30 g of seeds using 250 mL of petroleum ether, with the resultant oil containing high levels of ximenynic and oleic acids. This lower oil extraction yield, compared to the theoretical content (~50%–60%), is possibly due to the high seed-to-solvent ratio.

Conclusion: These results demonstrate that the Soxhlet extraction process remains an effective laboratory-scale technique for obtaining valuable oil from sandalwood seed, offering strong potential for further research applications.

Key words: Sandalwood seed oil, Soxhlet extraction, petroleum ether, ximenynic acid.

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INTRODUCTION

Sandalwood (*Santalum album* L.) is a high-value tree species, commonly known as East Indian sandalwood or *Chandana* in India[1] (Figure 1). The oil and heartwood of the mature tree (usually from 15–20 years of growth) are very fragrant and commonly used in perfumes, cosmetics, and traditional medicine[2]. Sandalwood is cultivated throughout South and Southeast Asia; in Vietnam, the tree is largely found in Tay Ninh Province. Sandalwood oil is particularly valued for its long-lasting fragrance and therapeutic properties, mainly attributed to the key bioactive compounds α- and β-santalol[3]. While the heartwood remains of low value, it is the focus of research for further applications.

Recently, sandalwood oil obtained from the heartwood has attracted interest. These parts contain multiple therapeutic ingredients that are beneficial to human health. Sandalwood seeds typically contain 50%–60% oil, with 7%–17% being unsaponifiable material[6]. The oil is particularly known for being rich in santalbic (ximenynic) and oleic acids, which together account for approximately 80%–85% of the total fatty acids (1). Ximenynic acid, an acetylenic fatty acid, exhibits anti-inflammatory, vasodilatory, and anti-aging effects; oleic acid is associated with the enhancement of skin barrier function and skin elasticity[7]. Sandalwood seed oil is an attractive renewable source of cosmetic and pharmaceutical products due to the functional and commercial value of its special composition.

Generally, sandalwood oil is primarily extracted from the volatile essential oil of the heartwood using steam distillation, hydro-distillation, or microwave-assisted extraction[8]. While these methods can provide significant benefits to the essential oils, they have major limitations, including being energy-demanding, time-consuming, and not always suitable for extracting nonvolatile fatty oils in seeds. Besides these options, two common methods exist for fixed oil: mechanical pressing, which is easy and clean, and solvent extraction, which extracts up to 98% of the oil, depending on the polarity of the solvent and the conditions of the extraction process[9]. In the latter method, solvents—such as *n*-hexane, petroleum ether, and ethyl acetate—are used for their dissolving ability.

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Figure 1: Sandalwood tree (forest, leaf and flower, woodcore, and seed) [4,5]

Two common extraction methods are used in the case of fixed oils. Mechanical pressing is simple and causes minimal environmental impact; however, it usually results in a large amount of residual oil remaining in the seed matrix. In contrast, recovery efficiencies in solvent extraction can be as high as 98%, depending on the solvent polarity and extraction conditions [9]. In this method, organic solvents with strong dissolving capacity—such as *n*-hexane, petroleum ether, and ethyl acetate—are commonly used to extract the oil.

Soxhlet extraction is considered one of the most promising solvent-based methods for recovering seed oil. In this approach, the solid matrix can be re-washed with fresh solvent by refluxing and siphoning, thus increasing the rates of mass transfer at a steady temperature close to that of the boiling point of the solvent [10,11]. This process reduces solvent consumption, minimizes oxidation, and provides reproducible yields with minimal manual intervention [12]. Soxhlet extraction can also be used to extract compounds from small quantities of a substance, due to the possibility of extracting compounds with varying solubilities by changing the solvent, and because of the high extraction efficiency provided by continuous washing with solvent [13]. Due to these advantages, this method has been successfully used for plant extraction with thermolabile or high-molecular-weight compounds. Nevertheless, the technique has not been well-studied with regard to the extraction of sandalwood seed oil. Most past research has dealt with the extraction of essential oils from sandalwood heartwood or roots, with scant research having been conducted on seed oil [13]. The majority of studies have used hydro-distillation or simple solvent extraction, with few thoroughly studying the influence of solvent type or seed-to-solvent ratio on extraction yields and oil composition. In addition, the chemical composition of sandalwood seeds

can be influenced by geographical and soil factors; because of this, data from the other countries (such as India and Australia) may not be generalizable to *S. album* grown in Vietnam in terms of the levels of compounds such as ximenynic and oleic acids.

Moreover, the chemical composition of sandalwood seeds can differ due to geographic and soil characteristics. Thus, data reported from other areas, such as India and Australia, may not reflect the composition of *S. album* grown in Vietnam, especially in the content of ximenynic- and oleic-acid-rich oils.

The purpose of the study is therefore to assess the extraction of the sandalwood seed oil using the Soxhlet technique with *S. album* grown in Vietnam. This was examined through exposure to various solvents—petroleum ether, *n*-hexane, and ethyl acetate—at varying seed-to-solvent ratios of 30–70 grams of seeds to 250 mL solvent. The physico-chemical properties of the recovered oils—including acid value, saponification value, and specific gravity—were measured, and the composition of fatty acids of the recovered oils was determined using gas chromatography coupled with mass spectrometry (GC–MS) to identify the optimum extraction conditions. This strategy offers a long-term solution for the recovery of seed oil, and promotes the economical and environmentally friendly Soxhlet extraction method. These data could be useful for the creation of natural bioactive compounds for cosmetic and pharmaceutical applications.

MATERIALS AND METHODS

Materials

Sandalwood seeds (*S. album L.*) were purchased from Quoc Phat sandalwood tea store, Tay Ninh Province, Vietnam. All chemicals used in this study were of analytical grade and applied without further purification. Petroleum ether (purity $\geq$ 95%, boiling point range 60–80 °C), *n*-hexane (purity $\geq$ 95%), ethyl acetate (purity $\geq$ 99%), phenolphthalein indicator (purity $\geq$ 98%), potassium hydroxide (purity $\geq$ 85%), and hydrochloric acid (37% w/w) were obtained from Xilong Chemical Co., Ltd. (China). Absolute ethanol (HPLC grade, purity $\geq$ 99.8%) was purchased from Fisher Chemical (USA).

Methods

Effect of conditions on sandalwood oil extraction

Sandalwood seeds were finely ground using a mortar and pestle and then loaded into a thimble. For experiments investigating the solid-to-solvent ratio, 250 mL petroleum ether was used as the extraction solvent. Extraction time was 6 h, with seed loadings of 30, 50, and 70 g per 250 mL solvent. For solvent-comparison experiments, the optimal ratio identified in the previous stage (30 g per 250 mL) was implemented with petroleum ether (60–80 °C), *n*-hexane (69 °C), or ethyl acetate (77 °C) for 6 h. After 6 h, a rotary evaporator was used to eliminate the remaining solvent from the oil solution. The recovered oils were collected and stored at 4 °C, and the residue was weighed to calculate the oil yields.

Oil extraction efficiency

The yield of extracted oil (Y) was determined gravimetrically based on the difference between the initial and residual seed masses after extraction and was calculated using Eq. (1):

$$Y = \frac{m_0 - m_1}{m_0} \times 100\% \quad (1)$$

where Y is the oil yield (%), m_o is the initial mass of the seed (g), and m_1 is the mass of the seed residue after extraction (g).

Physico-chemical characteristics of sandalwood seed oil

Determination of specific gravity

All measurements were conducted under ambient laboratory conditions (25 $\pm$ 1 °C, 1 atm). The mass and volume of the extracted oil were measured after measuring an equivalent volume of distilled water under the same conditions. The densities were calculated according to Eq. (2), and the specific gravity was determined using Eq. (3).

$$\rho = \frac{m}{V} \quad (2)$$

$$SG = \frac{\rho_{oil}}{\rho_{water}} \quad (3)$$

where ρ is the density (g·mL^{-1}), m is the mass (g), V is the volume (mL), and SG is the specific gravity of the oil.

Determination of acid value

To determine the amount of free fatty acids in oils, the acid value (AV) was calculated. Sandalwood seed oil (0.5 g) was weighed into a 250 mL Erlenmeyer flask, then dissolved in 5 mL of absolute ethanol. After adding three drops of the phenolphthalein, the mixture was gently heated for approximately 2 minutes and then was titrated against 0.1 N KOH solution. This titration was run until a pale pink color appeared

for 30 seconds. An additional blank titration, without the oil sample, was also performed under identical conditions, and measurements were conducted in triplicate to confirm the consistency of findings. The acid value was calculated by using Eq. (4):

$$AV = \frac{V\ x\ N\ x\ 56.11}{m} \quad (4)$$

where AV is the acid value (mg KOH g^{-1} sample), V is the volume of KOH used for titration (mL, calculated as V_{final} - $V_{initial}$), N is the normality of the KOH solution (0.1 N), 56.11 is the molecular weight of KOH (g mol^{-1}), and m is the mass of the oil sample (g).

Determination of saponification value

The saponification value (SV) was calculated to calculate the amount of alkali needed to convert one gram of oil or fat into glycerol and soap-forming fatty acid salts. In the first step, 0.5 g of sandalwood seed oil was mixed with 25 mL of 0.5 N KOH solution. Next, 2–3 drops of phenolphthalein indicator were added and the mixture was refluxed for 15 minutes to ensure complete saponification. The resulting solution was titrated with 0.5 N hydrochloric acid (HCl) until the pink color disappeared, which is the endpoint of the titration. A blank experiment without the oil sample was conducted under identical conditions, and all measurements were performed in triplicate to ensure the reproducibility of the results. The saponification value was calculated according to Eq. (5):

$$SV = \frac{(A-B)\ \times N\ \times\ 56.11}{W} \quad (5)$$

where SV is the saponification value (mg KOH g^{-1} sample), A is the volume of HCl used for the blank (mL), B is the volume of HCl used for the sample (mL), N is the normality of the HCl solution (0.5 N), W is the mass of the oil sample (g), and 56.11 is the molecular weight of KOH (g mol^{-1}).

Determination of the chemical composition of sandalwood seed oil

The chemical composition of the extracted sandalwood seed oils was analyzed using GC–MS on an Agilent 7890A gas chromatograph (Agilent Technologies, USA; with a mass selective detector 5975C MSD, USA). Compound separation was achieved using a capillary column (30 m × 0.25 mm × 0.25 μm). The injector temperature was maintained at 250 °C, and helium was used as the carrier gas at a constant flow rate of 1.0 mL min^{-1}. Compounds were identified by comparing the obtained mass spectra with those in the NIST 2014 mass spectral library. The analysis was performed on three replicate samples extracted using different solvents to determine the major constituents, including acetylenic fatty acids such as ximenynic acid.

RESULTS

The effect of ratio and solvent on extraction efficiency

The effects of seed-to-solvent ratio and solvent type on the extraction yield of sandalwood seed oil were investigated (Figure 2). In Soxhlet extraction, the solid-to-solvent ratio is a critical parameter affecting mass transfer efficiency. As shown inFigure 2 **a,** the oil yield decreased significantly when the seed mass increased from 30 to 70 g per 250 mL of petroleum ether. This trend can be attributed to the reduced solvent–solid contact area and limited diffusion within the extraction matrix at higher solid loadings[14]. The highest oil yield (12.68 ± 1.44%) was obtained at a ratio of 30 g per 250 mL, which was therefore selected as the optimal condition for subsequent experiments.

The same phenomenon has been observed for *Jatropha curcas* and neem seed oils, for which overloading of the seeds causes saturation of the solvent and subsequent low extraction efficiency[15]. The drop in oil yield at higher seed loadings can also explained due to the dense packing of crushed seeds in the thimble, which limits the circulation of the solvent and prevents complete extraction of lipids. In contrast, lower seed loading offers higher solvent accessibility, increasing the dissolution of nonpolar compounds like triglycerides and free fatty acids. However, the seed mass should not be less than 30 g, otherwise the quantity of recovered oil is too small to allow additional analyses. A ratio of 30 g seeds per 250 mL solvent was deemed as the practical optimum for use in further experiments.

The effect of solvent type was examined using the oil yield at the optimum ratio (30 g per 250 mL) and extraction time (6 h), as indicated in Figure 2**b**. The highest yield of oil was obtained using petroleum ether (12.68%), followed by *n*-hexane (9.63%) and ethyl acetate (7.96%). These results point to the impact of solvent polarity on extraction efficiency. Petroleum ether and *n*-hexane are nonpolar solvents; therefore, they are better at dissolving lipophilic triglycerides in sandalwood seeds[16]. In contrast, the semi-polar nature of ethyl acetate leads to a decrease in the strength of its interactions with hydrophobic lipid molecules, decreasing the extraction efficiency.

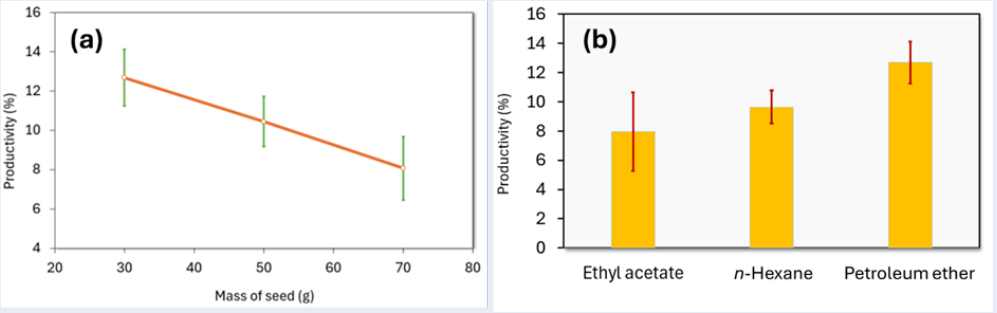

Figure 2: (a) Effect of mass of seed-to-petroleum ether solventratio on oil yield; (b) Effect of solvent type on oil yield under identical extraction conditions (30 g seed/250 mL solvent, 6 h, 69–78 °C). [Source: Authors]

To summarize, the solvent type and the ratio of seed to solvent are important factors in determining the efficiency of oil recovery. Among the solvents tested, petroleum ether exhibited the highest performance due to its nonpolar nature and relatively low boiling range; this leads to increased mass transfer and allows extraction under mild thermal conditions. These conditions preserve heat-sensitive fatty acids such as ximenynic acid and oleic acid. The current results align with previous literature on solvent-assisted plant lipid extraction [17], and indicate the suitability of Soxhlet extraction as a cost-effective and reproducible technique for extracting high-quality sandalwood seed oil.

Physico-chemical characteristics of sandalwood seed oil

Oils extracted by the tested solvents—petroleum ether, *n*-hexane and ethyl acetate—exhibited distinct differences in their physicochemical characteristics, as depicted in Table 1.

The extracted oils were of different colors, dependent on the polarity of the extraction solvent. Extraction with petroleum ether yielded a pale greenish-yellow oil, extraction with *n*-hexane gave a pale-yellow oil, and extraction with ethyl acetate gave a darker brownish-yellow oil, as presented in Figure 3b. This tendency points to the fact that larger quantities of colorful phenolic compounds and pigments are dissolved in more polar solvents, resulting in darker oils. Similar effects have been observed in other seed oils [18].

Specific gravity (SG) is another vital parameter indicative of the quality and composition of oil through the density of lipid molecules. The major value below 32 g/L (0.90 S) relates to the percentage concentration of long-chain triglycerides, unsaponifiable matter, and other dense components [19]. Figure 3**c** illustrates that oil extracted using ethyl acetate solvent had the lowest SG (0.79 $\pm$ 0.03), indicating a lighter composition with a smaller percentage of heavy lipid fractions. On the contrary, the oils extracted with either petroleum ether (1.78 $\pm$ 0.16) or *n*-hexane (1.85 $\pm$ 0.43) exhibited higher SG values, indicating that a larger percentage of nonvolatile long-chain triglycerides or trace components contributed to the higher density. The higher SG values of the oils collected using nonpolar solvents are consistent with the higher solubility of the heavier and more hydrophobic constituents of the seed matrix [20,21].

The amount of free fatty acids in the oils was determined using the acid value (AV) as a parameter of rancidity and oxidative degradation caused by hydrolysis. Smaller AV values are typically associated with increased storage stability and reduced triglyceride hydrolysis. However, larger AV values can be indicative of either lipid oxidation or extended solvent exposure. The AVs of sandalwood seed oils extracted with petroleum ether (10.90 mg KOH g^{-1}) and ethyl acetate (25.95 mg KOH g^{-1}) are shown in Figure 3d. Oil produced by petroleum ether and *n*-hexane extraction gave similar values of acidity (10.90 and 11.32 mg KOH g^{-1}), each much lower than those of ethyl acetate extraction. This finding can be explained by the middle polarity of ethyl acetate, which increases the extraction of polar compounds and may lead to partial hydrolysis of triglycerides during the process of reflux [22]. The AV values obtained here are marginally higher than those previously reported for *S. album* seed oil extracted with *n*-hexane (0.748 mg KOH g^{-1}) [23]. This discrepancy could be explained by variations in seed maturity, storage, or environmental source. Nevertheless, the relatively low AV obtained with petroleum ether extraction implies low degradation and thus good oxidative stability. The same effect has been noted in the case of *Moringa oleifera* and *Nigella sativa* seed oils, for which nonpolar solvents

Table 1: Physico-chemical characteristics of sandalwood seedoil. [Source: Authors]

No.	Description	Characteristics features of the sample		
		Petroleum ether	Ethyl acetate	n-hexane
1	Color	Pale greenish yellow	Brown yellow	Pale yellow
2	Appearance	Wax	Wax	Wax
3	Specific gravity (room temperature)	1.78 0.16	0.79 0.03	1.85 0.43
4	Acid value	10.90 0.48	25.95 0.94	11.32 2.09
5	Saponification value	3.06	11.57	20.23

tend to give rise to oils that are less acidic and offer higher stability[24].

The saponification value (SV)—the number of grams of alkali required to saponify one gram of oil—provides an impression of the mean quantity of oil fatty acids. The SV was generally lower for longer and heavier fatty acid chains and higher for shorter chains in both the *n*-hexane and ethyl acetate extracts, between 93–197 mg KOH g^{-1}, as shown in Figure 3e. The relatively small SV of the *n*-hexane extract suggests the greater presence of larger triacylglycerols and a predominance of long-chain unsaturated fatty acids. On the other hand, the higher SV of the ethyl acetate extract indicates that it contains a higher percentage of shorter-chain lipid species which are more easily saponifiable. Petroleum ether extraction produced intermediate values of SV, indicating intermediate extraction performance and lipid composition. Overall, these results demonstrate that the higher the polarity of solvents, the smaller the molecules of lipids that can be identified, resulting in elevated SV values. This has previously been reported for *Sesamum indicum* and *Jatropha curcas* seed oils. Oils with SV less than 195 mg KOH g^{-1} are typically vegetable oils, while those with higher values (above 200 mg KOH g^{-1}) are typical of fats or hydrogenated oils[25,26]. In presented approach, the ethyl acetate extract could have uses for the manufacture of soap or detergents due to its SV.

Generally, these results indicate that solvent polarity is a significant determining parameter for physicochemical properties, purity, and stability of sandalwood seed oil. Petroleum ether-extracted oils showed moderate density, moderate acidity, and balanced SVs, indicating the presence of stable triglycerides with low rates of hydrolysis. In contrast, ethyl acetate extraction produced darker oils with higher acid and saponification values, perhaps due to the extraction of more polar, partially oxidized compounds. The extract collected using *n*-hexane had a higher density, indicating heavier lipid components. Among the solvents tested, petroleum ether was found to be the best solvent for extracting sandalwood seed oil with the optimum physicochemical characteristics.

Chemical composition of sandalwood seed oil

The chemical profiles of sandalwood seed oils extracted using ethyl acetate, *n*-hexane, and petroleum ether were analyzed by GC–MS, as shown in Figure 3a. The ethyl acetate oil extract contained five prominent peaks, with retention time values from 28.95 to 31.07 min, representing oleic acid and ximenynic acid, respectively. In contrast, the oil extracted using *n*-hexane had 12 peaks, with the biggest percentage being cis-vaccenic acid at 27.92 min and oleic acid at 32.99 min. Meanwhile, the oil extracted using petroleum ether showed only one major peak at 29.72 min, which was attributed to a low concentration of ximenynic acid. The *n*-hexane and petroleum ether extracts had lower concentrations of ximenynic acid (1.21% and 1.21%, respectively) compared to the ethyl acetate extract (24.10%). The biochemical potential of sandalwood seed oil in the cosmetic and pharmaceutical industries are related to the breakdown of major fatty acids, including ximenynic acid, and related anti-inflammatory and skin-protective properties[27]. The recorded dissimilarities in fatty acid solvency between the tested solvents can be explained by polarity-related solubility distinctions. Ethyl acetate is moderately polar and more effective for extracting oxygenated lipids and conjugated polyunsaturated fatty acids compared to nonpolar solvents like *n*-hexane and petroleum ether, which selectively dissolve neutral triglycerides[28].

Previous reports on oil extractions, from seeds such as *Nigella sativa* and *Jatropha curcas*, have shown yields of ethyl acetate containing more unsaturated fatty acids compared to extracts using nonpolar solvents[20,29]. Here, we saw favorable increased levels

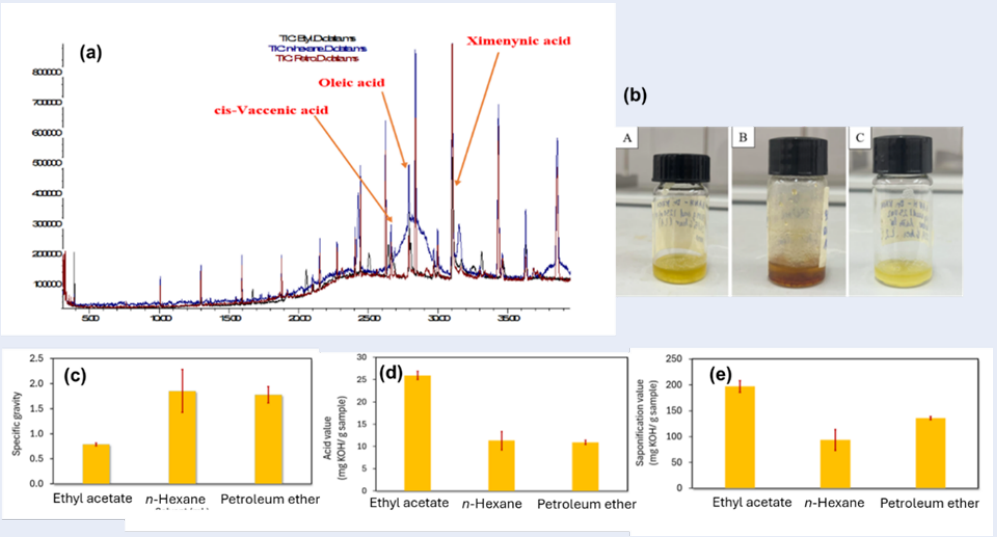

Figure 3: (a) GC–MS chromatogram of sandalwood seed oil;(b) Visual appearance of oils extracted with different solvents: A – petroleum ether, B – ethyl acetate, C – n-hexane; (c) specific gravity, (d) acid value; and (e) saponification value under corresponding extraction conditions. [Source: Authors]

of ximenynic acid in the ethyl acetate extract, and the oil obtained had a higher acid content and darker color, suggesting it was partially oxidized and less stable. Further, the data provided by the GC–MS results confirmed the physicochemical data, as petroleum ether produced the most stable oil fraction with adequate contents of unsaturation, while ethyl acetate produced the highest ximenynic acid recovery at the cost of oxidative stability.

DISCUSSION

The seed-to-solvent ratio is a significant determinant of the efficiency of extraction. The extraction yield results indicated that efficiency declined with increasing quantity of seed relative to solvent. This can be explained by the fact that a high density of crushed seeds prevents the penetration of the solvent and effective contact between the solvent and the plant matrix, causing incomplete leaching of lipids. The maximum yield was obtained at 30 g of seed per 250 mL of solvent, implying that this is the optimum ratio to use in future research.

Interactions between solvent polarity, solubility, and the chemical composition of the oil dominated the effects of solvent type on the extraction yield. We observed that petroleum ether and *n*-hexane extracted more oil, as nonpolar solvents with good lipid solubility. In contrast, ethyl acetate, a semi-polar solvent, did not interact effectively with hydrophobic compounds and thus produced lower extraction yields. The maximum oil yield was obtained under the optimal extraction condition of 30 g of seed per 250 mL of petroleum ether.

The polarity of the solvents was also reflected in the visual appearance of the extracted oils. The oils obtained using petroleum ether, *n*-hexane, and ethyl acetate had pale greenish-yellow, pale yellow, and dark brownish-yellow colors, respectively. These differences in color were most likely attributable to co-extraction of pigments and other smaller compounds, which are influenced by the solvent polarity.

Furthermore, physicochemical analysis and GC–MS samples revealed that the polarity of solvents caused extensive changes, not only in the extraction yield but also in the quality, stability, and compositional characteristics of the produced sandalwood seed oil. Among the three tested solvents, petroleum ether produced oil with no thermal or hydrolytic degradation. The AV was low, and the SV was moderate, meaning that long-chain triglycerides were extracted primarily by relatively nonpolar solvents, and an insignificant amount of free fatty acids was formed. Conversely, oils extracted using ethyl acetate showed higher acid and saponification indices, likely due to extraction of more polar degradation products and shorter-chain lipid fractions.

The GC–MS data also indicated that oils extracted with petroleum ether and *n*-hexane had more ximenynic and oleic acids. Since these are nonpolar sol-

vents, they better dissolve hydrophobic fatty acids, resulting in cleaner chromatographic profiles and fewer minor peaks. Conversely, the ethyl acetate extract exhibited a wider spectrum of minor elements, as it can dissolve lipid compounds as well as semi-polar compounds. However, this more extensive profile of extraction also indicates enhanced acidity and stability of the oils recovered using ethyl acetate.

Overall, petroleum ether was the solvent with the highest performance for effectively extracting sandalwood seed oil. Besides having the highest extraction yield at the best ratio of seed-to-solvent, this method also retained important fatty acids and reduced chemical degradation. These findings illustrate that Soxhlet petroleum ether extraction is a prospective technique for extracting bioactive oil of *S. album* grown in Vietnam, yielding oils with good physicochemical properties and a preferential fatty acid profile.

CONCLUSION

In this study, sandalwood (*S. album* L.) seed oil was successfully extracted using the Soxhlet extraction method. Among the solvents evaluated (petroleum ether, *n*-hexane, and ethyl acetate), the highest oil yield ($12.68\% \pm 1.44\%$) was obtained using petroleum ether at a seed-to-solvent ratio of 30 g seeds per 250 mL solvent, over an extraction period of 6 h. Under these conditions, the extracted oil possesses low AV (10.90 ± 0.48 mg KOH g^{-1}), a moderate SV, and suitable specific gravity (1.78 ± 0.16), indicating relatively high purity and good oxidative stability. In contrast, extraction with ethyl acetate yielded oil with the highest AV and a darker color, suggesting lower stability and partial oxidation. GC–MS analysis further confirmed that these oils were rich in bioactive fatty acids, particularly ximenynic and oleic acids, which are well known for their anti-inflammatory and anti-aging activities. Overall, the findings of this study indicate that Soxhlet extraction is a cost-effective and practical approach for obtaining high-quality sandalwood oil. This study also highlighted sandalwood seeds as potential sustainable sources of anti-inflammatory properties, with promising future cosmetic and pharmaceutical applications.

ABBREVIATIONS

AV: Acid value
GC-MS: Gas chromatography – Mass spectroscopy
NIST: National Institute of Standards and Technology
SG: Specific gravity
SV: Saponification value

COMPETING INTERESTS

The author(s) declare that they have no competing interests.

AUTHOR CONTRIBUTION

Anh Hue Lam: investigation, writing – original draft, data curation and formal analysis
Khoa Tran: supervision
Thanh Khoa Phung: supervision, writing – review & editing

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