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Evaluation of the Refining Process of Tamanu Oil (*Calophyllum inophyllum* L.)

HONG NGUYET THI NGUYEN, THIEN PHU NGUYEN NGO, THUONG NHAN PHU NGUYEN and HUYNH CANG MAI*

Faculty of Chemical Engineering and Food Technology, Nong Lam University, Ho Chi Minh City 700000, Vietnam

*Corresponding author: E-mail: maihuynhcang@hcmuaf.edu.vn

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This study established an optimised laboratory-scale refining process for *Calophyllum inophyllum* L. (Tamanu) oil, consisting of three key stages: resin removal, neutralisation and decolorisation. The refined oil exhibited a remarkable improvement in quality, with the acid value reduced by over 99% (from 54.582 mg KOH/g to 0.112 mg KOH/g) and viscosity decreased from 98.667 mPa·s to 42.9 mPa·s indicating the effective elimination of free fatty acids and impurities. The optimal parameters were identified as 90% ethanol at 50 ºC for resin removal (oil recovery approximately 81.85%, resin removal approximately 62.7%), a KOH/oil ratio of 0.2 (w/w) at 65 ºC for neutralisation (acid value approximately 0.084 mg KOH/g) and 2.5% activated clay at 90 ºC for 15 min for decolorisation (colour removal approximately 7.8%). The final product complied with the specifications of the Vietnamese Pharmacopoeia V, exhibiting a clear, golden appearance indicative of high purity. The structural integrity was confirmed by the preservation of triglyceride composition, suggesting minimal degradation or alteration during processing.

Keywords: Tamanu oil, Bleaching, Neutralizing, Separating resin.

INTRODUCTION

Tamanu (*Calophyllum inophyllum* L.) seed oil is a valuable source of pharmacologically active constituents including calophyllolide, inophyllic acid, coumarins, xanthones, flavonoids, phospholipids and other phenolic compounds, which are associated with antimicrobial, anti-inflammatory and antioxidant properties [1], as well as wound-healing and skin-regenerative effects, supporting its application in pharmaceutical and cosmetic formulations [2]. In addition to these uses [3], tamanu oil has been explored as a renewable feedstock for biodiesel production [4] and as a precursor for biodegradable polymeric materials, where ethanol-soluble resin fractions contribute to enhanced antioxidant activity [5]. Furthermore, novel xanthone derivatives have been reported from related *Calophyllum* species [6]. In Vietnam, *C. inophyllum* is widely distributed across tropical regions of Asia, Africa and the Pacific [7], with established traditional uses such as oil extraction for lighting, soap making and cosmetic applications. Ethnomedicinally, it has been employed for the treatment of rheumatic and dermatological conditions, while diluted latex has been used for ocular irritation in certain regions [8].

Despite its broad potential, conventional extraction and refining methods often result in limited oil recovery and may lead to partial degradation or transformation of sensitive bioactive compounds. This highlights the need for improved and sustainable refining strategies that enhance yield while preserving functional constituents [9].

The present study aims to develop and optimise a laboratory-scale refining process for tamanu oil to improve its physico-chemical quality, maximise recovery efficiency and retain bioactive integrity. The process focuses on three key stages *viz*. resin removal using ethanol, neutralisation for effective reduction of free fatty acids (FFA) and decolourisation using activated clay. The refined product is expected to meet pharmacopoeial standards, preserve triglyceride structure and biological activity, and be suitable for pharmaceutical and cosmetic applications.

EXPERIMENTAL

Tamanu oil was extracted from the seeds of *Calophyllum inophyllum* which is originating from Chau Thanh district (10.30078ºN, 106.34587ºE), Ben Tre province of Vietnam. The chemicals used included ethanol (C_2H_6O, 96% purity), activated clay, phosphoric acid (H_3PO_4, 85% purity), ethyl acetate ($C_4H_8O_2$, 99% purity), petroleum ether (96%) were purchased from Xilong, Xilong Scientific Co., Ltd., China.

Oil refining process: The refining of crude Tamanu oil was achieved through a sequential three-stage process designed to progressively eliminate impurities and enhance oil quality. Initially, in the resin removal stage, the oil was treated with 80-96% ethanol at 30-60 ºC under continuous stirring for 5-15 min, using an oil-to-solvent ratio (w/v) of 1:1 to 1:4, after which the mixture was heated in a water bath at around 70 ºC to recover the ethanol. The partially purified oil is then subjected to neutralisation, where a 20% KOH solution is added at controlled temperatures of 50-80 ºC with an oil-to-alkali ratio (w/w) of 1:0.15-1:0.2 to remove free fatty acids through soap formation; the soap was separated by centrifugation, followed by washing with distilled water and drying to eliminate residual alkali. Finally, in the decolourisation stage, the oil was treated with 1-10% activated clay at 60-80 ºC with stirring for 10-20 min and the clay was subsequently removed by centrifugation, yielding a clear, high-quality refined Tamanu oil.

Determination of viscosity: The viscosity of Tamanu oil was measured by Brookfield viscometer based on TCVN 11196:2017 (National Standard TCVN 11196:2017 on Bitumen, Method of Determination of Brookfield Viscosity, n.d.).

Determination of acid value: The acid value was determined by titrating the sample, dissolved in a ethanol solvent, with a 0.1 N KOH standard solution to neutralize the free fatty acids present, using phenolphthalein as indicator. The analysis was performed in accordance with the TCVN 6045: 1995 standard for the determination of acid value and acidity in animal and vegetable fats and oils.

Determination of saponification value: The saponification value was determined by measuring the number of milligrams of KOH required to saponify 1 g of fat. The analysis was carried out in accordance with TCVN 6126:2015 (ISO 3657:2013), the standard method for determining the saponification value of animal and vegetable fats and oils.

GC-MS analysis: The GC-MS analysis of the headspace was carried out of Tamanu oil. A 25 µL sample was diluted in 1.0 mL of *n*-hexane for analysis. The GC-MS system operated with helium as carrier gas at a flow rate of 1.0 mL/min, with a split ratio of 1:100 (v/v). The injection volume was set at 1.0 µL and the injection temperature was maintained at 250 ºC. The oven temperature program conditions were as follows: the initial temperature of 50 ºC was held for 2 min, then increased at a rate of 2 ºC/min until reaching 150 ºC, followed by an increase at a rate of 10 ºC/min to 200 ºC and finally increased to 300 ºC at a rate of 20 ºC/min, held for 5 min.

Statistical analysis: All the experiments were conducted with three replicates and the results are presented as mean ± standard deviation. ANOVA (analysis of variance) was conducted at a 95% confidence level. ANOVA and LSD analysis were conducted to compare the differences between treatments using IBM SPSS Statistic 20. All data were processed and graphically represented using Microsoft Excel.

RESULTS AND DISCUSSION

Physico-chemical properties of Tamanu oil: Table-1 presents the analytical results, demonstrating that the refining process of Tamanu oil led to substantial improvements in key physicochemical properties, thereby enhancing its suitability for pharmaceutical, cosmetic and potential food applications. A remarkable reduction in acid value (>99%) was observed, decreasing from 54.582 mg KOH/g to 0.112 mg KOH/g, indicating near-complete removal of free fatty acids (FFAs). This value is significantly below the commonly accepted limit of 4 mg KOH/g for oils used in pharmaceutical and cosmetic formulations, reflecting the high efficiency of the neutralisation stage and improved oxidative stability of the refined oil.

In addition, viscosity decreased from 98.667 mPa·s to 42.9 mPa·s, indicating effective removal of viscous impurities. This reduction can be attributed to the elimination of FFAs, resinous materials, and phospholipid-type compounds that contribute to strong intermolecular interactions in crude oil. GC-MS analysis further supports this observation, revealing the disappearance of major free fatty acids such as oleic, palmitic and stearic acids after refining. Consequently, the refined oil matrix becomes predominantly composed of triglycerides and fatty acid methyl esters, which exhibit lower resistance to flow, resulting in decreased viscosity.

A slight reduction in specific gravity suggests the removal of heavier constituents such as gums, waxes and other organic residues. Meanwhile, the saponification value showed only a marginal decrease (~1%), indicating that the triglyceride content, representing the valuable bioactive fraction of the oil, remained largely preserved. When compared with previous studies, the present work demonstrates superior refining efficiency. For instance, Betiku *et al.* [10] reported a reduction in acid value from 35.68 to 1.68 ± 0.57 mg KOH/g following esterification, along with a viscosity of 52.96 mPa·s. In contrast, the significantly lower acid value and viscosity achieved in this study highlight the effectiveness of the optimised refining conditions in removing FFAs and associated impurities.

To further emphasise the novelty of the proposed method, comparative data presented in Table-2 show that the final acid value (0.112 mg KOH/g) is considerably lower than those reported in earlier studies (typically 0.2-1.68 mg KOH/g). Similarly, the lower viscosity (42.9 mPa·s) indicates enhanced purification efficiency. These findings confirm that the integrated approach, comprising ethanol-based resin removal, alkaline neutralisation and activated clay decolourisation, offers a highly effective strategy for improving the quality,

TABLE-1
PHYSICO-CHEMICAL PROPERTIES OF TAMANU OIL BEFORE AND AFTER REFINING

Parameter	Crude Tamanu oil	Refined Tamanu oil
Viscosity (mPa·s)	98.667	42.9
Relative density	0.941 ± 0.0014	0.9102 ± 0.001
Acid value (mg KOH/g sample)	54.582 ± 0.816	0.112 ± 0.001
Saponification value (mg KOH/g sample)	182.559 ± 0.875	180.837 ± 2.355

TABLE-2
COMPARISON OF THE REFINING EFFICIENCY WITH PREVIOUS STUDIES

Raw material	Refining method	Acid value after treatment (mgKOH/g)	Viscosity (mPa·s)	Oil recovery (%)	Key findings	Ref.
Tamanu oil	Esterification	1.68 ± 0.57	52.96	–	Moderate removal of FFA	[10]
Tamanu oil	Alkali neutralisation	~0.2	–	–	Effective FFA reduction using NaOH	[11]
Tamanu oil	Mixed solvent extraction	–	–	82.8	High resin separation efficiency	[12]
Tamanu oil	Alkali neutralisation	~0.2	–	–	Optimal stirring time 10-15 min	[13]
Tamanu oil	Ethanol resin removal + KOH neutralisation + clay bleaching	0.112	42.9	81.85	Higher deacidification efficiency and improved viscosity reduction	Present study

stability and applicability of Tamanu oil while preserving its essential bioactive components.

Resin separation process

Effect of solvent concentration and temperature: In this experiment, the effects of temperature (30-60 ºC) and ethanol solvent concentration (80, 90, 96%) on oil recovery yield and resin removal efficiency were investigated. Both factors showed a significant influence on the two performance parameters (Fig. 1). Two-way analysis of variance (ANOVA) confirmed that the solvent concentration had a statistically significant effect on both oil recovery yield ($p < 0.05$) and resin removal efficiency ($p < 0.05$). The interaction between solvent concentration and temperature was also statistically significant, indicating that these two factors simultaneously affected resin removal efficiency ($p < 0.05$) (Fig. 1a). This suggests that while oil recovery yield primarily depends on the solvent type, the combination of temperature and solvent concentration is the determining factor for resin removal efficiency. Based on the ranking results, ethanol 80% (EtOH80) exhibited the highest oil recovery yield at most temperature levels, with statistically significant differences compared to other concentrations ($p < 0.05$). However, when the goal was impurity removal, ethanol 90% (EtOH90) showed a significantly higher resin removal rate compared to both EtOH80 and EtOH96. Particularly, EtOH90 stood out for maintaining a stable and high resin removal efficiency across the entire temperature range tested.

The specific results (Fig. 1b) indicated that the optimal condition for resin removal was obtained using 90% ethanol (EtOH90) at 50 ºC, achieving an oil recovery yield of 81.85% and a resin removal efficiency of 62.70%. Although EtOH90 produced an oil recovery yield about 5-10% lower than that of EtOH80, it offered a crucial advantage in resin removal, which is vital to improve oil quality. The selection of EtOH90 is reasonable due to its medium polarity, which allows effective lipid dissolution while efficiently removing highly polar impurities (such as phenolic and coumarin compounds). The removed "resin" fraction mainly consists of polar and semi-polar secondary metabolites naturally present in *C. inophyllum* oil including phenolic compounds, coumarins, xanthones and other resinous substances. These compounds generally have higher polarity than triglycerides, which are the dominant non-polar constituents of the oil. Therefore, the use of aqueous ethanol (particularly 90% ethanol) facilitates the selective dissolution of these polar and semi-polar compounds while maintaining most of the non-polar lipid fraction in the oil phase. This polarity-based partitioning explains the effective removal of resinous impurities during the ethanol treatment step. Furthermore, the observed trend of increasing oil recovery yield from 30 ºC to 50 ºC, followed by a slight decline at 60 ºC (possibly due to solvent evaporation), aligns well with the ethanol-based resin removal mechanism. This conclusion is completely consistent with the physico-chemical properties of Tamanu seed oil reported in previous studies such as Singh *et al.* [14], which indicated that *C. inophyllum* oil has a high content of unsaturated fatty acids such as oleic acid (~44.5-58%) and linoleic acid (~12-21%). Therefore, choosing EtOH90 as the main extraction solvent is a reasonable choice, not only based on experimental data but also reinforced by the molecular structure characteristics of the chemical components in Tamanu oil.

Influence of raw material/solvent ratio and stirring time: A consistent increase in both oil recovery and resin separation efficiencies with increasing stirring time across all raw material-to-solvent ratios (Fig. 2). The highest oil reco-

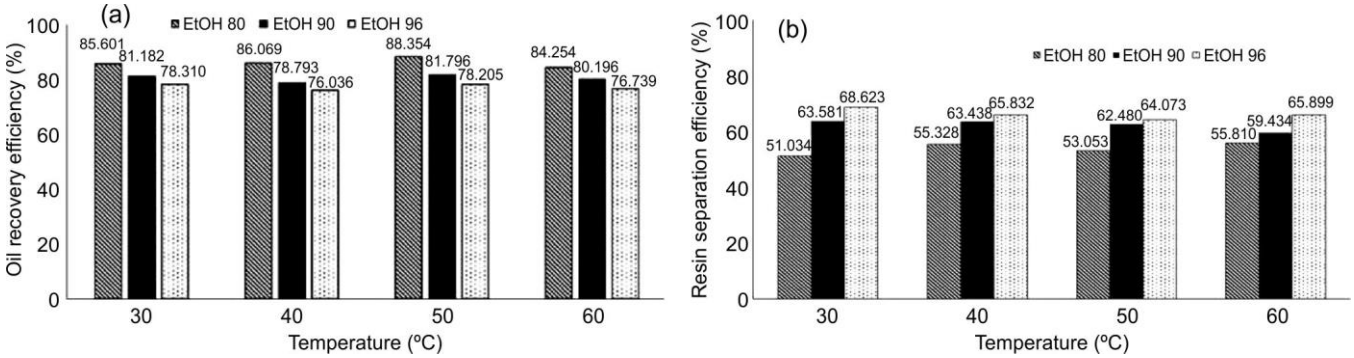

Fig. 1. Effect of ethanol concentration and temperature on (a) oil recovery yield and (b) resin removal efficiency

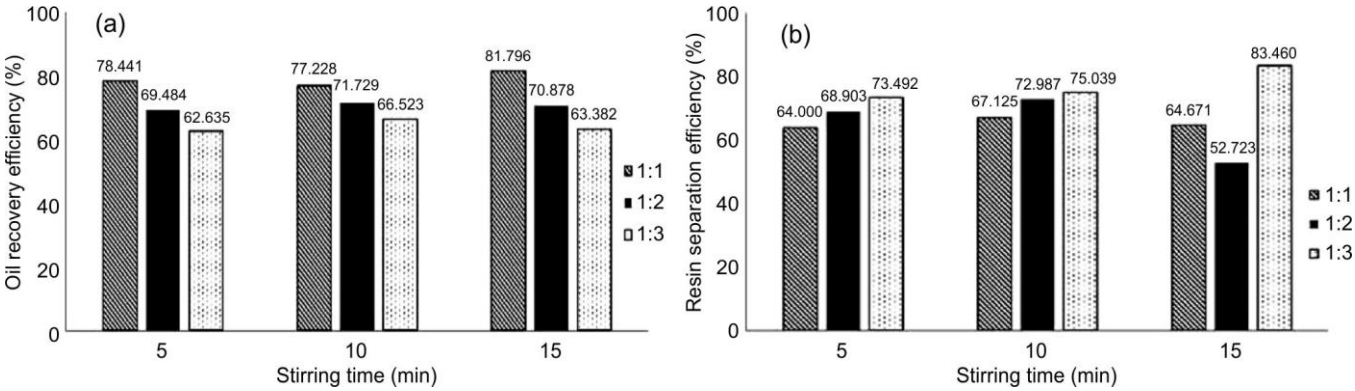

Fig. 2. Influence of raw material/solvent ratio and stirring time on (a) oil recovery and (b) resin separation efficiency

very, 81.80%, was obtained at a ratio of 1:1 with a stirring time of 15 min, while the maximum resin separation efficiency, 83.46%, was achieved at a ratio of 1:3 under the same conditions. These findings indicate that lower solvent ratios favour oil recovery, whereas higher solvent ratios promote more effective removal of resinous impurities.

Statistical analysis confirms that the 15 min treatment produced significantly higher efficiencies compared to 5- and 10 min intervals. The resin separation efficiency consistently remained highest at the 1:3 ratio, exceeding 82% at 15 min, further supporting the role of increased solvent volume in enhancing impurity removal.

The performance observed in this study is comparable to that reported by Rajendran & Gurunathan [12], who achieved a resin removal efficiency of 82.8% using a mixed solvent system over a longer extraction time of 45 min. In contrast, the present method achieves similar efficiency within only 15 min using a single solvent system, demonstrating improved process efficiency and operational simplicity. In addition, the oil recovery of approximately 80% is significantly higher than values reported for ultrasound-assisted extraction using *n*-hexane, which are typically around 55-55.44%. This highlights the advantage of the current approach in achieving both higher yield and reduced processing time. Considering the need to balance high oil recovery with efficient resin removal, the use of 90% ethanol at a solvent ratio of 1:2 represents the most suitable condition. This intermediate ratio avoids the lower resin removal observed at 1:1 and the reduced oil recovery associated with 1:3, thereby providing an optimal compromise between yield and purification efficiency.

Neutralisation process

Effects of temperature and KOH/oil ratio (w/w): The results presented in Fig. 3, supported by two-way ANOVA, demonstrate that both the KOH-to-oil ratio (w/w) and neutralisation temperature significantly influence the acid value of Tamanu oil ($p < 0.05$). A statistically significant interaction between these factors was also observed, indicating that the effect of the KOH-to-oil ratio depends on the applied temperature and *vice-versa*. An increase in the KOH-to-oil ratio from 0.15 to 0.2 resulted in a general decrease in acid value. The LSD test confirmed that the ratio of 0.2 produced the lowest mean acid value (0.170 mg KOH/g), significantly different from the lower ratios. With respect to temperature, 65 ºC and 80 ºC showed no significant difference between them, yet both were significantly more effective than 50 ºC.

At 50 ºC, only a marginal reduction in acid value was observed with increasing KOH dosage and the values remained relatively high, ranging from 0.196 to 0.504 mg KOH/g. In contrast, at 65 ºC, a KOH-to-oil ratio of 0.2 achieved the most efficient neutralisation, reducing the acid value to 0.084 mg KOH/g. Increasing the temperature further to 80 ºC did not improve neutralisation efficiency, even at higher alkali concentrations. These findings are consistent with previous studies. Mohadesi *et al*. [11] reported that increasing the base concentration (NaOH/KOH) significantly reduces acid value, although exceeding the optimal ratio offers no additional benefit and may promote unwanted saponification. Similarly, studies on *C. inophyllum* oil neutralisation using NaOH have reported acid values around 0.2 mg KOH/g at a base-to-oil ratio of 0.2,

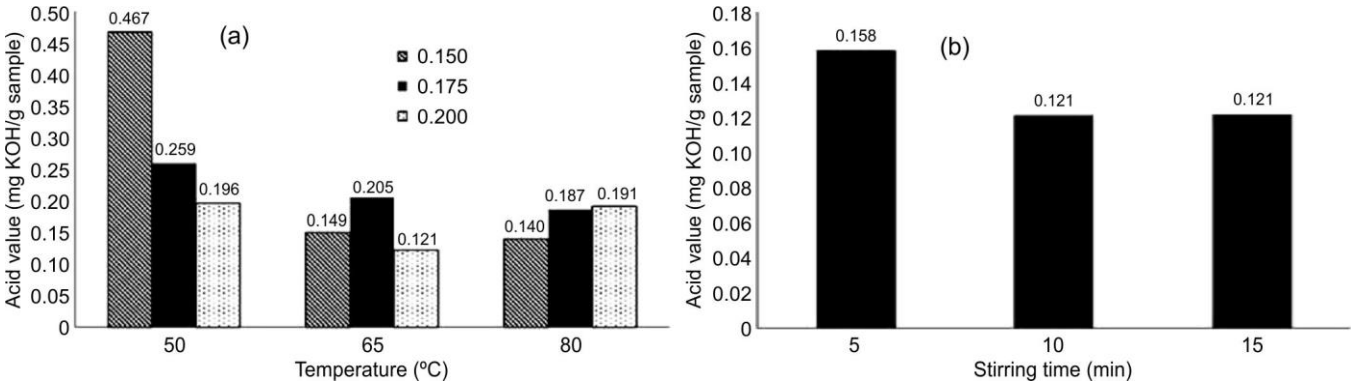

Fig. 3. Effect of neutralisation conditions on Tamanu oil quality (a) temperature and KOH/oil ratio and (b) stirring time

aligning closely with the present results. The consistent decrease in acid value with increasing base concentration suggests a stable neutralisation behaviour of Tamanu oil. Minor variations in optimal conditions across studies can be attributed to differences in initial oil composition, particularly free fatty acid content, as well as variations in processing parameters such as reaction time, agitation and solvent system.

Influence of stirring time on the acid value: The results presented in Fig. 3, supported by ANOVA, indicate that stirring time influences the acid value of Tamanu oil; however, the effect is not statistically significant ($p > 0.05$). The lowest acid value, 0.084 mg KOH/g, was obtained at 15 min, whereas values at 5 and 10 min ranged from 0.121 to 0.158 mg KOH/g. Despite these numerical differences, Tukey and Duncan tests confirmed the absence of statistically significant variation among the time intervals.

These findings indicate that the neutralisation reaction approaches completion within approximately 10 min, and extending the duration to 15 min does not result in a meaningful reduction in acid value. This behaviour suggests that the system reaches near-equilibrium within a short reaction time under the selected conditions. This trend is consistent with earlier reports. Liu *et al*. [15] observed that increasing stirring time beyond 10 min did not significantly reduce free fatty acid content during the neutralisation of non-food oils. Similarly, Wulandari *et al*. [13] reported an optimal stirring time in the range of 10-15 min for *C. inophyllum* oil under controlled agitation, after which the efficiency of neutralisation reached a plateau. Comparable observations were reported by Mao *et al*. [16] indicating that stirring time is not a determining parameter once the KOH-to-oil ratio and temperature are appropriately optimised. Thus, adequate stirring is required to ensure proper mixing and completion of the neutralisation reaction; however, extending the duration beyond 10-15 min does not significantly improve acid value reduction under the studied conditions.

Bleaching process

Effect of clay percentage on oil colour separation percentage: The tabulated results, including ANOVA and post hoc (Duncan and Tukey HSD) analyses indicate that the clay ratio significantly influences colour removal efficiency. Variation in clay content from 1% to 10% resulted in statistically significant differences in decolourisation performance, confirming that adsorption efficiency is strongly dependent on the amount of clay applied.

The highest colour removal efficiency was obtained at a clay ratio of 2.5%, with an average value of 7.82% under identical conditions. In contrast, the lowest efficiency was observed at 10.0%, with a value of 1.88% (Fig. 4a). These results indicate that increasing clay content does not necessarily enhance decolourisation performance and exceeding the optimal level may reduce efficiency. The 2.0% and 2.5% groups exhibited the highest efficiencies and were classified within the same statistical subset in both Duncan and Tukey tests, showing significant differences from the remaining treatment levels.

One-way ANOVA further confirmed that the effect of clay ratio on decolourisation efficiency is statistically significant ($F = 282.511$; $p = 0.000$), with differences among groups significant at the 95% confidence level ($p < 0.05$). Ranking analysis identified the 2.0-2.5% range as the most effective, outperforming the 1%, 5%, 7.5% and 10% treatments. The 10.0% ratio formed a distinct group with significantly lower efficiency. This behaviour suggests that excessive clay loading may lead to adsorption site saturation or reduced mass transfer efficiency, thereby limiting effective interaction between the oil and the adsorbent.

Effect of temperature and stirring time: The results presented in Fig. 4b, together with ANOVA and post hoc analyses (Tukey HSD and Duncan tests), indicate that both decolourisation temperature and stirring time exert statistically significant effects on oil decolorisation efficiency ($p = 0.000$ for all main factors). At the 95% confidence level, variations in these parameters significantly influence the percentage of colour removed during activated clay treatment. Post hoc analysis reveals clear differences among stirring time levels. A duration of 15 min produced the highest average colour removal (6.2988%), exceeding values obtained at 10 min (5.9346%) and 20 min (5.3827%). This trend indicates that increasing the stirring time from 10 to 15 min enhances adsorption efficiency, whereas further extension to 20 min reduces performance, likely due to adsorption equilibrium or partial desorption effects.

Temperature also demonstrated a significant influence on decolourisation efficiency. The highest average colour removal was observed at 90 ºC (6.7793%), followed by 50 ºC (5.6420%), while the lowest value was recorded at 70 ºC

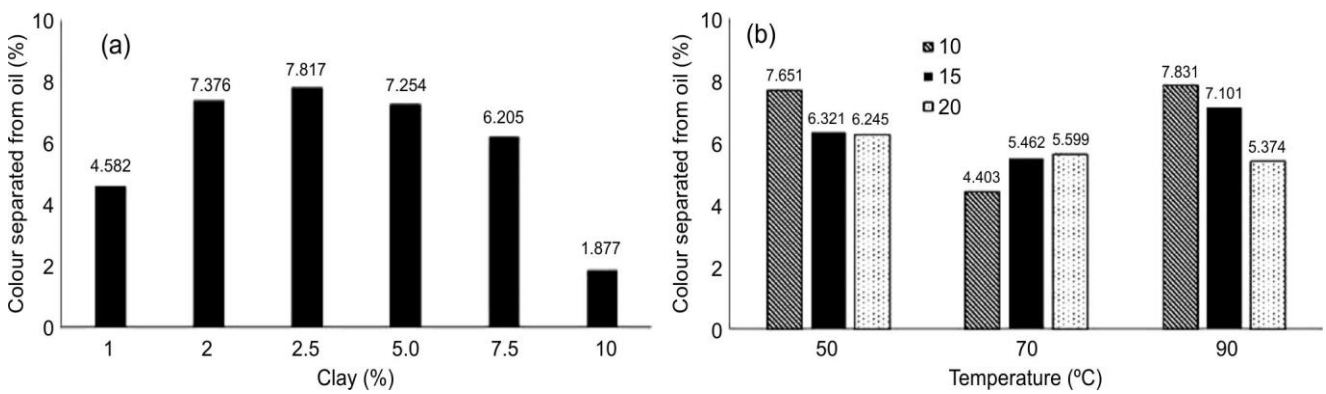

Fig. 4. Effect of bleaching conditions on colour removal efficiency (a) clay percentage and (b) temperature and stirring time

TABLE-3
FATTY ACID COMPOSITION OF TAMANU OIL

Compound name	Compound group classification	Before refining	After refining
Hexadecanoic acid, methyl ester (methyl palmitate)	FAME (Este methyl)	Present	Present
n-Hexadecanoic acid (palmitic acid)	FFA (free fatty acid)	Present	Absent
Hexadecanoic acid, ethyl ester (ethyl palmitate)	FAEE (Este ethyl)	Present	Absent
9,12-Octadecadienoic acid (Z,Z), methyl ester	FAME (Este methyl)	Present	Present
9-Octadecenoic acid, methyl ester, (E)-	FAME (Este methyl)	Present	Present
Octadecanoic acid, methyl ester (methyl stearate)	FAME (Este methyl)	Present	Present
Oleic Acid	FFA (free fatty acid)	Present	Absent
Octadecanoic acid (stearic acid)	FFA (free fatty acid)	Present	Absent
Ethyl Oleate	FAEE (Este ethyl)	Present	Absent
Octadecanoic acid, ethyl ester (ethyl stearate)	FAEE (Este ethyl)	Present	Present
1-Docosanol, acetate	Impurities (phos-glycerides)	Present	Absent
Eicosanoic acid, methyl ester (arachidic acid methyl ester)	FAME (Este methyl)	Present	Present
Methyl hexadec-9-enoate	FAME (Este methyl)	Absent	Present
Heptadecanoic acid, methyl ester	FAME (Este methyl)	Absent	Present
Ethyl 9-octadecanoate	FAEE (Este ethyl)	Absent	Present

(5.1948%). The reduced efficiency at 70 ºC suggests that this intermediate temperature may not sufficiently facilitate the disruption of colour-associated compounds or optimise adsorption dynamics. These findings indicate that decolorisation efficiency does not follow a linear relationship with temperature but is governed by specific optimal conditions. The combined results identify 90 ºC and 15 min as the optimal conditions for achieving maximum colour removal. This outcome is consistent with adsorption mechanisms in which elevated temperature enhances molecular mobility and interaction with the adsorbent surface, while sufficient contact time ensures effective adsorption.

Decolorisation efficiency was determined from the reduction in absorbance measured by UV-Vis spectrophotometry before and after treatment. The achieved efficiency of approximately 7.8% is comparable to values reported in previous studies including Elangovan & Natarajan [17], indicating that the present method is effective. In conjunction with the clay ratio analysis, these findings support the selection of a 2.5% clay dosage as the optimal condition, balancing decolourisation efficiency, material usage and minimisation of residual adsorbent in the final oil product.

Fatty acid composition of Tamanu oil before and after refining: Fatty acid composition analysis confirms the high selectivity and efficiency of the Tamanu oil refining process. Undesirable free fatty acids (FFA) including palmitic acid (C16:0), oleic acid (C18:1), and stearic acid (C18:0), were effectively removed, consistent with the observed reduction in acid value. In addition, impurities such as ethyl oleate (FAEE) and 1-docosanol acetate, a long-chain fatty alcohol ester (C22), were eliminated, demonstrating the effectiveness of both the neutralisation and resin removal stages (Table-3). Importantly, beneficial fatty acid esters, including both saturated and unsaturated derivatives such as methyl palmitate and 9,12-octadecadienoic acid methyl ester, were preserved in the refined oil. This selective removal of undesirable components while retaining valuable lipid fractions indicates that the refining process enhances oil purity and oxidative stability without compromising its key bioactive constituents.

Conclusion

This study established an optimised laboratory-scale refining process for *C. inophyllum* L. (Tamanu) oil, comprising three stages *viz*. resin removal, neutralisation and decolourisation. The refining process resulted in substantial improvement in oil quality, with the acid value reduced by more than 99%, from 54.582 mg KOH/g to 0.112 mg KOH/g, and viscosity decreased from 98.667 mPa·s to 42.90 mPa·s. These changes confirm the effective removal of free fatty acids and associated impurities. The optimal conditions were identified as 90% ethanol at 50 ºC for resin removal, achieving an oil recovery of approximately 81.85% and resin removal efficiency of 62.7%; a KOH-to-oil ratio of 0.2 (w/w) at 65 ºC for neutralisation, resulting in an acid value of approximately 0.084 mg KOH/g; and treatment with 2.5% activated clay at 90 ºC for 15 min for decolourisation, achieving a colour removal efficiency of approximately 7.8%. The refined oil satisfied the requirements of Vietnamese Pharmacopoeia V, exhibiting a clear golden appearance while preserving the triglyceride structure. These findings demonstrate that the proposed process is effective in enhancing oil quality and provides a reliable basis for further scale-up and application in pharmaceutical and cosmetic formulations.

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CONFLICT OF INTEREST

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

DECLARATION OF AI-ASSISTED TECHNOLOGIES

During the preparation of this manuscript, the authors used an AI-assisted tool(s) to improve the language. The authors reviewed and edited the content and take full responsibility for the published work.

REFERENCES

1. C. Dweck and T. Meadows, *Int. J. Cosmet. Sci.*, **24**, 341 (2002); https://doi.org/10.1046/j.1467-2494.2002.00160.x
2. P. Raharivelomanana, J.L. Ansel, E. Lupo, L. Mijouin, S. Guillot, J.F. Butaud, R. Ho, G. Lecellier and C. Pichon, *Oilseeds Fats Crops Lipids*, **25**, D504 (2018); https://doi.org/10.1051/ocl/2018048
3. J. Girish, M. Gustiananda, R.G. Nandhira and P. Hartrianti, *Evid. Based Complement. Alternat. Med.*, **2021**, 6332867 (2021); https://doi.org/10.1155/2021/6332867
4. K. Venkanna and C.V. Reddy, *Bioresour. Technol.*, **100**, 5122 (2009); https://doi.org/10.1016/j.biortech.2009.05.023
5. M. Cassien, A. Mercier, S. Thétiot-Laurent, M. Culcasi, E. Ricquebourg, A. Asteian, G. Herbette, J.-P. Bianchini, P. Raharivelomanana and S. Pietri, *Antioxidants*, **10**, 199 (2021); https://doi.org/10.3390/antiox10020199
6. C. Morel, D. Séraphin, J.-M. Oger, M. Litaudon, T. Sévenet, P. Richomme and J. Bruneton, *J. Nat. Prod.*, **63**, 1471 (2000); https://doi.org/10.1021/np000215m
7. S. Ferdosh, *Sci. Pharm.*, **92**, 6 (2024); https://doi.org/10.3390/scipharm92010006
8. S.S. Erdogan, T.F. Gur, N.K. Terzi and B. Dogan, *J. Wound Care*, **30**, VI (2021); https://doi.org/10.12968/jowc.2021.30.Sup9a.V
9. W.M. Oo, *Int. J. Photochem. Photobiol.*, **2**, 28 (2018); https://doi.org/10.11648/j.ijpp.20180201.16
10. E. Betiku, E.A. Olatundun, D.A. Taiwo, O.F. Omotunde, V.I. Omofaye, B.A. Babalola, A.A. Agboola and L.M. Latinwo, *J. Oleo Sci.*, **73**, 1149 (2024); https://doi.org/10.5650/jos.ess24022
11. M. Mohadesi, B. Aghel, M. Maleki and A. Ansari, *Renew. Energy*, **136**, 677 (2019); https://doi.org/10.1016/j.renene.2019.01.039
12. N. Rajendran and B. Gurunathan, *Ind. Crops Prod.*, **162**, 113273 (2021); https://doi.org/10.1016/j.indcrop.2021.113273
13. W.N. Wulandari, M. Darsin and R.K.K. Wibowo, *AIP Conf. Proc.*, **2278**, 020010 (2020); https://doi.org/10.1063/5.0015792
14. L.B. Singh, K. Abirami and S. Rana, *Biotica Res. Today*, **2**, 298 (2020).
15. R. Liu, X. Guo, M. Cheng, L. Zheng, M. Gong, M. Chang, Q. Jin and X. Wang, *J. Food Sci. Technol.*, **56**, 3109 (2019); https://doi.org/10.1007/s13197-019-03810-w
16. D. Mao, J. Xia, B. Zhang and G. Lu, *Energy Convers. Manage.*, **51**, 1134 (2010); https://doi.org/10.1016/j.enconman.2009.12.022
17. E. Elangovan and S.K. Natarajan, *Environ. Prog. Sustain. Energy*, **41**, e13812 (2022); https://doi.org/10.1002/ep.13812