

HOMOGENIZER PRETREATMENT INTENSIFIES MICROWAVE-ASSISTED HYDRODISTILLATION OF PATCHOULI LEAVES FOR ENHANCED OIL YIELD AND PATCHOULI ALCOHOL ENRICHMENT

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ABSTRACT

This work evaluates whether homogenizer pretreatment can enhance microwave-assisted hydrodistillation (MAHD) for the extraction of patchouli oil (*Pogostemon cablin*) by assessing extraction efficiency, chemical composition, and biological properties. The study optimises homogenization parameters such as dispersion time and rotational speed to disrupt leaf cell structures and enhance oil release. The oil yield of 6.48% was achieved at 4000 rpm and 25 minutes, showing a significant improvement over conventional methods. The Box-Behnken response surface design method was used to study the interactions among leaf-to-water ratio, microwave power, and distillation time to accurately predict oil yield and patchouli alcohol concentration. Optimal MAHD conditions produced a significantly higher concentration of patchouli alcohol (40.57%) than traditional hydrodistillation (25.50%). However, the MAHD oil showed lower DPPH radical-scavenging activity, with an IC_{50} of 593.7 $\mu\text{g/mL}$ compared with 19.53 $\mu\text{g/mL}$ for the hydrodistilled oil, indicating that enhanced patchouli alcohol recovery was accompanied by reduced retention of some antioxidant-active sesquiterpenes. MAHD also exhibited measurable antibacterial activity against *Escherichia coli*, whereas no inhibition was observed for the hydrodistilled oil under the tested conditions. Overall, the results demonstrate that homogeniser pretreatment can intensify MAHD by improving oil recovery and selectively enriching patchouli alcohol, while process conditions must be controlled to minimise losses of heat-sensitive constituents. The findings provide a basis for further development of intensified and more resource-efficient extraction processes for value-added patchouli oil. This work supports Sustainable Development Goal 12 (Responsible Consumption and Production) by contributing to the development of more efficient and resource-conscious extraction technologies for plant-derived high-value products.

Keywords: Patchouli oil, Microwave-assisted hydrodistillation (MAHD), Homogenizer Pre-Treatment, Essential Oil Extraction Optimisation.

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INTRODUCTION

Patchouli oil is a highly valued essential oil from *Pogostemon cablin* leaves. This plant is found mainly in Southeast Asia, particularly in Indonesia, Malaysia, and the Philippines.¹ The essential oil is widely used in perfumes, serving as a fixative and base for its long-lasting aroma. In cosmetics, particularly in skincare, patchouli oil provides strong antimicrobial and anti-inflammatory properties. These effects can promote better skin health.² Traditionally, oil is used to treat headaches, fever, and digestive issues. It is still popular in aromatherapy for its pacifying and mood-boosting effects.³ Patchouli oil has traditionally been recovered by Soxhlet extraction, steam distillation, and hydrodistillation. However, these techniques have drawbacks such as requiring large amounts of dried plant material and solvents, involving long extraction times, and usually producing low oil yield.^{3,4} For instance, steam distillation conducted for 8 h

has been reported to produce only 2.2–2.8 kg of oil from 100 kg of dried patchouli leaves.⁵ MAHD has been introduced as a modern approach to address these drawbacks and raise efficiency.^{1,6-8} This method has yielded promising results, such as raising patchouli oil yield to 6.012% in 72 minutes—about 4 times more than traditional hydrodistillation. Other plant oils have shown similar improvements with microwave techniques.⁹ However, much of the essential oil remains trapped in intact leaf tissue because epidermal cell walls resist rupture during extraction.^{10,11} Therefore, disruption of the plant cell-wall structure through an appropriate pretreatment is necessary to enhance the liberation of essential oil. Past studies have applied physical techniques such as ultrasound (high-frequency sound waves), electrolysis (inducing a chemical reaction with an electric current), and electric fields (controlled electrical energy) to enhance efficiency.^{2,6,12-14} Barros *et al.*, (2022) used an electric field treatment on eucalyptus and rosemary leaves, boosting yields by 17% and 11%, respectively.¹³ However, there is little literature on combining mechanical pretreatment with a homogeniser (which physically breaks down tissue) and MAHD (which uses microwave energy and water to extract oil) for patchouli oil extraction. Homogenizers are used in industry to disperse solids in liquids and speed up mass transfer.^{15,16} The rotor-stator system generates high turbulence, enhancing molecular interactions and possibly disrupting plant cells. Our previous studies used homogenizers to improve biodiesel production and achieved 98.9% conversion in 10 minutes at room temperature with palm kernel ash as a catalyst.¹⁷ Homogenizers also use less energy than conventional equipment. For example, using a homogenizer to intensify the esterification reaction to produce isoamyl oleate saved 92% energy compared with the traditional reflux method.¹⁸ Based on this, this study examines how homogenizer pre-treatment affects patchouli oil yield using MAHD. The chemical profile of the oil—including patchouli alcohol, β -caryophyllene, α -guaiene, and seychellene—is analysed. The antioxidant and antimicrobial activities of the extracted oils are compared with those of oils obtained by conventional hydrodistillation. The development of efficient extraction technologies for plant-derived products aligns with Sustainable Development Goal 12 (SDG-12) by promoting sustainable consumption, efficient resource use, and process intensification through homogeniser-assisted MAHD to improve the recovery and value of patchouli oil.

EXPERIMENTAL

Materials

Patchouli leaves were obtained from local patchouli farmers in Tapak Tuan, Aceh, then dried, cut into smaller pieces, and kept in sealed glass containers until further use. The microwave is a home model adapted for the Stahl hydrodistillation tool.

Homogenizer Pre-Treatment Effect on Extraction of Patchouli Oil

The effect of homogenizer pretreatment on patchouli oil yield was evaluated at dispersion times of 5, 10, 15, 20, 25, and 30 min and rotational speeds of 2000 to 6000 rpm at 1000 rpm intervals. Forty grams of dried patchouli leaves was placed in a flask containing 600 mL of distilled water at a leaf-to-water ratio of 1:15. The mixture was stirred using a homogenizer, adjusting stirring time and speed. Following dispersion, the flask was transferred to a modified microwave system connected to a Stahl apparatus. The extract was then hydrodistilled for 5 hours at 630 watts. Next, patchouli oil was collected with a separating funnel, and saturated NaCl (aq) was added to form two layers, with oil on top. The oil was transferred to a vial, and anhydrous Na₂SO₄ was added to remove water. The patchouli oil was then stored for analysis.

Microwave Hydro-Distillation Extraction of Patchouli Oil

A Box-Behnken design experiment was employed to evaluate the effects of dried leaf-to-water ratio, microwave power, and extraction time. Each variable had three levels (see Table-1). Extraction conditions for hydrodistillation were optimised by measuring oil yield as the response. The pre-treatment for optimal MAHD used a 25-minute dispersion time and 4000 rpm.

Statistical Analysis

Statistical v14 software was used for graphical and regression analysis. The experiment had three factors, each with three levels, yielding 15 experimental sets plus three validation experiments. The relationship

between the experimental parameters and patchouli oil yield was described using a second-order polynomial model, and the optimum oil yield was determined using the quadratic model presented in Eqn.-1.

Table-1: Extraction Conditions used in Microwave Hydro-Distillation of Patchouli Oil

Symbols	Factors	Levels		
		Low	Medium	High
A	Ratio of leaf mass: water volume	1:10	1:15	1:20
B	Hydrodistillation time (hours)	3	4	5
C	Microwave power (%)	50	70	90

$$Y = \beta_0 + \sum_{i=1}^I \beta_i X_i + \sum_{i=1}^I \beta_{ii} X_i^2 + \sum_{i=1}^I \sum_{j=i+1}^J \beta_{ij} X_i X_j \quad (1)$$

Where Y = patchouli oil yield; X_i and X_j are the independent factors; and 0, i, ii and ij are the intercept, linear, quadratic, and interaction coefficients, respectively.

Antioxidant Activity Evaluation

The antioxidant activity of patchouli oil was assessed using the DPPH radical-scavenging assay according to the method reported by Recio-Cázares, *et al.*, 2024]. Oil samples dissolved in methanol were mixed with 0.1 mM DPPH solution and incubated for 30 minutes at room temperature. The absorbance was measured at 517 nm. Ascorbic acid was used as the positive control. Radical-scavenging activity was calculated as $[(A_0 - A_1)/A_0] \times 100$, where A_0 and A_1 represent the absorbance of the control and sample, respectively. The IC_{50} values were subsequently estimated by linear regression analysis.

Antimicrobial Activity Evaluation

Antimicrobial activity was assessed using the disk diffusion technique in accordance with CLSI (Clinical and Laboratory Standards Institute) guidelines. Patchouli oil was dissolved in DMSO to obtain concentrations of 6.25–50 mg/mL. Sterile 6-mm paper disks were loaded with 10 μ L of each sample concentration and placed on Mueller-Hinton agar plates previously inoculated with bacterial lawns. Gentamicin (10 μ g) and DMSO were used as positive and negative controls, respectively. The plates were incubated at 37 °C for 18–24 h, and the resulting inhibition zones were measured to the nearest 0.1 mm.

RESULTS AND DISCUSSION

The experimental data provide a thorough study of the optimisation of homogenizer pretreatment parameters for MAHD extraction of patchouli oil (*Pogostemon cablin*). Two critical parameters were evaluated: rotational time (5-30 minutes) and rotational speed (2000-6000 rpm), with oil yield measured across triplicate experiments.

The Effect of Rotational Time on Patchouli Oil Yield

The homogeniser pretreatment times markedly influenced patchouli oil yield from patchouli biomass at a constant rotational speed of 4000 rpm. Figure-1A depicted that increasing homogenization time from 5 to 25 minutes resulted in a considerable increase in oil yield. The lowest patchouli oil yields were recorded at the shortest treatment time of 5 minutes ($4.36\% \pm 0.2$), while the highest yields were achieved at 25 minutes ($6.43\% \pm 0.1$), indicating an optimal disruption of the plant cell structure for maximum oil liberation. This trend can be attributed to the mechanical shearing forces generated by the homogeniser, which facilitate the breakdown of cellular walls and promote solvent access to intracellular oil glands. Similar enhancements in oil yield have been reported in other studies of essential oil extraction employing mechanical pretreatments.⁶ However, a further increase in homogenization time beyond 25 minutes resulted in a decline in yield ($5.20\% \pm 0.1$ at 30 minutes). This phenomenon may result from the possible degradation of volatile components due to continued shear-induced thermal effects or from reabsorption of oil into biomass residues as the matrix becomes overly disrupted.²⁰ It is also plausible that prolonged homogenization generates heat in the mixture, releasing the essential oil into the atmosphere.^{21,22} These results show that 25 minutes is the optimal homogenization time under 4000 rpm to maximise oil extraction from patchouli.

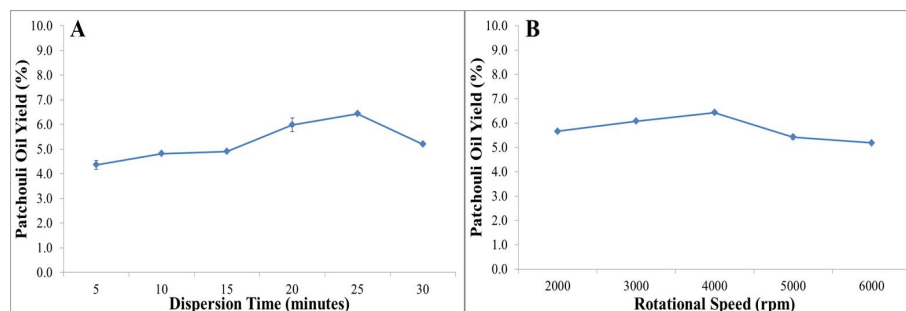


Fig.-1: The Effect of (A) Dispersion Time and (B) Rotational Speed on Patchouli Oil Yield

The Effect of Rotational Speed on Oil Recovery

The effect of rotational speed on patchouli oil yield was assessed at a constant homogenization time of 25 min. The experimental results show a parabolic trend: the oil yield increased with speed up to 4000 rpm and declined thereafter (Fig.-1B). At 2000 rpm, the oil yields were moderate (5.61% and 5.71%), increasing steadily to peak values of 6.48% and 6.38% at 4000 rpm. This improvement reflects the enhanced turbulence and cavitation at moderate speeds, which play a key role in breaking down plant tissues and releasing entrapped oils.²³ The enhanced mixing intensity at 4000 rpm likely optimises mass transfer between the biomass and the surrounding solvent medium. Interestingly, further increasing the rotational speed beyond 4000 rpm resulted in a consistent decline in oil yield, reaching as low as 5.24% and 5.15% at 6000 rpm. One plausible explanation is that excessive mechanical stress at high speeds may generate localised thermal heating, possibly resulting in thermal degradation or evaporation of volatile oil components.^{21,22} Additionally, high shear rates may cause emulsification, complicating oil recovery and reducing the measurable yield. This pattern mirrors observations in our previous biodiesel work, where excessive catalyst or agitation lowered performance due to phase separation challenges.^{24,25} Therefore, it can be concluded that 4000 rpm represents a maximum rotational speed for homogenizer pretreatment to maximise patchouli oil yield, balancing shear intensity with thermal and mechanical stability. This result is consistent with the mechanistic insights delivered by Chemat *et al.*, 2019, in their detailed review of green extraction technologies.²⁶

Effect of Interaction Parameters on Patchouli Oil Yield

Response surface methodology (RSM) based on a Box-Behnken design was applied to investigate the individual and interactive effects of the leaf mass-to-water volume ratio (A), hydrodistillation time (B), and microwave power (C) on patchouli oil yield. The 3D response surface plots in Fig.-2 illustrate the interdependence among these parameters. As illustrated in Fig.-2A, increasing the hydrodistillation time and leaf-to-water ratio resulted in a modest increase in oil yield. The AB interaction coefficient (+0.1096) indicated only a weak positive effect. This observation agrees with the findings of Beyecha Hundie *et al.*, 2023, who noted that prolonged heating improves the diffusion of volatiles but risks degradation over extended times.⁹ The interaction of A and C (Fig.-2B) displays a contrasting trend. A negative coefficient (-0.1003) indicates that increasing the leaf mass-to-water ratio while simultaneously increasing microwave power slightly suppresses yield. This is presumably due to inadequate moisture transfer at low solvent availability, resulting in uneven heating. This phenomenon is also discussed by Mallaei *et al.*, 2019, in MAHD of *Ferulago angulata* essential oils.²⁷ Figure-2C shows that increasing both microwave power and distillation time considerably increases patchouli oil yield. This is attributed to accelerated thermal penetration and rupture of glandular trichomes, therewith facilitating the release of essential oils. The strongest single-factor effect was from microwave power (coefficient = +0.5871), showing its dominant role. A similar trend was reported by Li *et al.*, 2024 for the microwave-assisted extraction of *Pinus koraiensis* essential oil.⁶

Effect of Interaction Parameters on Patchouli Alcohol Concentration

Patchouli alcohol concentration responded differently to parameter interactions. Figure-3A showed that the combined increase in the leaf-to-water ratio and hydrodistillation time resulted in a decrease in

patchouli alcohol content, despite the positive AB interaction coefficient (+6.92), which contrasts with the negative individual effects of A (−2.4) and B (−1.2375).

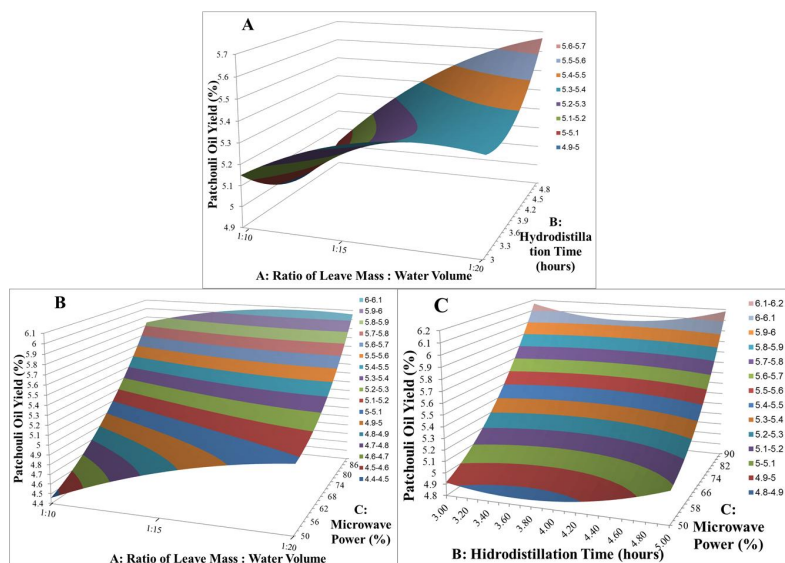


Fig.-2: Three-dimensional Response Surface Plots Illustrating the Effects of (A) Leaf Mass-to-Water Volume Ratio and Hydrodistillation Time, (B) Leaf Mass-To-Water Volume Ratio and Microwave Power, and (C) Hydrodistillation Time and Microwave Power on Patchouli Oil Yield

However, the interaction indicates a compensatory effect, suggesting that under supervised pairing, degradation is mitigated. Microwave power (C) had the greatest influence on patchouli alcohol concentration, with a coefficient of +11.635, corroborating its ability to rupture oil glands more efficiently than conventional heating. As noted by Ozcan *et al.*, 2024 elevated microwave energy significantly increased recovery without causing degradation when optimised for time and solvent ratio.²⁸ The positive AC and BC interactions (+1.42 and +3.18, respectively) support the hypothesis that microwave energy synergises with appropriate solvent conditions and time to improve selectivity for patchouli alcohol.

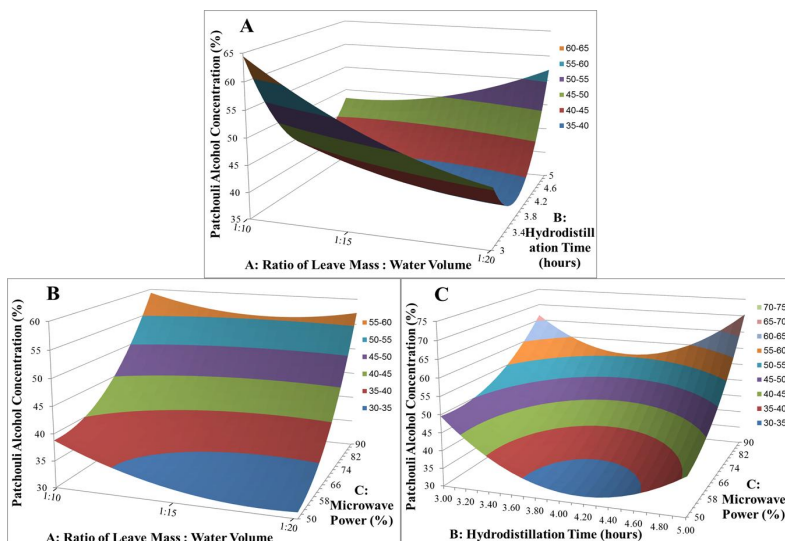


Fig.-3: Three-Dimensional Response Surface Plots Illustrating the Effects of (A) Leaf Mass-to-Water Volume Ratio and Hydrodistillation Time, (B) Leaf Mass-to-Water Volume Ratio and Microwave Power, and (C) Hydrodistillation Time and Microwave Power on Patchouli Alcohol Content

Regression Model and Statistical Validation

The quadratic model for patchouli oil yield shows good forecasting precision, as reflected by a low deviation between predicted and observed values ($\pm 0.2\%$). ANOVA results indicated that microwave

power (C) had the strongest influence ($p < 0.01$), while the other terms showed marginal or non-significant contributions ($p > 0.05$). The model's F-value fell within acceptable confidence limits, suggesting statistical significance, although the interaction terms contributed differently.

$$\text{Patchouli Oil Yield} = 5.2695 + 0.2118A + 0.0467B + 0.5871C + 0.1096AB - 0.1003AC - 0.0367BC - 0.0997A^2 + 0.1292B^2 + 0.1884C^2$$

For patchouli alcohol concentration, the model equation showed stronger statistical significance, particularly with high values of B^2 and C^2 (12.78 and 5.50), reflecting substantial non-linear effects. The F-value for this model was high, and $R^2 > 0.90$, indicating its strong predictive power for patchouli alcohol yield. These outcomes support earlier research by Conde-Hernandez *et al.*, 2021 who used RSM to optimize essential oil recovery and confirmed that quadratic effects control the prediction of alcohol concentration.²⁹

$$\text{Patchouli Alcohol Yield} = 38.57 - 2.4A - 1.2375B + 11.635C + 6.92AB + 1.42AC + 3.18BC + 2.56A^2 + 12.78B^2 + 5.50C^2$$

Model Validation

Model validation was performed by comparing observed and predicted values at the centre points (runs with $A = 1:15$, $B = 4$ h, $C = 70\%$). Patchouli oil yield was consistently 5.2–5.3%, while patchouli alcohol concentration ranged from 37.1–39.9%, with estimated errors below 5%, confirming the model's high predictive ability and adequacy. Furthermore, the response trends closely align with mechanistic principles in essential oil thermodynamics, in which power input and extraction time influence the volatility and selectivity of oil components. Similar validation results were observed in MAHD of lemongrass by Beyecha Hundie *et al.*, 2023, who reported that optimised models predicted santol recovery with <1.3% error.⁹

Table-2: Experimental Conditions Generated by the Box-Behnken Design with the Corresponding Observed and Predicted Response Values

Parameters			Patchouli Oil Yield (%)		Patchouli Alcohol Concentration (%)	
A	B	C	Observed	Prediction	Observed	Prediction
1:15	4	70	5.3	5.3	39.9	38.6
1:15	4	70	5.3	5.3	38.6	38.6
1:15	3	90	6.4	6.2	70.6	66.5
1:15	5	50	4.8	5.1	36.8	40.8
1:20	5	70	5.9	5.7	54.3	57.2
1:20	4	50	5.1	5.1	38.1	31.2
1:10	3	70	4.9	5.2	67.4	64.5
1:10	5	70	5.1	5.0	49.8	48.2
1:15	5	90	6.1	6.2	75.8	70.4
1:10	4	90	5.8	5.8	52.3	59.2
1:15	4	70	5.2	5.3	37.1	38.6
1:10	4	50	4.6	4.5	41.2	38.8
1:15	3	50	5.0	4.9	44.3	49.6
1:20	3	70	5.3	5.4	44.2	45.8
1:20	4	90	5.9	6.1	54.9	57.3

Constituents and Phytochemical Aspects of Patchouli Oil

A comparison of patchouli oils obtained by hydrodistillation (HD) and microwave-assisted hydrodistillation (MAHD) demonstrates the effects of the extraction method on their chemical composition and biological activities. Both methods were pre-treated using homogenization to facilitate the release of essential oil from plant tissues. However, MAHD, a more modern and efficient technique, yielded significantly different outcomes in constituent concentrations and bioactivity compared with the conventional HD process.³⁰ One of the most notable differences lies in the composition of Patchouli alcohol, the primary bioactive compound accountable for patchouli oil's characteristic fragrance and biological properties. MAHD resulted in a markedly higher concentration of Patchouli alcohol (40.57%) compared to HD (25.50%). This substantial increase suggests that rapid, uniform heating in MAHD may

enhance cell wall rupture and reduce thermal degradation of heat-sensitive compounds. Similarly, the concentrations of other sesquiterpenes, such as α -Guaiene and Seychellene, were slightly lower in MAHD, suggesting selective preservation or differential volatilisation under microwave conditions. Interestingly, Caryophyllene was significantly reduced in the MAHD extract, implying that this compound may be more susceptible to breakdown under microwave exposure.¹ Antioxidant activity, as represented by the IC₅₀ value, was significantly lower in the hydro-distillation (HD) extract (19.53 μ g/mL) compared to the microwave-assisted hydro-distillation (MAHD) extract (593.7 μ g/mL). Since a lower IC₅₀ value indicates stronger antioxidant activity, this result suggests that HD-extracted patchouli oil possesses much higher antioxidant potential. The weaker antioxidant activity in the MAHD sample may be linked to the lower concentrations of various key sesquiterpene compounds—namely Caryophyllene, α -Guaiene, and Seychellene—which are known contributors to antioxidant behaviour.³¹ These components were substantially reduced in MAHD, possibly due to degradation or volatilisation under rapid microwave heating. This shows that while MAHD enhances Patchouli alcohol yield, it may simultaneously compromise the levels of other antioxidant-active constituents, leading to an overall reduction in antioxidant potency. Differences in antioxidant activity among plant-derived extracts can be associated with differences in their phytochemical composition and the relative abundance of antioxidant-active constituents, as demonstrated in recent investigations of plant-based antioxidant systems.³² Antimicrobial activity data also reveal differences between the two methods. Against *Staphylococcus aureus*, HD-extracted oil showed a slightly larger zone of inhibition (14.53 mm) than MAHD (13.35 mm), suggesting that elements responsible for antibacterial activity against Gram-positive bacteria might be more effectively retained by HD. On the other hand, MAHD-extracted oil demonstrated measurable activity against *Escherichia coli* (10.25 mm), whereas HD extract showed no inhibition.³³ This wider spectrum of antimicrobial efficacy from MAHD shows its advantage in producing a more functionally diverse extract. The observed differences can be ascribed not only to the extraction technique but also to the effect of homogenization as a pre-treatment. Homogenization enhances cell wall disruption and increases surface area, thus enabling better solvent penetration and volatile oil release. While this process supports both HD and MAHD, the interaction with MAHD appears more effective, possibly because microwaves further intensify internal heating and rupture within glandular structures of the plant matrix. Hence, microwave-assisted hydrodistillation coupled with homogenizer pretreatment offers superior extraction efficiency and bioactivity of patchouli oil in comparison to traditional hydrodistillation. The higher yield of Patchouli alcohol, significantly improved antioxidant activity, and broader antimicrobial action make MAHD a more promising method for generating high-quality essential oils for pharmaceutical and cosmetic applications. Nonetheless, careful optimisation is still needed to minimise potential heat losses from heat-sensitive components such as Caryophyllene during microwave processing.

Table-3: The Main Component and Bioactive Activity of Patchouli Oil

	Hydro-distillation	Microwave-assisted hydro-distillation
<u>Main component (%)</u>		
- Caryophyllene	4.81	1.56
- α -Guaiene	14.48	6.71
- Seychellene	8.39	7.45
- Patchouli alcohol	25.50	40.57
Antioxidant activity (μ g/mL)	19.53*	593.7
<u>Antimicrobial activity (zone of inhibition, mm)</u>		
- <i>Staphylococcus aureus</i>	14.53**	13.35
- <i>Escherichia coli</i>	NA	10.25

* cited from ref. ³⁴** cited from ref. ³⁵

Taken together, the findings demonstrate that homogenizer pretreatment provides an effective mechanical intensification step before MAHD of patchouli leaves. The main contribution of this study is the integration of rotor-stator homogenization with MAHD, which resulted in improved oil recovery and

enrichment of patchouli alcohol compared with conventional hydrodistillation. The results also demonstrate that improved recovery of the major target constituent does not necessarily correspond to improved antioxidant activity, as some antioxidant-active sesquiterpenes may be reduced during microwave processing. From a broader sustainability perspective, the improved extraction performance obtained through homogeniser-assisted MAHD is relevant to SDG-12 (Responsible Consumption and Production), particularly in relation to the development of more efficient production processes for value-added plant-derived products.

CONCLUSION

Homogenizer pretreatment effectively intensified microwave-assisted hydrodistillation (MAHD) of patchouli leaves. The optimum homogenization condition was obtained at 4000 rpm for 25 min, producing an oil yield of 6.48%. Box-Behnken response surface methodology demonstrated that leaf-to-water ratio, hydrodistillation time, and microwave power influenced the extraction performance, with the optimised MAHD process producing a higher patchouli alcohol concentration than conventional hydrodistillation (40.57% versus 25.50%). However, the MAHD oil exhibited lower DPPH radical-scavenging activity than the HD oil, indicating that enhanced patchouli alcohol enrichment was not necessarily accompanied by improved antioxidant activity. MAHD also exhibited measurable antibacterial activity against *Escherichia coli* under the tested conditions. Overall, homogeniser-assisted MAHD provides a promising process-intensification approach for improving patchouli oil recovery and patchouli alcohol enrichment. The approach is relevant to SDG 12 (Responsible Consumption and Production) through its focus on improved processing of a plant-derived value-added product, although its overall environmental performance requires further quantitative assessment. Future studies should evaluate energy consumption, process scalability, constituent stability, and life-cycle environmental performance to establish the broader technological and sustainability potential of the process.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-12: Responsible Consumption and Production*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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