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Optimization of Essential Oil Formulations for Ultrasonic Diffusers Based on Aroma Profile and Persistence

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ABSTRACT

Background: Ultrasonic diffusers disperse essential oils without direct heating, making them suitable for aromatherapy. Combining oils with citrus, floral, herbal, and fixative characteristics may produce a more balanced and longer-lasting aroma, although information on optimal formulations for ultrasonic diffusers remains limited.
Aims: This study aimed to obtain an optimal essential oil formulation for ultrasonic diffuser products based on aroma preference and persistence.
Methods: Seven essential oils (kaffir lime, ylang-ylang, bergamot, rosemary, cajuput, peppermint, and patchouli) were combined into five formulations. Thirty untrained panelists assessed aroma preference and intensity using direct sniffing. Aroma persistence was monitored for 12 hours at three-hour intervals using 10 drops of each formulation in 300 mL of water.
Results: Formulation F3 obtained the highest preference score and showed the best aroma persistence. The combination of citrus and floral oils with patchouli as a fixative produced a balanced, favorable, and longer-lasting aroma compared to other formulations.
Conclusion: Formulation F3 was identified as the optimal formulation based on aroma preference and persistence. Combining complementary essential oils with patchouli as a fixative shows potential for developing natural essential oil-based ultrasonic diffuser products.

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1. Introduction

Aromatherapy is a complementary therapy that utilizes essential oils to promote relaxation, improve mood, and enhance psychological comfort (Maesaroh & Putri, 2019). One commonly used method for dispersing essential oils into the air is an aromatherapy diffuser. A diffuser converts a mixture of water and essential oil into a fine mist that is dispersed into the air, allowing the aroma to distribute evenly throughout a room (Hasanah & Lestari, 2023). Among various types of diffusers, ultrasonic technology is widely used because it generates a fine mist without direct heating, thereby better preserving volatile components and bioactive compounds in essential oils than heat-based methods (Oktaviyanti *et al*., 2023). Therefore, ultrasonic diffusers are a promising medium for optimizing the use of essential oils in aromatherapy.

Essential oils are natural, volatile substances composed of various volatile compounds, particularly terpenoids and their derivatives (Sadgrove *et al*., 2022). Their volatility leads to differences in aroma profile, intensity, and persistence during diffusion, as the composition of emitted VOCs changes over time and some constituents evaporate more rapidly than others (Itoh *et al*., 2022). The selection and combination of essential oils are therefore important in determining aroma characteristics and persistence (Sadgrove *et al*., 2022). Essential oils can produce relaxing or stimulatory effects, including changes in alertness and concentration (Lizarraga-Valderrama *et al*., 2021; Sattayakhom *et al*., 2023). However, studies specifically evaluating essential oil combinations for both favorable aroma and persistence in ultrasonic diffusers remain limited.

In addition to their aromatic effects, several volatile components in essential oils exhibit antimicrobial and antioxidant activities. Compounds such as 1,8-cineole in cajuput oil exhibit antibacterial activity against various microorganisms (Abers *et al*., 2021; Zabcı *et al*., 2026), while citronellal in kaffir lime oil contributes to antibacterial and antioxidant activities (Thonglem *et al*., 2023; Phewphong *et al*., 2025). Menthol in peppermint oil also exhibits various biological activities, including antimicrobial and anti-inflammatory effects (Kazemi *et al*., 2024; Zabcı *et al*., 2026). The volatile constituents of essential oils may retain antimicrobial activity in the airborne phase, suggesting their potential contribution to indoor air quality by reducing airborne microorganisms (Abers *et al*., 2021). Therefore, the development of essential oil formulations may not only produce pleasant aromas but also provide additional functional value to aromatherapy products.

Essential oil formulation for ultrasonic diffusers requires a balance between initial aroma intensity and aroma persistence during use. Citrus oils such as kaffir lime and bergamot are rich in volatile compounds, especially mono- and sesquiterpenes, and citrus essential oils are widely used for their pleasant aroma in fragrance and aromatherapy applications (González-Mas *et al*., 2019; Schwartz-Narbonne *et al*., 2021; Agarwal *et al*., 2022). In contrast, patchouli oil (*Pogostemon cablin*) is widely used as a base oil in fragrance formulation because of its sesquiterpenoid alcohol content, particularly patchoulol, which supports longer-lasting aroma characteristics (Jain *et al*., 2022; Pramestie *et al*., 2023). This is consistent with broader evidence that essential oils often face high-volatility and stability limitations, so formulation strategy is important (Pavoni *et al*., 2020). Recent work also shows that patchouli and peppermint oils can be combined into a stable and consumer-preferred formulation (Wahyudi *et al*., 2024). Based on these considerations, this study was conducted to obtain an optimal essential oil formulation for ultrasonic diffusers by considering panelist preference and aroma persistence during use.

2. Methods

The essential oils used in this study were ylang-ylang (*Cananga odorata*), makrut lime (*Citrus hystrix*), bergamot (*Citrus bergamia*), rosemary (*Rosmarinus officinalis* L.), cajuput (*Melaleuca cajuputi*), peppermint (*Mentha piperita*), and patchouli (*Pogostemon cablin* Benth.). The equipment included an analytical balance, beakers, droppers, glass stirring rods, an ultrasonic diffuser, and amber glass bottles. Five essential oil formulations (F1–F5) were prepared by blending these oils with different aroma profiles, including citrus, floral, herbal, and fixative notes. The composition of each formulation is presented in Table 1.

Table 1. Essential oil formulations for ultrasonic diffuser products

Essential oil	Formulation				
	F1 (ml)	F2 (ml)	F3 (ml)	F4 (ml)	F5 (ml)
Kaffir lime oil	1.5	5	-	-	-
Ylang-ylang oil	7.9	-	-	5.2	-
Bergamot oil	-	-	-	4.7	-
Peppermint oil	-	4.9	4	-	1.1
Rosemary oil	-	-	5.9	-	3.7
Cajuput oil	-	-	-	-	3.9
Patchouli oil	0.1	0.1	0.1	0.1	0.1

An initial evaluation was conducted on the five formulations to identify formulations with favorable aroma characteristics. Based on the initial evaluation, three formulations (F1, F3, and F5) were selected for further testing. Organoleptic evaluation was conducted with 30 untrained panelists to assess aroma preference, aroma intensity, and aroma quality through direct sniffing. Each parameter was evaluated based on the panelists' sensory perception of the diffuser formulations.

Aroma persistence was evaluated by adding 10 drops of each selected formulation to an ultrasonic diffuser containing 300 mL of water. The diffuser was operated for 12 h, and aroma intensity was assessed at 3-h intervals during the observation period.

The production cost of the diffuser oil was calculated using the full-costing method, which included all production costs from raw materials to the finished product. The calculation assumed that one production batch produced 10 packages of diffuser oil for each formulation, with a volume of 10 mL per package.

3. Results and Discussion

3.1. Organoleptic Evaluation

Organoleptic evaluation was conducted to assess panelist acceptance of the diffuser aroma based on three attributes: aroma preference, aroma intensity, and aroma quality. The evaluation was performed on three selected formulations (F1, F3, and F5) obtained from the initial screening of five formulations using a direct olfactory assessment. Based on the organoleptic evaluation (Figure 1), F3 obtained the highest scores for all evaluated attributes. The higher aroma preference of F3 compared with F1 and F5 indicates that its essential oil combination produced a more favorable aroma profile. This response was likely attributed to the balance of aroma intensity and composition, as balanced odor intensity can contribute to higher aroma preference and acceptability (Choi *et al*., 2024; Rerung & Oktaviani, 2023).

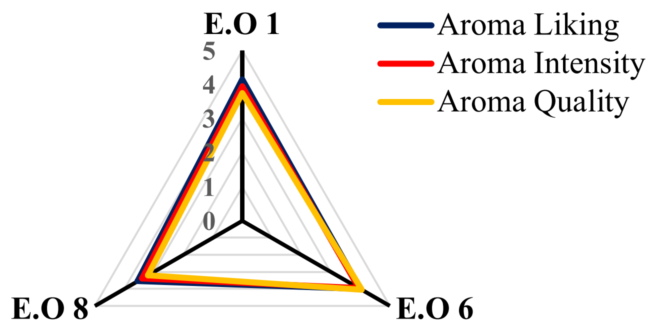

Figure 1. Radar chart of organoleptic evaluation

The aroma characteristics of essential oil formulations are influenced by their volatile composition. Highly volatile compounds are generally perceived earlier and contribute to the initial aroma, whereas less volatile components contribute to the aroma perceived at later stages (Zhang *et al*., 2023; Itoh *et al*., 2022). In this study, citrus oils such as kaffir lime and bergamot contributed fresh and light initial notes, while ylang-ylang and rosemary contributed floral and herbal characteristics to the formulation (Agarwal *et al*., 2022; Ye *et al*., 2026). Patchouli oil, which contains patchouli alcohol, functioned as a base note and fixative, supporting greater aroma persistence (Jain *et al*., 2022).

The balance among these aroma components likely contributed to the higher acceptance of F3, as the resulting aroma was perceived as neither too strong nor too weak and provided a more harmonious sensory profile. This finding is consistent with previous studies indicating that aroma composition and perceived intensity influence sensory preference and acceptability (Choi *et al*., 2024).

3.2. Aroma Persistence

The results of the aroma persistence test are presented in Table 2. The test was conducted for 12 hours with observations at three-hour intervals to evaluate the ability of each formulation to maintain aroma intensity.

Table 2. Results of the aroma persistence test

Formulation	Observation period (h)			
	1-3	3-6	6-9	9-12
F1	++++	++++	+++	+++
F4	+++	+++	++	++
F5	++	++	+	+

All formulations maintained detectable aromas until the end of the 12-hour observation period, although their aroma intensities differed. F1 showed the highest aroma persistence, with very strong intensity (++++) during the first six hours and strong intensity (+++) until 12 hours. This result indicates that the composition of F1 was more favorable for maintaining aroma intensity over the observation period. The greater persistence can be attributed to the presence of less volatile components that evaporate more slowly (Turek & Stintzing, 2013; Zhang *et al*., 2023; Asben *et al*., 2025).

F3 showed lower aroma persistence than F1 but maintained moderate to strong aroma intensity throughout the observation period. Despite this, F3 received the highest preference scores in the organoleptic evaluation. This finding indicates that the most preferred formulation does not necessarily have the highest aroma persistence, as panelist acceptance is also influenced by the balance and characteristics of the aroma (Zhang *et al*., 2023; Choi *et al*., 2024; Asben *et al*., 2025).

F5 showed the fastest decrease in aroma intensity, from moderate (++) during the first six hours to weak (+) after nine hours. This pattern indicates that the formulation lost its aroma intensity more rapidly than F1 and F3, which can be associated with a greater contribution of highly volatile components.

Overall, F1 exhibited the best aroma persistence, whereas F3 showed the highest panelist acceptance. Considering both parameters, F3 can be considered the optimal formulation because it provided the best balance between aroma acceptance and persistence during ultrasonic diffuser use.

3.3. Economic Analysis

Economic analysis was conducted using the full costing method, which accounts for all production costs, including raw materials, direct labor, and production overhead (Purwanto & Watini., 2020; Widhajati *et al*., 2024; Sarah, 2024). This calculation was performed to evaluate the economic feasibility of the diffuser oil formulations. Based on Table 3, the highest production cost was obtained for F4 at IDR 369,917 per batch, while the lowest was obtained for F5 at IDR 240,667 per batch. The differences in production costs were mainly attributed to variations in the composition and types of essential oils used in each formulation, as raw materials represented the largest component of production costs.

Table 3. Details of Production Costs

No.	Description	Total Cost (IDR)				
		F1	**F2**	**F3**	**F4**	**F5**
1	Labor costs	50,000	50,000	50,000	50,000	50,000
2	Raw material costs	215,250	166,583	128,333	245,917	116,667
3	Variable overhead costs					
	Consumable costs	66,000	66,000	66,000	66,000	66,000
	Equipment depreciation costs	5,000	5,000	5,000	5,000	5,000
	Electricity costs	3,000	3,000	3,000	3,000	3,000
4	Cost of Goods Manufactured	339,250	272,583	252,333	369,917	240,667

On a 10 mL package basis, the production costs were IDR 24,067 for F5, IDR 25,233 for F3, IDR 27,258 for F2, IDR 33,925 for F1, and IDR 36,992 for F4. These costs were lower than the price of commercial diffuser products, which was approximately IDR 51,089 per 10 mL package. This finding indicates that the developed formulations have potential for economical production and competitive pricing in the market (Antono *et al*., 2020; Widhajati *et al*., 2024).

Considering the results of the organoleptic evaluation, aroma persistence, and production costs, F3 was identified as the most promising formulation because it achieved the highest panelist acceptance while maintaining a relatively low production cost compared with F1 and F4. This finding indicates that the formulation offers a favorable balance between sensory acceptance and production cost, supporting its potential for further development as an ultrasonic diffuser product (Ahmad *et al*., 2022; Salsabila, 2023; Lufika *et al*., 2023).

4. Conclusion

Formulation 3 (F3) was identified as the optimal ultrasonic diffuser formulation, showing the highest panelist acceptance for aroma preference, intensity, and quality, with good aroma persistence. The combination of citrus and floral essential oils with patchouli as a natural fixative produced a balanced aroma, while the production cost of IDR 25,233.3 per 10 mL package indicates potential for further commercial development. These findings highlight the importance of essential oil selection and combination in developing natural aromatherapy products with favorable sensory and economic characteristics.

5. Authors Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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