ISSN: 2621-4709 E-ISSN: 2621-2528
Journal of Applied Agricultural Science and Technology
Vol. 9 No. 2 (2025): 205-215

Evaluation of the Characteristics and Controlled Release of Citronella Essential Oil in Aromatherapy Necklaces via Sensory Analysis

Alfi Asben [a], Annisa Putri [a,*], Anwar Kasim [a], Dini Novita Sari [a]

[a] Department of Agro-Industrial Technology, Faculty of Agricultural Technology, Andalas University, Padang, Indonesia.

Abstract. *Essential oils, including those used in aromatherapy, are currently in high demand as consumers increasingly prefer products made from natural ingredients. Citronella oil, when used as aromatherapy, is intended to relieve headaches, enhance breathing, and produce a warming effect upon inhalation. Aromatherapy necklaces provide a convenient and portable method for delivering the benefits of essential oils. Encapsulation technology addresses the volatility of essential oils in aromatherapy gels by creating a controlled slow-release mechanism, enabling the gradual release of essential oils over a specified period. This study aims to evaluate the characteristics of aromatherapy necklaces and assess the aroma intensity of citronella oil through sensory analysis. Sensory analysis was conducted using semi-trained and trained panelists. The aromatherapy necklace comprises a mixture of gels and emulsions containing encapsulated essential oils, formulated for immediate use. The sensory analysis results indicated that the addition of 10% essential oils yielded the highest scores for color and texture assessments (4.08 and 3.96, respectively), while the addition of 7.5% essential oils produced the highest score for aroma assessment (4.16). The aroma intensity decreased from a score of 6.00 on day 1 to 3.17 on day 7. The gradual and controlled decline in aroma intensity aligns with the intended purpose of the essential oil encapsulation process.*
Keywords: *aromatherapy necklace; citronella; essential oils; encapsulation; sensory analysis.*

Type of the Paper: Regular Article.

1. Introduction

Global awareness and interest in the use of aromatherapy applications are steadily increasing [1]. Aromatherapy has experienced high demand in the global market, particularly for its use in promoting health and traditional relaxation [2–4]. Essential oils, the primary ingredients in aromatherapy, are extracted from aromatic plants. *Cymbopogon nardus,* commonly known as citronella, is a major essential oil-producing plant cultivated across much of Indonesia, including in West Sumatra. Citronella oil is produced through the distillation of the leaves and stems of the citronella plant. Citronella oil is a key ingredient in aromatherapy products due to its distinctive aroma profile, which combines notes of wood, grass, and lemon. When inhaled, this aroma produces a warming and refreshing effect, alleviates headaches, and promotes smoother breathing [5].

Citronella oil contains bioactive compounds that are volatile and less stable under

https://doi.org/10.55043/jaast.v9i2.347
Received September 18, 2024; Received in revised form April 8, 2025; Accepted May 12, 2025; Published May 25, 2025
* First corresponding author
Email: annisaputri@ae.unand.ac.id *

environmental changes, such as variations in temperature, humidity, and pH. It also possesses antibacterial, antifungal and antioxidants properties [6–8]. Therefore, technologies such as encapsulation are required to preserve these bioactive compounds and prevent their rapid evaporation [9]. Encapsulation forms a protective matrix around the bioactive compounds, shielding them from the external environment [10] and safeguarding the core material [11]. The use of encapsulation technology enables the controlled release of essential oil aromas in aromatherapy products. Aromatherapy can be administered in various ways, one of which is through inhalation [12]. Each essential oil affects health in distinct ways [13,14].

Aromatherapy products are available in various forms, with aromatherapy gel being an ideal preparation when essential oils serve as the base ingredient. Gel-based formulations are an alternative to liquid or solid phase and offer the advantage of easier handling and packaging [15]. Preparations in gel form offer several advantages: 1) they can be directly mixed with essential oils or emulsions, and 2) their semi-solid texture allows for even distribution in containers of various shapes. Aromatherapy gel, when packaged in a glass bottle and designed as a necklace, provides users with easy access to the benefits of aromatherapy, particularly through inhalation. Aromatherapy necklaces are convenient and can be worn at any time. This study aimed to evaluate the characteristics of aromatherapy necklaces and assess the intensity of citronella oil aroma at varying essential oil concentrations using sensory analysis methods.

2. Materials and Methods

2.1 Materials and tools

The materials used in this study included citronella oil sourced from essential oil farmers near Andalas University, distilled water, powdered carrageenan (Indofood Chem-SGP 168M), glucomannan (Aroma Kencana), propylene glycol (Sanco) and sodium benzoate (Buana Cham). The tools used in this study included stirring rods, glassware, analytical balances, hotplates, thermometers, gas chromatography-mass spectrometry (GC–MS) system (Agilent 5977C) with FID & Headspace PAL system, small glass bottles, and necklace chains.

2.2 Encapsulation of Citronella Oil

This method follows the procedure outlined in previous research by Putri et al. [16]. A total of 2.5 g of gelatin was dissolved in 100 mL of water and homogenized at 600 rpm and 50 ° C for 1 hour to form a gelatin solution. The same procedure was applied to prepare the maltodextrin solution. Subsequently, 100 mL of gelatin solution was mixed with 2.5 g of citronella oil and Tween 80 (oil-to-surfactant ratio 1:1.12) and homogenized. The next step was to add 100 mL of maltodextrin solution and homogenize until the emulsion phase was formed. For the complex coacervation process, 2 mL of a 10% acetic acid solution was added to the emulsion phase until the pH value reached 4. The homogenization process was then repeated, and the emulsion was

stored at approximately 10 °C for 30 minutes.

The emulsion is allowed to stand, then 20 mL of a sodium tripolyphosphate crosslinking agent solution is added, followed by homogenization. The next step involves adding a 20% NaOH solution to the emulsion until the pH reaches 9. The emulsion is then homogenized at 500 rpm and room temperature for 2 hours, and subsequently stored at approximately 10 °C for 16 hours before use.

2.3 Aromatherapy Gel and Necklace

The initial process involves preparing 50 g of gel with a 3% concentration, using a 60:90 ratio of the main gel-forming ingredients. 39.95 mL of distilled water is heated in a beaker to 75° C. Next, 0.9 g of powdered carrageenan and 0.6 g of glucomannan are added and stirred rapidly until dissolved. Then, 0.05 g of sodium benzoate is added and stirred until homogeneous. The next step is to stir the solution rapidly until the temperature drops to 65° C, then add 5 mL of propylene glycol and stir quickly again. Afterward, the citronella oil emulsion is added to the gel solution at varying concentrations and stirred rapidly until homogeneous, forming an aromatherapy gel. The next step is to place the aromatherapy gel into a 5 mL glass bottle, which will serve as the container for the aromatherapy necklace. The bottle is then sealed with a plastic or cork lid, leaving space for airflow. Afterward, the aromatherapy gel is allowed to reach room temperature, and a necklace chain, approximately 20 cm in length, is attached.

2.4 Sensory Analysis

The sensory analysis method employed in this study is the affection test, which measures consumers' subjective attitudes toward products based on sensory properties. This method aims to assess individual responses, including acceptance or preference, towards existing products, new products, or distinct characteristics of the products being evaluated [17].

The amount of essential oil added to the emulsion included 5 variations: 0%, 2.5%, 5%, 7.5% and 10%. The sensory tests conducted in this study were as follows: (1) An aromatherapy necklace preference test assessing color, aroma, and texture characteristics, with a rating scale from 1 to 5, where 1 indicates dislike, 2 indicates neither dislike nor like, 3 indicates slight liking, 4 indicates moderate liking, and 5 indicates strong liking; (2) An aromatherapy necklace preference test evaluating aroma intensity parameters to measure the controlled release of citronella oil's volatile compounds over seven days, with observation times on days 1, 3, 5, 7. The rating scale for aroma intensity ranged from 1 to 5, where 1 indicated an almost imperceptible odor, 2 indicated a weak odor, 3 indicated a light odor, 4 indicated a strong odor, and 5 indicated a very strong odor. This study involved 25 semi-trained panelists for the aromatherapy necklace preference test and three trained panelists for the aroma intensity preference test. The data will be analyzed using Analysis of Variance (ANOVA), with a significance level set at $p < 0.05$. If a

significant difference is found, Duncan's post hoc test will be conducted for further analysis.

3. Results and Discussion

3.1 Sensory Analysis-Preference Test of Aromatherapy Necklace Based on Characteristic

The bioactive compounds in citronella essential oil were analyzed using Gas Chromatography-Mass Spectrometry (GC–MS). GC–MS provides a precise method for identifying and quantifying the components of essential oils [18]. The results of the bioactive compound analysis of citronella essential oil are shown in Fig. 1.

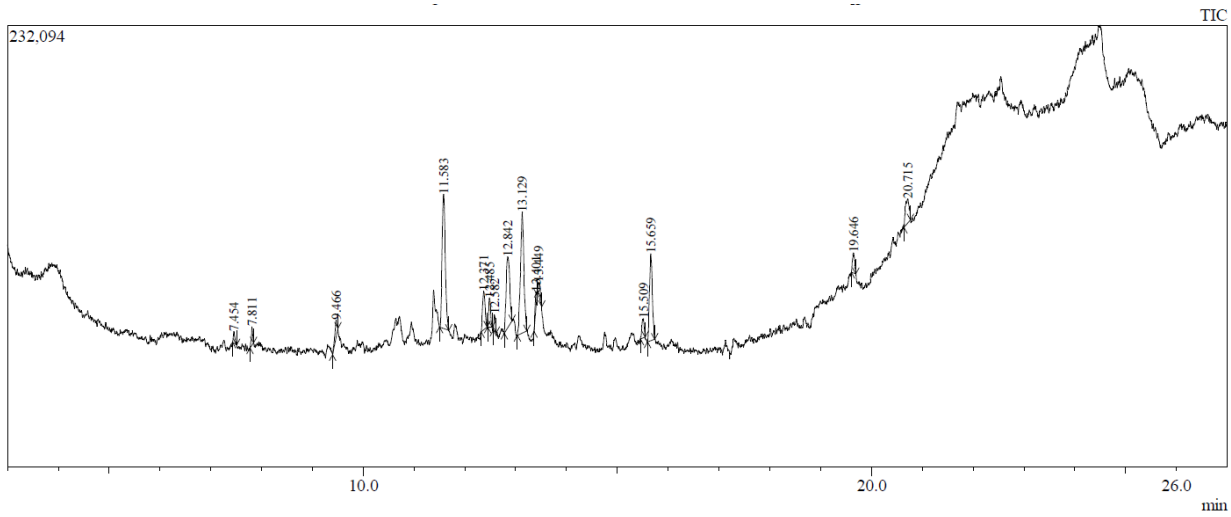


Fig. 1. Chromatogram of the bioactive compounds of citronella oil.

Table 1. Bioactive compounds of citronella oil

No	Compound Name	Amount (%)
1	(1R)-2,6,6-Trimethylbicyclo [3.1.1]hept-2-ene	1.79
2	Bicyclo[2.2.1]heptane, 2,2-dimethyl-3-methylene	2.91
3	Undecane, 1,2-dibromo-2-methyl-	2.69
4	Naphthalene	21.10
5	6-Octen-1-ol, 3,7-dimethyl-, (R)-	6.09
6	2,6-Octadienal, 3,7-dimethyl-, (E)-	4.61
7	Linalyl acetate	2.61
8	Geraniol	30.22
9	2,6-Octadienal, 3,7-dimethyl-, (E)-	2.30
10	Cinnamaldehyde, (E)-	2.03
11	Geranyl acetate	16.68
12	Cedrene	3.17
13	Dodecanoic acid	3.80
	Amount	**100**

Aromatherapy gel products utilize emulsions encapsulated via a complex coacervation process, which has been successfully employed in various studies, yielding favorable results in terms of quantity [19,20]. Sensory analysis, specifically organoleptic testing, is crucial in assessing consumer acceptance of a product. Sensory analysis of products encompasses aroma, taste, texture, and color [21]. The aromatherapy characteristics of the necklace products are evaluated based on

three parameters: color, aroma, and texture. The final aromatherapy necklace product is illustrated in Fig. 2.

Fig. 2. Aromatherapy necklace

3.1.1 Color

The analysis of variance (ANOVA) results showed that the addition of citronella oil had a significant effect ($P < 0.05$) on the color of the aromatherapy gel. The ANOVA results and Duncan's post hoc test for the color of the aromatherapy gel are presented in Table 2.

Table 2. Panelists assessment of aromatherapy gel color

Sample	Color
Citronella EOs 2.5%	3.52 ± 0.71 a
Citronella EOs 5%	3.80 ± 0.56 ab
Citronella EOs 7.5%	3.84 ± 0.69 ab
Citronella EOs 0%	3.92 ± 0.70 b
Citronella EOs10%	4.08 ± 0.91 b

Description: Numbers in the same column followed by different lowercase letters are significantly different according to DNMRT at the 5% level of significance.

The color assessed by the panelists originated from the aromatherapy gel contained in the aromatherapy necklace bottle. The gel produced was white but not too dense. Based on the results in Table 1, the panelist's level of preference for color testing are based on the results in Table 1; the panelists' preference score for the aromatherapy gel ranged from 3.52 to 4.08. The most preferred aromatherapy gel color, with a score of 4.08, was observed in the treatment with 10% citronella oil. The lowest preference score, 3.52, was recorded for the 2.5% citronella oil treatment. The panelist's preference level for color assessment was influenced by the amount of essential oil added.

The color of the aromatherapy gel with the lowest concentration of essential oil appeared whiter. Research on air freshener aromatherapy gels containing citronella oil and calamansi orange showed that they tend to produce a clear appearance and a whitish color [22]. The aromatherapy gel with the highest concentration of essential oil has a slightly yellow color, corresponding to the natural yellowish color of citronella oil [23].

3.1.2 Aroma

The analysis of variance (ANOVA) results showed that addition of citronella oil had a significant effect ($P < 0.05$) on the aroma of aromatherapy gel. The ANOVA results and Duncan's post hoc test for the aroma of aromatherapy gel are presented in Table 3.

Table 3. Panelists assessment of the aroma of aromatherapy gel

Sample	Aroma
Citronella EOs 0%	2.25 ± 0.65 a
Citronella EOs 2.5%	3.44 ± 0.77 b
Citronella EOs 5%	3.68 ± 0.63 bc
Citronella EOs 10%	3.96 ± 0.84 cd
Citronella EOs 7.5%	4.16 ± 0.75 d

Description: Numbers in the same column followed by different lowercase letters are significantly different according to DNMRT at the 5% level of significance.

Semi-trained panelists conducted the sensory analysis of the essential oil scent. Each formulation exhibited a different aroma depending on the amount of citronella oil added. The results showed that the concentration of citronella oil, the stronger the aroma of the essential oil aromatherapy gel.

Based on the results in Table 3, the panelists' preference test for aroma showed that the most preferred aromatherapy gel was the one with the addition of 7.5% citronella oil, with a score of 4.16. The lowest panelists' preference score for aroma, 2.25, was recorded for the aromatherapy gel without the addition of citronella oil (0% citronella oil). The lowest value was observed in the control treatment, where no citronella oil was added. Consistent with previous research findings, the addition of citronella and calamansi essential oils to the air freshener aromatherapy gel was preferred by panelists compared to the control [22].

One reason the citronella aroma from the aromatherapy necklace is not immediately noticeable is that the encapsulation matrix remains intact. Encapsulation protects the active compounds of essential oils from completely evaporating [24,25]. It also enables the sustained release of aroma, thereby prolonging the effect of aromatherapy and increasing its efficiency [26]. A study reported that the microencapsulation of essential oils using liposome technology or biodegradable polymers can provide a gradual release of up to 48 hours, compared to pure essential oils, which lasts only a few hours. The distinctive aroma of citronella is attributed to its main content: Citronellal, Citronellol, and Geraniol [27].

Table 4. Panelists' assessment of aromatherapy gel texture

Sample	Texture
Citronella EOs 2.5%	3.28 ± 0.74 a
Citronella EOs 7.5%	3.72 ± 0.54 b
Citronella EOs 0%	3.76 ± 0.66 b
Citronella EOs 5%	3.80 ± 0.71 b
Citronella EOs 10%	3.96 ± 0.68 b

Description: Numbers in the same column followed by different lowercase letters are significantly different according to DNMRT at the 5% level of significance.

3.1.3 Texture

The analysis of variance (ANOVA) results showed that the addition of citronella oil at a concentration of 2.5%, compared to concentrations of 0%, 5%, 7.5%, and 10% had a significant effect ($P < 0.05$) on the texture of the aromatherapy gel. However, the ANOVA results for

concentrations of 0%, 5%, 7.5%, and 10% showed that the addition of citronella oil had no significant effect on the texture ($p>0.05$). The ANOVA results and Duncan's post hoc test for the texture of the aromatherapy gel are presented in Table 4.

The aromatherapy gel has a chewy texture, contains no water, and is slightly oily. According to Aksari [28], a good gel texture is chewy but not easily broken. Based on the results in Table 4, panelist's preference level test for texture based on the results in Table 4 show the panelist's preference score for the texture of the aromatherapy gel ranged from 3.28 to 3.96. The best texture, preferred by the panelists, was observed in the gel with the addition of 10% citronella oil, with a score of 3.96. The lowest preference for texture was recorded in the 2.5% citronella oil treatment. The results showed that the texture of the aromatherapy gel did not differ significantly between treatments, as the composition of the glucomannan and carrageenan was the same in all formulations. The only variation across treatments was the amount of essential oil, resulting in the texture that ranged from non-oily to oilier. Studies indicate that as the essential oil concentration increases, the viscosity level of the gel decreases, which can lead to a more liquid or less consistent texture [29]. All sensory analysis results for color, aroma, and texture parameters are presented in Fig. 3.

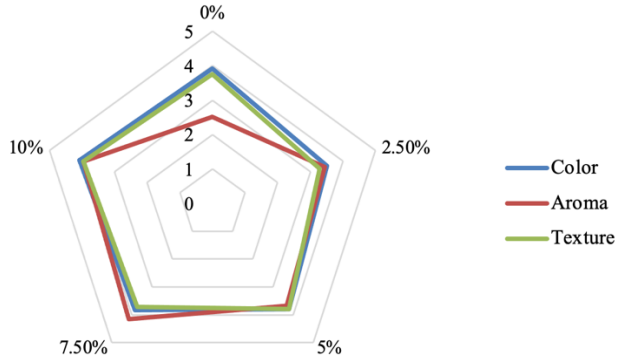


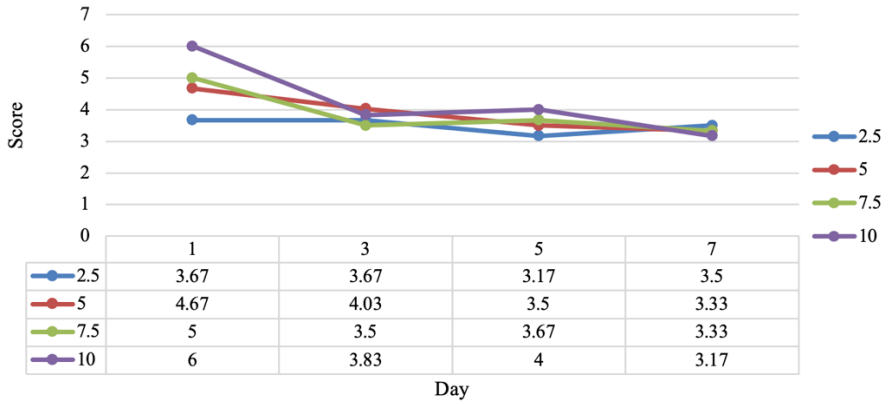
Fig. 3. Sensory analysis of aromatherapy necklace characteristics

3.2 Sensory Analysis-Preference Test of Aromatherapy Necklace Based on Aroma Intensity

Aroma intensity in essential oils is defined as the strength and density of the aroma produced. It can be influenced by several factors, including the concentration and composition of the volatile compounds that make up the essential oil. As the essential oil concentration increases, the intensity of the aroma also strengthens [30]. Furthermore, encapsulation technology allows the aroma to evaporate gradually. The use of crosslinking agents can create a stronger matrix structure, enabling the slow release of the aroma [31,32]. The durability of the aroma of aromatherapy gel across different treatments, based on sensory analysis through organoleptic tests, is shown in Fig. 4.

Aroma intensity is closely related to the encapsulation of essential oils. Encapsulated essential oils control evaporation over time, maintaining their function for a specific duration [33]. Based on sensory analysis by trained panelists, aromatherapy necklaces with the addition of 10%

essential oil received the highest score of 6 on the first day, with aroma decreasing to a score of 3.17 by the seventh day. Aromatherapy necklaces with 2.5% essential oil received a score of 3.67 on the first day, which slightly decreased to 3.5 on the seventh day.



	1	3	5	7
2.5	3.67	3.67	3.17	3.5
5	4.67	4.03	3.5	3.33
7.5	5	3.5	3.67	3.33
10	6	3.83	4	3.17

Fig. 4. Aroma intensity of aromatherapy necklace

This aroma intensity assessment was measured based on the human sense of smell and conducted subjectively. The aroma of essential oils significantly influences the product produced [34]. The data presented show that the decrease in aroma intensity from the first to the seventh day occurred gradually. However, it is recommended that future research conduct in vitro aroma intensity tests to obtain more accurate data.

4. Conclusions

The characteristics and intensity of the aromatherapy necklace were measured through sensory analysis. The aromatherapy necklace produced is well-designed for direct, daily use by consumers. Sensory analysis results for aromatherapy necklaces with the addition of 10% essential oils showed the best results for color and texture assessment (score 4.08 and 3.96, respectively), while the addition of 7.5% essential oils yielded the best result for aroma assessment (score 4.16). The aroma intensity decreased from a score of 6.00 on day 1 to 3.17 on day 7. This gradual and controlled decrease in aroma intensity aligns with the intended purpose of the essential oil encapsulation process. It is recommended that further research measure aroma intensity more precisely using laboratory equipment and examine the structure of the encapsulation matrix.

Abbreviations

GC-MS	Gas Chromatography and Mass Spectroscopy
ANOVA	Analysis of Variance
EOs	Essential Oils

Data availability statement

Data will be shared upon request by the readers.

CRedit authorship contribution statement

Alfi Asben: Writing – Original draft, Conceptualization, Funding acquisition. **Annisa Putri**:

Writing – Original draft, Conceptualization, Methodology, Resources, Data curation. **Anwar Kasim**: Validation, Funding acquisition. **Dini Novita Sari**: Data curation, review, and editing.

Declaration of Competing Interest

The authors declare no competing interest.

Acknowledgment

The members of the research team would like to thank the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia for assisting in the form of facilities and funds in the "Matching Fund" program for the success of this research carried out at Andalas University.

References

[1] Vora LK, Gholap AD, Hatvate NT, Naren P, Khan S, Chavda VP, Khatri DK. Essential oils for clinical aromatherapy: a comprehensive review. J Ethopharmacol 2024;330:118180. https://doi.org/10.1016/j.jep.2024.118180.

[2] Mohammadpourhodki R, Sadeghnezhad H, Ebrahimi H, Basirinezhad MH, Maleki M, Bossola M. The effect of aromatherapy massage with lavender and citrus Aurantium essential oil on quality of life of patients on chronic hemodialysis: A parallel randomized clinical trial study. J Pain Symptom Manage 2021;61:456–463. https://doi.org/10.1016/j.jpainsymman.2020.08.032.

[3] Yan MR, Wang CH, Jose CFN, Su YY. Targeting open market with strategic business innovations: A case study of growth dynamics in essential oil and aromatherapy industry. J Open Innov Technol Mark Complex 2019;5:7. https://doi.org/10.3390/joitmc5010007.

[4] Silva LCDMA, Dos Santos KVG, Dos Santos JJDS, Arruda RPDPO, e Silva SYB, Silva HMMD, Ribeiro KRB, Dantas DV, Dantas RAN. Efficacy of aromatherapy with Lavandula angustifolia oil on postoperative pain after cardiac surgery: A randomized clinical trial. Explore 2024;20:103034. https://doi.org/10.1016/j.explore.2024.103034.

[5] Sulaswatty A, Rusli MS, Abimanyu H, Tursiloadi S. Minyak Serai Wangi dan Produk Turunannya. Jakarta: LIPI Press; 2019.

[6] Sarah M, Ardiansyah D, Misran E, Madinah I. Extraction of citronella oil from lemongrass (Cymbopogon winterianus) by sequential ultrasonic and microwave-assisted hydro-distillation. Alexandria Eng J 2023;70:569–583. https://doi.org/10.1016/j.aej.2023.03.019.

[7] Siswanto AP, Ariyanto HD, Yulianto ME, Faisal MM, Wardani OK, Kuvshinov D. Formulation and physical properties of citronella oil emulsion on differences in emulsifiers with the addition of maltodextrin. Materials Today: Proceedings 2023;87:147–151. https://doi.org/10.1016/j.matpr.2023.02.389.

[8] Wu H, Jiang X, Dong Z, Fan Q, Huang J, Liu H, Chen L, Li Z, Ming L. New insights into the influence of encapsulation materials on the feasibility of ultrasonic-assisted encapsulation of Mosla chinensis essential oil. Ultrason Sonochem 2024;103:106787. https://doi.org/10.1016/j.ultsonch.2024.106787.

[9] Bastos LPH, Santos CHC, Carvalho MG, Rojas EEG. Encapsulation of The Black Pepper (Piper nigrum L.) Essential Oil by Lactoferrin-Sodium Alginate Complex Coacervates: Structural Characterization and Simulated Gastrointestinal Conditions. Food Chemistry 2020;316:126345. https://doi.org/10.1016/j.foodchem.2020.126345.

[10] Niu B, Chen H, Wu W, Fang X, Mu H, Han Y, Gao H. Co-encapsulation of chlorogenic acid and cinnamaldehyde essential oil in Pickering emulsion stabilized by chitosan nanoparticles. Food Chemistry: X 2022;14:100312. https://doi.org/10.1016/j.fochx.2022.100312.

[11] Soleimani H, Mostowfizadeh-Ghalamfarsa R, Zarei A. Chitosan Nanoparticle Encapsulation

of Celery Seed Essential Oil: Antifungal Activity and Defense Mechanisms Against Cucumber Powdery Mildew. Carbohydr Polym Technol Appl 2024;8:100531. https://doi.org/10.1016/j.carpta.2024.100531.

[12] Liang J, Zhang Y, Chi P, Liu H, Jing Z, Cao H, Du Y, Zhao Y, Qin X, Zhang W, Kong D. Essential oils: Chemical constituents, potential neuropharmacological effects and aromatherapy-A review. Pharmacol Res - Mod Chinese Med 2023;6:100210. https://doi.org/10.1016/j.prmcm.2022.100210.

[13] Hedigan F, Sheridan H, Sasse A. Benefit of inhalation aromatherapy as a complementary treatment for stress and anxiety in a clinical setting–A systematic review. Complement Ther Clin Pract 2023;52:101750. https://doi.org/10.1016/j.ctcp.2023.101750.

[14] Chung YH, Chen SJ, Lee CL, Chang YS. Kokedama and essential oils had a relaxing psychophysiological effect on Taiwanese women during the COVID-19 pandemic. Explore 2024;20:371–379. https://doi.org/10.1016/j.explore.2023.09.009.

[15] Purwanto URE, Munisih S. Formulation and Physical Characterization of Essential Oil Bangle (Zingiber cassumunar Roxb.) Nanoemulsion Gel. J Sci Technol Res Pharm 2021;1:1–11. http://dx.doi.org/10.15294/jstrp.v1i1.43500.

[16] Putri A, Rusli MS, Setyaningsih D. Enkapsulasi Campuran Minyak Atsiri sebagai Produk Sediaan Aromaterapi dengan Teknik Koaservasi Kompleks. Jurnal Teknologi Industri Pertanian 2020;30:299–307. https://doi.org/10.24961/j.tek.ind.pert.2020.30.3.299.

[17] Setyaningsih D, Apriyantono A, Sari MP. Analisis Sensori untuk Industri Pangan dan Agro. Bogor: IPB Press; 2010.

[18] Mahanta BP, Lahon D, Kalita D, Lal M, Haldar S. Study on aroma-profile, key odorants and ontogenetic variability of black turmeric (Curcuma caesia Roxb.) essential oil: An aroma perspective. Ind Crop Prod 2023;193:116115. https://doi.org/10.1016/j.indcrop.2022.116115.

[19] Movahed MD, Sahari MA, Barzegar M. Microencapsulation of flaxseed oil by complex coacervation of with apricot tree (Prunus armeniaca L.) gum and low molecular chitosan: Formation and structural characterization. Appl Food Res 2024;4:100519. https://doi.org/10.1016/j.afres.2024.100519.

[20] Xuan J, Xia Q, Tu Y, Luo T, Mao Q, Han Z, Barron CJ, Liu S, Wang B. Effect of enzymatically produced tuna oil acylglycerol on the characteristics of gelatin O/W emulsion during microencapsulation using complex coacervation. LWT 2023;190:115580. https://doi.org/10.1016/j.lwt.2023.115580.

[21] Piatti D, Marconi R, Caprioli G, Zannotti M, Giovannetti R, Sagratini G. White Acqualagna truffle (Tuber magnatum Pico): Evaluation of volatile and non-volatile profiles by GC-MS, sensory analyzes and elemental composition by ICP-MS. Food Chemistry 2024;439:138089. https://doi.org/10.1016/j.foodchem.2023.138089.

[22] Nur'aini W, Silsia S, Syafnil. Karakteristik gel aromaterapi pengharum ruangan dari karagenanglukomanan dengan minyak atsiri serai wangi dan jeruk kalamansi sebagai pewangi. Agrointek 2024;18:320–332. https://doi.org/10.21107/agrointek.v18i2.19033.

[23] Feriyanto YE, Sipahutar PJ, Mahfud, Prihatini P. Pengambilan Minyak Atsiri dari Daun dan Batang Serai Wangi (Cymbopogon winterianus) Menggunakan Metode Distilasi Uap dan Air dengan Pemanasan Microwave. Jurnal Teknik Pomits 2013;2:93–97. https://doi.org/10.12962/j23373539.v2i1.2347.

[24] Wojciechowski K, Stefanowicz A. Encapsulation of eucalyptus and lavender oils by spray drying improves their dispersibility. Journal of Molecular Liquids 2024;401:124634. https://doi.org/10.1016/j.molliq.2024.124634.

[25] Daza LD, López SD, Montealegre MÁ, Eim VS, Sandoval-Aldana A. Study of the physicochemical properties of hass avocado oil encapsulated by complex coacervation. LWT 2024;204:116491. https://doi.org/10.1016/j.lwt.2024.116491.

[26] Zuidam NJ, Heinrich E. Encapsulation of aroma. In: Zuidam NJ, Nedovic V (eds) Encapsulation technologies for active food ingredients and food processing. Springer, New

York 2022;127–160. https://doi.org/10.1007/978-1-4419-1008-0_5.
[27] Anggia M, Mutiar S, Arziah D. Teknologi Ekstraksi Bunga Kenanga (Cananga Odorata L.) dan Sereh Wangi (Cymbopogon Nardus L.) Sebagai Aroma Terapi Sabun Cair. Jurnal Daur Lingkungan 2018;1:5–9. http://dx.doi.org/10.33087/daurling.v1i1.2.
[28] Aksari NJ. Pembuatan Gel Pengharum Ruangan Menggunakan Karagenan dan Xanthan Gum sebagai Basis dengan Aroma Apel dan Minyak Akar Wangi. Skripsi. Universitas Sumatera Utara, 2018.
[29] Hardiansyah SC, Mawarni CS. Pengaruh Konsentrasi Minyak Atsiri Serai Wangi (Cymbopogon Nardus) Terhadap Stabilitas Formulasi Sediaan Emulgel. Jurnal Kesehatan: Jurnal Ilmiah Multi Sciences 2023;13:48–55. https://doi.org/10.52395/jkjims.v13i1.362.
[30] Mwithiga G, Maina S, Muturi P, Gitari J. Lemongrass (Cymbopogon flexuosus) growth rate, essential oil yield and composition as influenced by different soil conditioners under two watering regimes. Heliyon 2024;10:e25540. https://doi.org/10.1016/j.heliyon.2024.e25540.
[31] Ghoshal G, Sandal S. Neem essential oil: Extraction, characterization, and encapsulation. Food Chemistry Advances 2024;4:100702. https://doi.org/10.1016/j.focha.2024.100702.
[32] de Almeida JM, Crippa BL, de Souza VVMA, Alonso VPP, Júnior EDMS, Picone CSF, Silva NCC. Antimicrobial action of Oregano, Thyme, Clove, Cinnamon and Black pepper essential oils free and encapsulated against foodborne pathogens. Food Control 2024;144:109356. https://doi.org/10.1016/j.foodcont.2022.109356.
[33] Abdollahzadeh M, Elhamirad AH, Shariatifar N, Saeidiasl M, Armin M. Effects of nano-chitosan coatings incorporating free/nano-encapsulated essential oil of Golpar (Heracleum persicum L.) on quality characteristics and safety of rainbow trout (Oncorhynchus mykiss). International Journal of Food Microbiology 2023;385:109996. https://doi.org/10.1016/j.ijfoodmicro.2022.109996.
[34] Xu CC, Li QL, Wang N, Liu DK, Guo CX. Identifying and discriminating aroma attribute and bioactive components of five commercial essential oils of celery (Apium graveolens L.) seeds using E-nose, HS-GC-IMS, and GC-MS. LWT 2023;184:115094. https://doi.org/10.1016/j.lwt.2023.115094.