IJASST International Journal of Applied Sciences and Smart Technologies

Volume 06
Issue 02

p-ISSN 2655-8564, e-ISSN 2685-943, pp. 301-320, 2024

Recent Developments in The Influencing Variables of Hydrodistillation for Enhancing Essential Oil Yields in Indonesia: A Brief Review

Awaly Ilham Dewantoro[1,2], Alvita Rahma Alifia[2], Tanti Handini[2], Latifah Zainul Qolbi[2], Dita Amelia Ihsani[2] , Desy Nurliasari[2*]

[1] *Postgraduated Students in Technology of Agro-Industry, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, Jatinangor, Indonesia*
[2] *Department of Agricultural Industrial Technology, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, Jatinangor, Indonesia*
[*]*Corresponding Author: desy.nurliasari@unpad.ac.id*

(Received 17-07-2024; Revised 04-08-2024; Accepted 06-08-2024)

Abstract

Hydrodistillation is widely known as the simplest essential oils (EOs) isolation technique and is widely used by small-scale producers, such as in Indonesia. The main characteristic of hydrodistillation is the plant-source material of EOs soked in water, followed by boiling and diffusion. Variuos problems arise from the use of hydrodistillation, including the possibility of overheating, degradation of EOs because of the long heating time, difficulty in controlling the heat, and a slow process. The aim of this study was to review the recent developments in hydrodistillation technology that have been developed in Indonesia to improve the quality and yield of EOs. Bibliometric analysis trhough the Methodi Ordinatio was used to compile a systematic review of prior studies in the recent decade regarding the application of hydrodistillation in Indonesia. The results showed that five plant-source commodities were extensively isolated consisting of citrus, lemongrass, cinnamon, nutmeg, and ginger. Furthermore, this study investigated the variables that influnce the hydrodistillation process for EOs isolation. The variables were often evaluated according to the results are distillation time, pretreatment of raw materials, feed-to-solvent ratio, particle size, growth place, and plant developmental stage. A future perspective was considered and outlined to carroed out further novel study and development strategies.

Keywords: Bibliometric analysis, Hydrodistillation, Plant commodities, Process variables, Pretreatment.

1 Introduction

Essential oils (EOs) are one of the leading agro-industrial commodities with increasing demand each year. This is reinforced by the fact that worldwide EOs production has increased from 150 thousand tons to 370 thousand tons in the period of 2007-2020 [1]. Indonesia is the third largest EOs producer after China and India [2]. Despite its considerable market share, the quality of Indonesian EOs remains mediocre because of simple isolation and purification technology. This drives the evaluation of EOs isolation technologies, particularly in developing simple technologies that are suitable for developing countries, such as Indonesia. One simple technology that is widely applied in developing countries is hydrodistillation, which has been widely applied globally by micro- and small-scale producers [3].

Hydrodistillation, similar to common distillation, proceeds by evaporating the EOs content of the plant cells, which is then cooled (condensed) to separate it from water [4]. The main characteristic of employing hydrodistillation, compared to other techniques, is that the source of the material is soaked in water, followed by boiling and diffusion of the material [5,6]. This technology is concerned with isolating EOs from highly soluble materials in water, and is susceptible to damage by heat. However, hydrodistillation has several problems, including the possibility of overheating, degradation of essential oils because of the long heating and distillation time, difficulty in controlling the heat, and a slow process [7]. This phenomenon requires further investigation to resolve problems and enhance the hydrodistillation performance and the quality of EOs.

This study was carried out with the aim of reviewing the recent developments in hydrodistillation technology that have been developed in Indonesia to improve the quality of the obtained EOs. This is due to the simplicity with which hydrodistillation installations may be established by small-scale producers, such as Indonesian farmers. In addition, the yields still have strong notes that motivated the authors to investigate recent developments in hydrodistillation in Indonesia, despite the fact that the quality of EOs still has to be improved. Thus, the results of this study can serve as a reference for designing and developing further novel studies related to hydrodistillation of EOs.

2 Material and Methods

Data Collection

Methodi Ordinatio was used to collect data from numerous papers in the Google Scholar database, followed Pagani et al. [8] procedures with slight modifications. Data were collected on June 30, 2024, with search queries such as "**hidrodistilasi**" OR "**distilasi air**" OR "**penyulingan air**" OR "**penyulingan rebus**" AND "**minyak atsiri**" in Bahasa Indonesia terms, and 50 documents were collected. Data filtering is then performed on these documents to obtain high-quality documents by checking the accreditation and indexation of the journal in the Sinta and Garuda databases. Table 1 outlines the data collection procedures for the systematic review, which resulted in 42 documents for further analysis. An investigation was then carried out on the national indexation, year of publication, and keyword co-occurrences (related to the types of EOs commodities and variables that influence the hydrodistillation process).

2.2 Bibliometric Analysis

Bibliometric analysis was performed on the final portfolio (42 documents) by creating a visual map network using VOSviewer v1.6.20 [9, 10], following the analysis conditions as:

- Map based on bibliographic data;
- Type of analysis: co-occurrences;
- Unit of analysis: keywords;
- Minimum number of occurrences: 4;
- Number of terms selected: total number of itmes;
- Show: all items.

The resulting visual map network was then used as a reference for conducting a brief systematic review in this study, and it performed focused and minimized the bias of discussion.

Table 1. Main steps to perform the systematic review through Methodi Ordinatio

Steps		Description	
Database search	**I**	**Initial Portfolio**	
		Database	Google Scholar
		Keywords	129
		Number of documents	50
Filtering procedures	**II**	Filtering based on **Sinta** and/or **Garuda**	
	III	Screening title and keywords	
	IV	Reading abstracts	
	V	Reading full texts	
		Final Portfolio	
		Number of documents	42
		Keywords	19
Content analysis	**VI**	Year of publication	
		Indexation of documents	
		Keywords	

3 Results and Discussions

Visual Map Network

Fig. 1a shows an increase in the interest in hydrodistillation studies of EOs from 2021 to 2023 after experiencing fluctuations in the previous seven years. In terms of the number of related publications in 2024, four documents were discovered, with the number expected to increase owing to a positive trend of interest among Indonesian researchers. Further investigation was conducted to filter the data to obtain documents that had been indexed nationally (Sinta and Garuda) based on the latest journal indexation status. This was done to obtain high-quality data at the national level for a comprehensive review. Based on Fig. 1b, journals accredited by Sinta 4 and indexed by Garuda are researchers' favorites for publishing their studies in numerous documents after indexation screening (final portfolio). It is envisaged that these findings will increase the motivation among researchers and the number of studies published, particularly in journals with national indexation and international reputation.

Fig. 2 depicts the visual map network of the final portfolio obtained by applying Methodi Ordinatio. The development of hydrodistillation technology can be illustrated through this map, such as the results studies after 2021, which focus on evaluating the duration of distillation time and the effect of pretreatment on the EOs yield [11, 12]. Citrus is a commodity that has recently been developed as a source of EOs through

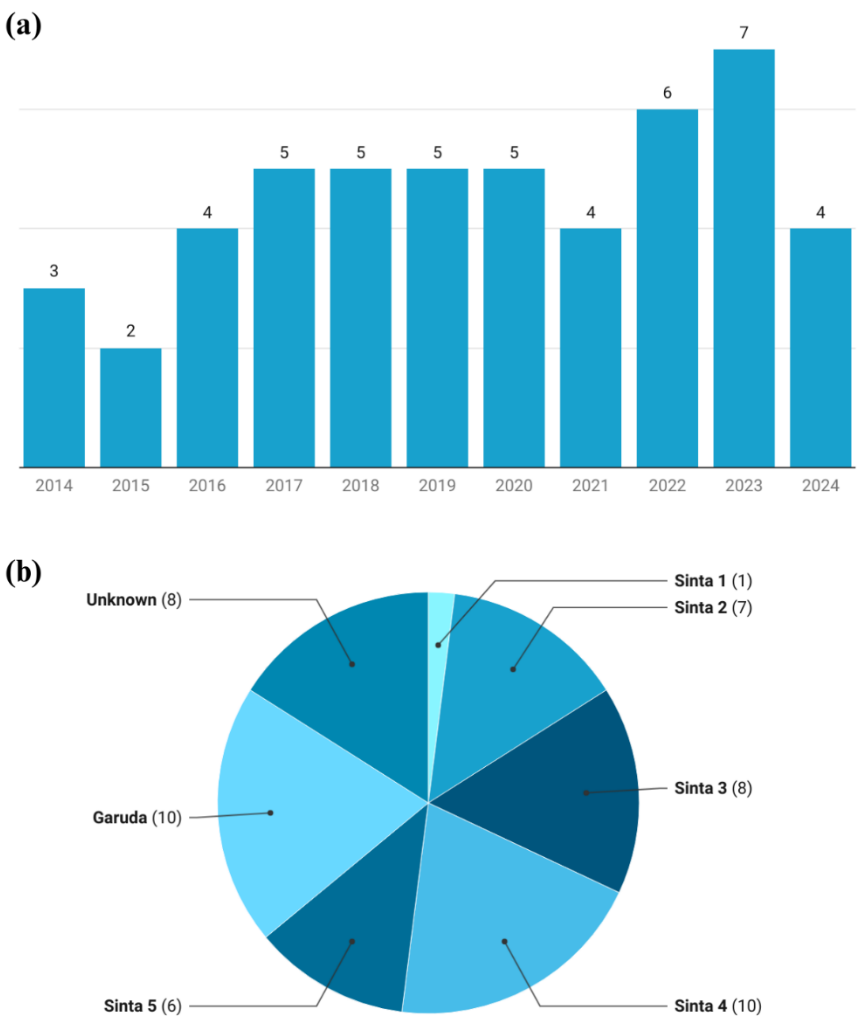

Figure 1. Distribution of the number of published documents: (a) based on publication years until June 30, 2024; and (b) national indexation.

hydrodistillation. Furthermore, the visual map network could be further studied in the future, based on the latest numerous results that have been evaluated. Some of these include the evaluation of the material's moisture content, particle size, microwave and/or ultrasound pretreatment, and the influence of plant development stages as promising novel topics to be investigated in the future.

A more in-depth investigation was carried out on EOs plant-source commodities based on keyword co-occurrences. Fig. 3 summarizes the findings for five EOs plant-source commodities that have been widely developed through hydrodistillation in the recent decade. As discussed in the previous section, citrus is the most often isolated commodity for its EOs content, both from the fruit peel and leaves [13-15]. In addition, lemongrass is another commodity that is often isolated, similar to citrus, with seven co-occurrences. Three other commodities have been developed in the recent decade to isolate their EOs content through hydrodistillation, namely cinnamon [16-18], nutmeg [19, 20], and ginger [21, 22].

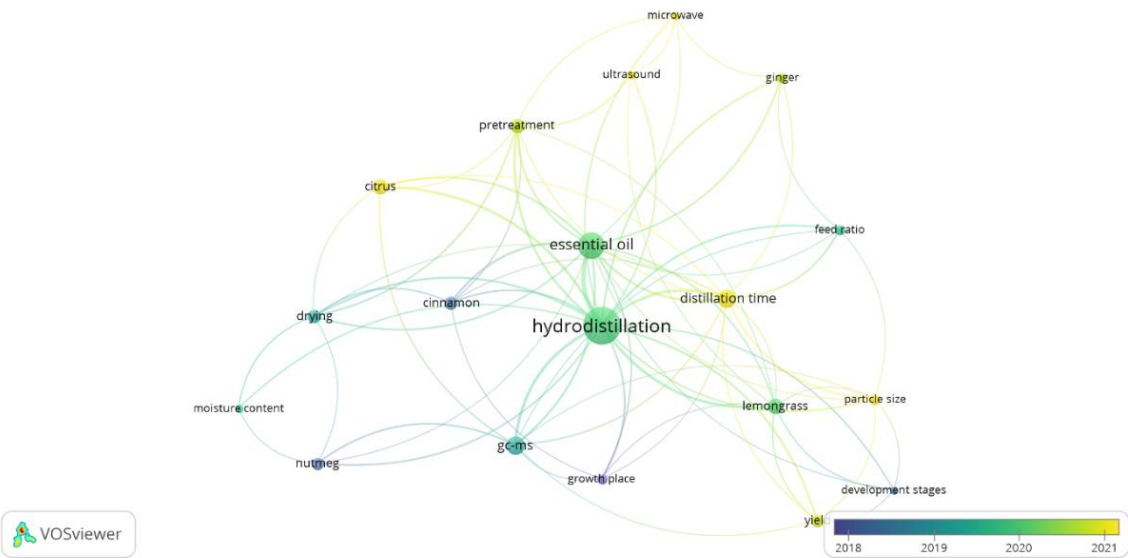

Figure 2. Visual map network of hydrodistillation development for EOs isolation in Indonesia (2014 to 2024).

Figure 3. Most developed Eos plant-source commodities in Indonesia based on bibliometric analysis results.

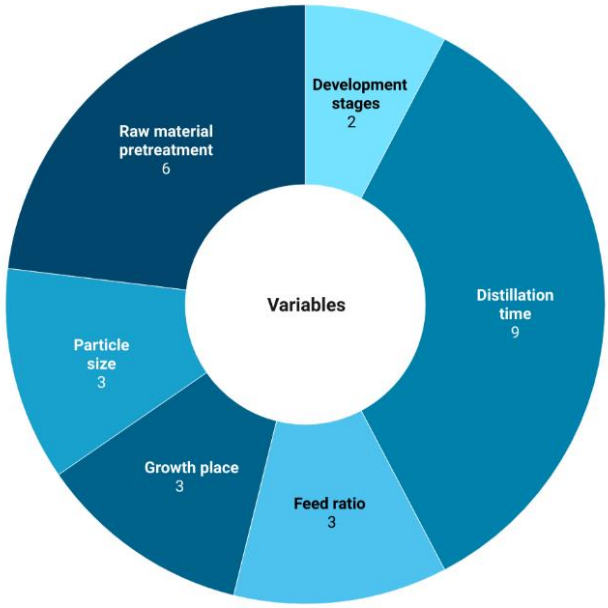

Figure 4. Most evaluated hydrodistillation variables for EOs isolation in Indonesia.

This study then evaluated the variables that influenced the hydrodistillation process based on the results of the bibliometric analysis. The results are shown in Fig. 4, with distillation time being the most frequently evaluated variable because it had nine co-occurrences. Pretreatment of raw materials is an interesting variable to evaluate in more depth because it can increase EOs yield and can be a promising novel study. Other commonly evaluated variables include feed ratio and particle size. The upstream variables that appear, such as growth place and plant development stages, show promising potential for further development, as well as referring to their position in the visual map network.

Distillation Time

Distillation time has become a crucial variable and has been most frequently evaluated in the recent decade in relation to EOs isolation through hydrodistillation. This is because the distillation process runs for a prolonged time, which can cause EOs degradation that is isolated from the plant source, which reduces the yield and quality [23, 24]. In addition, it is difficult to control the temperature, which can cause overheating and the formation of char in a still reactor that occurs if the process runs for a prolonged time [7]. Thus, a comprehensive investigation was performed on this variable to obtain recent developments in employing hydrodistillation according to collected data on Table 2.

Citrus and lemongrass are the most widely used plant-source commodities in the hydrodistillation isolation process, based on bibliometric analysis results. Leaves are an organ of citrus plants that are often used as a source of limonene, and hydrodistillation for 3 h can produce 0.65–0.80% of EOs [25]. A prolonged time to 7 h of hydrodistillation could not increase the yield of citrus leaf EOs because it only produced 0.72% [14]. Meanwhile, hydrodistillation of citrus leaves for 1-3 hours resulted in the highest yield at a distillation time of 2 h, that is, 1.48% of citrus leaves EOs [26]. In addition, interesting findings were observed in the hydrodistillation of lemongrass distilled for 1-5 hours. Hydrodistillation of untreated lemongrass resulted in the highest yield after distillation process for 4.5 hours [27]. The distillation time was proven to be shorter than 1 h by evaluating other variables, such as the size reduction and drying of the plant-source materials [12].

Table 2. Recent studies on the effects of hydrodistillation time to essential oils isolation.

Materials	Time	Other Operational Variables and Results	Ref.
Citrus leaves	1–2 h	• Feed-to-solvent ratio that used was 1:10. • Hydrodistillation for 2 h resulted in the highest yield and decreased the results obtained after a 3 h.	[26]
Lemongrass	3–5 h	• Performed different two-level temperatures (120°C and 130°C). • Time and temperature influenced to the results. • The highest yield obtained after 5 h. • Better quality of EOs achieved by employing hydrodistillation at 130°C for 4.5 h.	[27]
Lemongrass	30–90 min	• Lemongrass harvested at 3 months old then size reducted and wind-dried. • Ultrasound pretreatment employed to dried lemongrass for further EOs isolation. • Distillation time between 60 min and 90 min provided similar results (in 1:20 and 90% amplitudes).	[12]
Cinnamon leaves	3–7 h	• Several pretreatment performed, such as the use of fresh and dried leaves in whole and in reduced sizes. • The fresh and whole size cinnamon leaves provided high EOs yield. • Optimum distillation time at 5 h, because of no signifficant influence to the results after 6 h. • Cinnamaldehyde content was 13.60–25.57%	[28]
Red ginger	2–6 h	• Red ginger powder has 10.72% moisture content and size of 60 mesh. • The feed-to-solvent ratio employed as 1:12. • The longest distillation time provide the highest yields as 1.65%, but the optimum results was achieved after 4 h. • No signifficant influence between the results of 4 h (1.55%) and 5 h (1.57%).	[29]
Red ginger	2–6 h	• Others operational variables emplyed consist of 24 mesh of size, different feed-to-solvent ratio (1:8, 1:10, and 1:12), and hydrodistillation run at 80°C of temperature. • There was no signifficant influence from distillation time, feed-to-solvent ration, and the interaction. • The optimum variables achieved by 6 h hidrodistillation and 1:12 feed-to-ratio that provide 0.14% of yield.	[30]

An increase in the EO yield through hydrodistillation can also be achieved by prolonging the distillation time, for example, in red ginger. Evaluation was successfully performed by hydrodistillation for 2–6 h with the highest yield of 1.65% at 6 h [29]. The results of these studies showed that there was no significant difference between distillation times of 4 and 5 h, but when distillation was extended to 6 h, the yield of red ginger EOs increased. Similar findings were obtained from a hydrodistillation optimization study of red ginger, which obtained the highest yield after 6 h of distillation [30]. However, the distillation time in these studies did not have a significant effect, and the quality of the EOs obtained was not better than that in previous studies. This phenomenon shows that implementing a short distillation time is more considered, especially if combined with engineering other process variables such as size reduction and drying of the material which is a pretreatment for the plant-source material.

Pretreatment of Raw Materials

Process variables regarding the pretreatment of EOs plant sources should be evaluated more comprehensively in this study. This is because pretreatment has the second highest number of keyword co-occurrences after distillation time (Fig. 4). Various studies have shown that the pretreatment of plant-source materials can increase the yield and quality of EOs. As seen on Fig. 5, several pretreatment techniques have been developed in the recent decade, starting from the simplest technology, namely drying (related to plant material moisture content), to modern technologies such as microwaves and ultrasonics.

Drying is the simplest pretreatment technology and is directly related to the moisture content of the material, which can inhibit the EOs isolation process. Investigation of EOs yields from plant-source materials in several previous studies proved that material moisture content has an effect. Investigation of EOs yields from plant-source materials in several previous studies proved that material moisture content has an effect. Nutmeg flesh was dried until the initial moisture content decreased by 25% and had the highest yield compared to undried flesh [31]. Similar results were obtained after drying sintok bark until the moisture content reached 15%, which could increase the yield of EOs compared with undried bark [32]. A different finding occurred when the plant source was leaves because the moisture content in fresh leaves could catalyze the process of isolating EOs [33]. Further evaluations were performed on cinnamon leaves that were subjected to different treatments (without drying, withering, and wind drying), which showed that the yield of fresh leaves was higher than that of the wind dry and withering results [28]. This is in accordance with the results of studies on the different effects of drying cinnamon leaves (ripening, wind drying, and sun drying), which did not show any influence on EO yield [34]. These findings demonstrated the need for appropriate drying strategies, particularly for different plant organs.

Recent trends have led to the use of modern technologies to increase the yield of isolated EOs using hydrodistillation techniques. Some of these studies have successfully used microwave and ultrasonic technologies. Isolation of zingiberene from ginger showed the highest content after microwave pretreatment at 100 Watt for 2 min [35]. Isolation of zingiberene from ginger showed the highest content after microwave pretreatment at 100

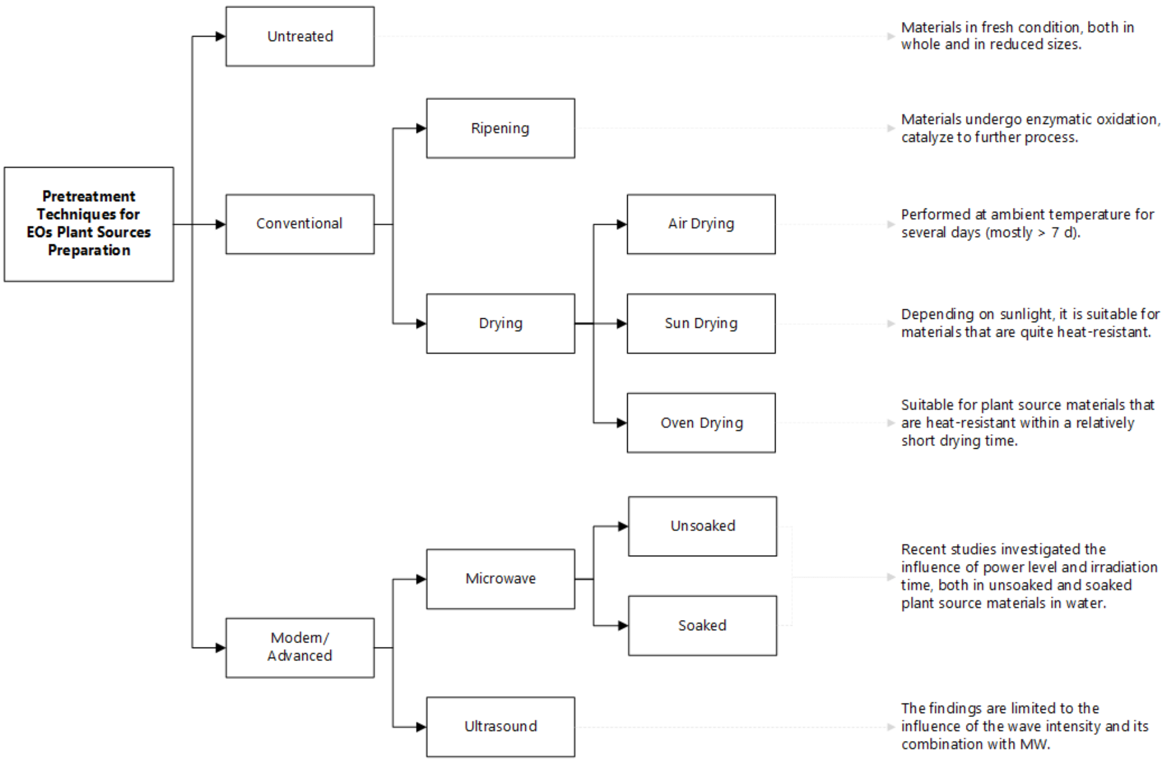

Figure 5. Most applicable pretreatment technologies in hydrodistillation for EOs isolation in Indonesia.

Watt for 2 min. These studies found a zingiberene content of 24.7%, which is close to that of commercial ginger EOs (24.8%). The innovative strategies for microwave pretreatment were then conducted by prolonging the soaking duration, as was done for agarwood. Soaking was performed to increase the yield and bioactive content of the product for 1-4 weeks which shows an increase in the last week of soaking [36]. However, the authors consider this additional treatment to be ineffective because it increases the duration of EOs isolation, driving the modern pretreatment combination of microwaves and ultrasonics. This combination has been proven to increase the yield, such as black cumin EOs, which have the highest yield through a combination of microwave and ultrasonic pretreatment, rather than applying each technology separately [37].

Various findings in recent decades have shown the effects of pretreatment on the produced EOs. The difference in plant organs as source material is one of the factors determining the appropriate pretreatment technique to be applied. In addition, the use of modern technology is a recent trend that has advantages in terms of duration compared to drying, such as withering, wind drying, and sun drying. Further investigation is required to apply modern pretreatment, particularly in terms of combining technologies that can increase the yield of EOs. An interesting topic that can be further developed in the future and is promising as a novel study is combining simple and modern pretreatment in a short treatment time.

Feed-to-Solvent Ratio and Particle Size

The feed-to-solvent ratio is a key variable in the isolation of EOs through hydrodistillation. This is related to the volume of solvent used, if the ratio is large (in w/v) it indicates that a large amount of solvent was used. Various studies have evaluated the effect of feed-to-solvent ratio, such as ginger. Under the same hydrodistillation conditions (T = 100°C for 6 h), a ratio of 1:2 gave a higher yield than that obtained using a ratio of 1:5 [22, 35]. Different findings occurred in red ginger because investigations into different ratios (1:8, 1:10, and 1:12 with a particle size of 24 mesh) had no effect on the yield of as 0.06–0.23% [30]. However, other findings have shown that hydro-distillation of red ginger at a ratio of 1:12 produced a yield of up to 1.65% after distillation for 6 h with a different particle size of 60 mesh [29]. These results show that, apart from the feed-to-solvent ratio, there are other variables that can influence EOs isolation yields, such as the particle size of the plant material.

Further investigation into the combined interaction of feed-to-solvent ratio with particle size has been performed for black pepper EOs. Optimization studies were performed on the variables of feed-to-solvent ratio (7/100, 12/100, and 17/100), size (10-20, 20-30, and 30-40 mesh), and distillation time (60, 135, and 210 min), which yielded an optimum EOs of 5.81% [11]. Based on these results, the feed-to-solvent ratio did not have a significant influence on the yield, meanwhile the particle size and distillation time had a significant influence. This led to further evaluation of the differences in particle size and/or plant materials used for isolating EOs via hydrodistillation. As previously discussed, the difference in the size of red ginger between 24 mesh and 60 mesh showed different results, with increased yield at smaller particle sizes [29, 30]. Other evaluation studies have been performed on lemongrass (whole size, 5 cm, 10 cm, and 15 cm), which had the highest yield at the smallest size of 5 cm [18]. These various findings led to further studies through optimization design, because these two variables, the feed-to-solvent ratio and particle size, have an influence that has an uncertain trend (because it can increase and/or decrease). Moreover, hydrodistillation requires soaking the plant source material and preventing agglomeration, which can inhibit the EOs isolation process.

3.5 Growth Places and Plant Developmental Stages

The growth and development environment of EOs plant sources is one of the variables that influences the results of hydrodistillation. Growth environment variables, or growth places, have three keyword co-occurrences in the development of EOs hydrodistillation studies. Several studies have shown a significant effect, such as the isolation of EOs from lemongrass, cinnamon, and basil. Isolation of EOs from lemongrass cultivated in the highlands resulted in higher yields than those cultivated in the lowlands [38]. Similar results were obtained from the hydrodistillation of basil leaves, which had a higher yield in plants cultivated in highlands [39]. In contrast, different findings show that cinnamon EOs that grow in lower areas, such as Purwokerto, have a higher yield than those from the Tawangmangu area, which is in the highlands [40]. Furthermore, these studies have investigated the differences in plant organs (leaves, twigs, and bark), and generally, the yield of EOs from the Cinnamons' Purwokerto area remains higher. These findings demonstrate the need for further investigation of the differences in growth location due to differences in environmental factors.

One of the variables that influences the results of the hydrodistillation of EOs is the developmental stage of the plant source materials. This is shown by the lack of studies on this variable because there have been only two keyword co-occurrences over the last decade. The findings that the authors discovered regarding studies evaluating this variable are still limited to lemongrass EOs. The yield of lemongrass EOs was known to be higher when this plant was harvested at six months, and there was a decrease when the lemongrass was nine months old [16]. This is similar to the results of hydrodistillation of 6 month old lemongrass under fresh conditions, which can produce approximately 1.35–2.09% of EOs [18]. Moreover, the EOs content of 3 month old lemongrass is known to remain high because it had a yield of 1.62%, but there was additional pretreatment through ultrasonic technology [12]. These findings can provide insights for further investigation into the influence of the developmental stages of EOs plant sources, especially for conducting studies on plant sources other than lemongrass. In addition, because of the lack of research on this topic, it can become a novel development study regarding hydrodistillation, particularly in Indonesia.

Future Perspective

Novel strategies for developing hydrodistillation technology to isolate EOs can be found in recent studies. Various influence variables have been briefly summarized and reviewed, showing promising potential for future development studies. Optimization studies are considered an appropriate strategy for investigating variables related to the hydrodistillation process, such as distillation time, feed-to-solvent ratio, and particle size [11, 12, 30]. To control the conditions of the optimized variables, instrumentation devices that can be controlled, such as microcontrollers, can be used to increase the yield of EOs [41]. In addition, optimization can be carried out on the pretreatment of plant source materials to catalyze the EOs isolation process. Some of them could investigate differences in pretreatment techniques and parameters or conduct experiments to combine the commonly applied pretreatment techniques [36, 37]. There are interesting and promising variables to be further investigated in the future because the biodiversity in

Indonesia that can be cultivated in various locations is related to the differences in growth places. This variable can be combined with plant developmental stages because the authors discovered that there was a peak in the yield of lemongrass EOs, and related published studies are still lacking [16]. The potency of novel studies has been described and is considered promising for future development to improve the performance of hydrodistillation technology for isolating EOs from various plant sources.

4 Conclusions

The trend of increasing interest in the development of hydrodistillation technology in Indonesia has been demonstrated by an increasing number of documents published in nationally indexed journals. Over the past decade, there have been five commonly used EOs plant source commodities, including citrus, lemongrass, cinnamon, nutmeg, and ginger. This finding provides novel strategies for developing other commodities isolated through hydrodistillation. To improve the performance and isolation results, this study investigated various variables that influence the process, especially those related to the yield. Distillation time, plant source material pretreatment, feed-to-solvent ratio, particle size, growth place, and plant developmental stages are variables that have often been evaluated in the recent decade. These variables have been successfully summarized and reviewed briefly and comprehensively to demonstrate their potential for performing novel studies that can be developed in the future. Several of these include conducting optimization studies, evaluating and combining pretreatment techniques, and investigating variables from upstream sectors (such as places of growth and plant developmental stages).

References

[1] C. Barbieri and P. Borsotto, “Essential oils: Market and legislation,” in *Potential of Essential Oils*, H. El-Shemy, Ed., IntechOpen, 2018. doi: 10.5772/intechopen.77725.

[2] S. Khan, A. Sahar, T. Tariq, A. Sameen, and F. Tariq, “Essential oils in plants Plant

physiology, the chemical composition of the oil, and natural variation of the oils (chemotaxonomy and environmental effects, etc.),” in *Essential Oils: Extraction, Characterization and Applications*, G. A. Nayik and M. J. Ansari, Eds., Academic Press Inc., 2023. doi: 10.1016/B978-0-323-91740-7.00016-5.

[3] M. A. Hanif, S. Nisar, G. S. Khan, Z. Mushtaq, and M. Zubair, “Essential oils,” in *Essential Oils Research: Trends in Biosynthesis, Analytics, Industrial Applications and Biotechnological Production*, S. Malik, Ed., Springer Nature Switzerland AG, 2019, pp. 3–17. doi: 10.1007/978-3-030-16546-8_1.

[4] S. Kholiya, A. Chauhan, K. Dipender, K. Venkatesha, R. K. Upadhyay, and R. C. Padalia, “Essential oils, application, and different extraction methods,” in *Essential Oils: Sources, Production and Applications*, R. C. Padalia, D. K. Verma, C. Arora, and P. K. Mahish, Eds., Walter de Gruyter GmbH, 2023, pp. 25–45. doi: 10.1515/9783110791600-002.

[5] I. Hasbay and C. M. Galanakis, “Recovery technologies and encapsulation techniques,” in *Polyphenols: Properties, Recovery, and Applications*, C. Galanakis, Ed., Elsevier Inc., 2018, pp. 233–264. doi: 10.1016/B978-0-12-813572-3.00007-5.

[6] A. Oreopoulo, D. Tsimogiannis, and V. Oreopoulou, “Extraction of polyphenols from aromatic and medicinal plants: An overview of the methods and the effect of extraction parameters,” in *Polyphenols in Plants (Second Edition)*, R. R. Waston, Ed., Academic Press, 2019, pp. 243–259. doi: 10.1016/B978-0-12-813768-0.00025-6.

[7] S. S. Handa, S. P. S. Khanuja, G. Longo, and D. D. Rakesh, *Extraction technologies for medicinal and aromatic plants*. Tieste, Italy: ICS-UNIDO, 2008.

[8] R. N. Pagani, J. L. Kovaleski, and L. M. Resende, “Methodi Ordinatio: a proposed methodology to select and rank relevant scientific papers encompassing the impact factor, number of citation, and year of publication,” *Scientometrics*, vol. 105, no. 3, pp. 2109–2135, 2015, doi: 10.1007/s11192-015-1744-x.

[9] A. Arias, S. González-Rodríguez, M. Vetroni Barros, R. Salvador, A. C. de Francisco, C. Moro Piekarski, and M. T. Moreira, “Recent developments in bio-based adhesives from renewable natural resources,” *J. Clean. Prod.*, vol. 314, no.

September 2021, 2021, doi: 10.1016/j.jclepro.2021.127892.

[10] A. Hariry, E. Mardawati, and N. Masruchin, "Nanocellulose research trends from pineapple plant waste in Indonesia: Bibliometric analysis using VosViewer," *AJARCDE (Asian J. Appl. Res. Community Dev. Empower.*, vol. 7, no. 2, pp. 1–7, 2023, doi: 10.29165/ajarcde.v7i2.247.

[11] S. Shintawati, A. Analianasari, and Z. Zukryandry, "Pemodelan kondisi optimum ekstraksi dan identifikasi senyawa penyusun minyak atsiri lada hitam," *J. Agro Ind. Perkeb.*, vol. 9, no. 2, pp. 99–108, 2021, doi: 10.25181/jaip.v9i2.2132.

[12] D. Sukandar, A. Sulaswatty, and I. Hamidi, "Profil senyawa kimia minyak atsiri sereh wangi (Cymbopogon nardus L.) hasil hidrodistilasi dengan optimasi perlakuan awal sonikasi," *ALCHEMY J. Penelit. Kim.*, vol. 18, no. 2, p. 221, 2022, doi: 10.20961/alchemy.18.2.60007.221-233.

[13] Q. R. Fakhira, S. Nurjanah, and S. Rosalinda, "Karakteristik dan komposisi minyak atsiri kulit jeruk nipis pada berbagai lama waktu penyulingan menggunakan metode hidrodistilasi," *Teknotan J. Ind. Teknol. Pertan.*, vol. 17, no. 3, pp. 217–226, 2023, doi: 10.24198/jt.vol17n3.8.

[14] D. R. Febrianti and N. Ariani, "Uji potensi minyak atsiri daun jeruk purut (Citrus hystrix D.C) sebagai antioksidan dan antibakteri," *J. Insa. Farm. Indones.*, vol. 3, no. 1, pp. 66–74, 2020, doi: 10.36387/jifi.v3i1.458.

[15] A. S. Ulandari, D. M. Ningrum, and D. A. S. Permana, "Identifikasi kandungan senyawa minyak jeruk nipis (Citrus aurantifolia) dan minyak nilam (Pogostemon cablin B.) sebagai anti repellent dengan metode GC-MS," *J. Etnofarmasi*, vol. 1, no. 2, pp. 1–9, 2022.

[16] R. Prabandari, "Perbandingan randemen minyak atsiri sereh (Cymbopogon citratus) yang umur panennya 6 bulan dan 9 bulan dengan metode destilasi air," *Viva Med. J. Kesehatan, Kebidanan dan Keperawatan*, vol. 11, no. 1, pp. 66–71, 2017, doi: 10.35960/vm.v10i3.430.

[17] D. Pratimasari, A. D. S. Saputri, A. Ariyanti, and S. Shania, "Perbandingan karakteristik minyak atsiri palmarosa (Cymbopogon martinii) hasil destilasi uap air dan destilasi air," *Benzena Pharm. Sci. J.*, vol. 2, no. 2, pp. 1–11, 2023, doi: http://dx.doi.org/10.31941/benzena.v2i02.3770.

[18] S. Shintawati, O. Rina, and D. Ermaya, “Sifat antimikroba dan pengaruh perlakuan bahan baku terhadap rendemen minyak sereh wangi,” *J. Sylva Lestari*, vol. 8, no. 3, pp. 411–419, 2020, doi: 10.23960/jsl38411-419.

[19] H. M. Ansory, P. K. P. Putri, N. ’Aini Hidayah, and A. Nilawati, “Analisis senyawa minyak atsiri fuli pala secara GC-MS dan uji aktivitas antibakteri terhadap Ecschericia coli dan Staphylococcus aureus,” *Maj. Farm.*, vol. 13, no. 2, pp. 56–64, 2018, doi: 10.22146/farmaseutik.v13i2.40915.

[20] S. G. Sipahelut, “Perbandingan komponen aktif minyak atsiri dari daging buah pala kering cabinet dryer melalui metode distilasi air dan air-uap,” *Agritekno J. Teknol. Pertan.*, vol. 8, no. 1, pp. 8–13, 2019, doi: 10.30598/jagritekno.2019.8.1.8.

[21] T. Barki, N. Kristiningrum, E. Puspitasari, and F. A. Fajrin, “Penetapan kadar fenol total dan pengujian aktivitas antioksidan minyak jahe gajah (Zingiber officinale var. officinale),” *J. Pustaka Kesehat.*, vol. 5, no. 3, pp. 432–436, 2017, doi: https://doi.org/10.19184/pk.v5i3.5897.

[22] E. D. Daryono and G. F. Hutasoit, “Ekstraksi minyak atsiri jahe (Zingiber officinale) dengan proses Distilasi: Pengaruh jenis jahe dan metode distilasi,” *Eksergi J. Ilm. Tek. Kim.*, vol. 21, no. 2, pp. 55–59, 2024, doi: https://doi.org/10.31315/e.v21i2.11625.

[23] F. Chemat and C. Boutekedjiret, “Extraction // Steam Distillation,” in *Reference Collection in Chemistry, Molecular Sciences and Chemical Engineering*, Elsevier, 2015. doi: 10.1016/B978-0-12-409547-2.11557-4.

[24] P. Kapadia, A. S. Newell, J. Cunningham, M. R. Roberts, and J. G. Hardy, “Extraction of high-value chemicals from plants for technical and medical applications,” *Int. J. Mol. Sci.*, vol. 23, no. 18, p. 10334, 2022, doi: 10.3390/ijms231810334.

[25] D. Febrina, “Pengaruh perbedaan perlakuan pendahuluan terhadap rendemen minyak atsiri daun jeruk purut (Citrus hystrix DC),” *Viva Med. J. Kesehatan, Kebidanan dan Keperawatan*, vol. 11, no. 02, pp. 104–110, 2019, doi: 10.35960/vm.v11i02.471.

[26] S. R. Ekasari, “Pengaruh metode pengambilan minyak atsiri dari daun jeruk purut (Citrus hystrix) terhadap kandungan geraniol dan sitronelal,” *Inov. Tek. Kim.*, vol.

5, no. 1, pp. 5–11, 2020, doi: http://dx.doi.org/10.31942/inteka.v5i1.3394.

[27] J. Adiandasari, W. Wusnah, and A. Azhari, “Pengaruh suhu dan waktu terhadap proses penyulingan minyak sereh wangi (Cimbopogon nardus L.),” *Chem. Eng. J. Storage*, vol. 1, no. 1, pp. 22–28, 2021, doi: 10.29103/cejs.v1i1.1493.

[28] R. Irwanto, A. Kasim, and S. D. Ismanto, “Penentuan kadar minyak atsiri daun kayu manis (Cinnamomum burmannii, Blume) dengan perlakuan pendahuluan pada daun,” *J. Teknol. Pengolah. Pertan.*, vol. 4, no. 1, pp. 1–11, 2022, doi: 10.35308/jtpp.v4i1.5661.

[29] A. F. Iskandar, S. Nurjanah, S. Rosalinda, and F. Nuranjani, “Penyulingan minyak atsiri jahe merah (Zingiber officinale var. Rubrum) menggunakan metode hidrodistilasi dengan variasi waktu penyulingan,” *Teknotan J. Ind. Teknol. Pertan.*, vol. 17, no. 1, pp. 53–60, 2023, doi: 10.24198/jt.vol17n1.7.

[30] A. Ramadhanti, S. Nurjanah, A. Widyasanti, and N. Ainina, “Pemodelan kondisi hidrodistilasi minyak atsiri jahe merah (Zingiber officinale var. Roscoe) dengan menggunakan Response Surface Methodology,” *Agrointek J. Teknol. Ind. Pertan.*, vol. 18, no. 2, pp. 429–439, 2024, doi: 10.21107/agrointek.v18i2.18904.

[31] L. Sari, D. Lesmana, and T. Taharuddin, “Ekstraksi minyak atsiri dari daging buah pala (Tinjauan pengaruh metode destilasi dan kadar air bahan),” in *Seminar Nasional Sains dan Teknologi 2018*, 2018, pp. 1–6.

[32] N. Nuwa, R. Jemi, and H. Joni, “Isolasi dan uji anti jamur minyak atsiri kulit kayu sintok (Cinnamomum sintoc BL) pada beberapa jamur perusak kayu,” *Agrienvi J. Ilmu Pertan.*, vol. 12, no. 2, pp. 32–36, 2020.

[33] D. B. G. Utomo and M. Mujiburohman, “Pengaruh kondisi daun dan waktu penyulingan terhadap rendemen minyak kayu putih,” Universitas Muhammadiyah Surakarta, 2018.

[34] K. S. Nugraheni, L. U. Khansanah, R. Utami, and B. K. Anandhito, “The effect of pretreatment and variation method of distillation on quality of cinnamon leaf oil,” *J. Teknol. Has. Pertan.*, vol. IX, no. 2, pp. 51–64, 2016, doi: https://doi.org/10.20961/jthp.v9i2.17466.

[35] B. D. Argo and F. A. Amaliyah, “Pengaruh gelombang mikro terhadap kualitas hasil minyak atsiri jahe (Zingiber officinale) dengan hidrodistilasi,” *agriTECH*,

vol. 40, no. 4, pp. 332–339, 2020, doi: 10.22146/agritech.40651.

[36] D. Defiza, A. Az Zahra, S. Supandi, and H. Aldrat, “Pengaruh pretreatment microwave terhadap rendemen dan profil kimiawi minyak gaharu Aquilaria Sp.,” *J. Farm. Higea*, vol. 15, no. 2, pp. 114–123, 2023, doi: 10.52689/higea.v15i2.555.

[37] E. R. W. Hapsari, A. F. P. Putra, and A. H. Sofani, “Optimasi proses pemisahan minyak jintan hitam dengan kualifikasi food grade menggunakan metode hydrodistillation melalui variasi treatment pra-ekstraksi,” *Akta Kim. Indones.*, vol. 7, no. 2, pp. 133–148, 2022, doi: 10.12962/j25493736.v7i2.14686.

[38] M. Dacosta, S. K. Sudirga, and I. K. Muksin, “Perbandingan kandungan minyak atsiri tanaman sereh wangi (Cymbopogon nardus L. Rendle) yang ditanam di lokasi berbeda,” *Simbiosis*, vol. 5, no. 1, pp. 25–31, 2017, doi: 10.24843/jsimbiosis.2017.v05.i01.p06.

[39] S. Nur, J. A. Baitanu, and S. A. Gani, “Pengaruh tempat tumbuh dan lama penyulingan secara hidrodestilasi terhadap rendemen dan profil kandungan kimia minyak atsiri daun kemangi (Ocimum canum Sims L.),” *J. Fitofarmaka Indones.*, vol. 6, no. 2, pp. 363–367, 2019, doi: 10.33096/jffi.v6i2.507.

[40] M. Budiarti, W. Jokopriambodo, and A. Isnawati, “Karakterisasi minyak atsiri dari simplisia basah ranting dan daun sebagai alternatif subtitusi kulit batang Cinnamomum burmannii Blume,” *J. Kefarmasian Indones.*, vol. 8, no. 2, pp. 125–136, 2018, doi: 10.22435/jki.v8i2.323.

[41] E. Parikesit, W. Kusbandono, and F. R. Sambada, “Microcontroller Based Simple Water Flow Rate Control System to Increase the Efficiency of Solar Energy Water Distillation,” *Int. J. Appl. Sci. Smart Technol.*, vol. 01, no. 02, pp. 129–146, 2019, doi: 10.24071/ijasst.v1i2.1923.