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A Century of Sandalwood Oil Research: Bibliometric Analysis using VOSviewer

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Abstract

Sandalwood oil is one of the most expensive essential oils with numerous benefits. This study analyzed the trend of sandalwood oil research from the year of 1914 to the first quarter of the 2023. The information was obtained from the Scopus database at 12 February 2023 using keyword (TITLE-ABS-KEY("Sandalwood Oil")) and analyzed with the VOSviewer software for the co-occurrences and the co-authorships. The analyzation show that the research of sandalwood oil increased gradually each year. The United states and India leading the research with the total of publications 64 and 54 out of 269 publications data gathered from Scopus. The most used keyword in sandalwood oil researches are sandalwood oil, unclassified drug and essential oil. This article represents the current research on sandalwood oil that can help on the development of sandalwood oil in the future.

Keywords: *Santalum album; sandalwood oil; essential oil; VOSviewer; bibliometric analysis*

1. Introduction

Sandalwood oil is one of the most valued essential oils in the world since a long time ago [1]. Essential sandalwood oil is extracted from the core wood of sandalwood plant that has a good smell and various health benefits [2]. Several studies shown that sandalwood oil has antioxidant, anti-inflammatory, antibacterial, antifungal, antiviral, neuroleptic, anti-hyperglycemic, anti-hyperlipidemic, and anticancer properties. The oils and extracts of sandalwood have been shown in safety studies to be a safe ingredient for health promotion uses. The phytoconstituents, bioactivities, and traditional uses of sandalwood have determined as the pharmaceutical, food, and biomedical industries innovative materials [3].

As a result of the continuous increase of the cosmetics and dermatology industries, sandalwood oil with anti-ageing properties has a significant economic potential. Indian sandalwood oil (*Santalum album L.*) has been used as a natural active ingredient traditionally in cosmetics to moisturize and brighten up the skin [4]. Due to its antioxidant properties sandalwood oil can be used as a preventative ingredient in the fight against environmental factors that cause premature skin aging [5]. Sandalwood oil is currently used in cosmetics as an additive for powder, mixture oil, roll-on, hair oil, and other products.

In the domain of essential oil research, sandalwood oil occupies a unique position that

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warrants examination within the broader context of similar studies on other essential oils. Various scholarly inquiries have investigated the bibliometric analysis of essential oils such as lavender, tea tree, and peppermint oils [7,8]. For instance, research on lavender oil has accentuated its therapeutic properties, leading to its widespread incorporation in aromatherapy and skincare products [9]. In a similar vein, research on tea tree oil have emphasized its antimicrobial and antifungal properties, showcasing its applications in medicinal and cosmetic industries [10]. Additionally, studies on peppermint oil have revealed its potential benefits in mitigating digestive issues and enhancing mental clarity [11]. Collectively, these investigations underscore the far-reaching impact of essential oils on health, wellness, and industry. A comparative analysis of sandalwood oil's bibliometric trends with these counterparts enables researchers to discern insights into the evolving landscape of essential oil research and its multifaceted applications.

Conducting a bibliometric analysis on sandalwood oil research is of paramount importance for several compelling reasons. Firstly, sandalwood oil stands as one of the most esteemed essential oils worldwide, with its multifaceted applications spanning from pharmaceuticals to cosmetics. By scrutinizing the trends, geographical distributions, and key institutions involved in sandalwood oil research over the past century, this study aims to provide a comprehensive understanding of its evolving significance. Moreover, as sandalwood oil continues to gain traction in various industries, a bibliometric analysis offers invaluable insights for researchers, policymakers, and industry stakeholders. This analysis not only identifies knowledge gaps but also guides future research directions, fostering innovation and sustainable utilization of this precious resource.

Thus, this bibliometric analysis aims to examine the trend on research of sandalwood oil from the year 1914 to 2023. Due to the large amount of data, bibliometric method was used to perform the analysis and the results can make the data easier to read. Based on Scopus data, this analysis visualizes the number of annual publications on sandalwood oil, the research subject area, the geographical distribution of research, also the co-occurrence and co-authorship of the research.

2. Methodology

The scope of the study is an important factor when conducting bibliometric analysis. Before starting an analysis, the important thing to do is clearly define the subject and quantity of studies to be analyzed. Otherwise, the results will be unsatisfactory and prone to errors, defeating the study's primary goal. As a result, it is critical to carefully consider the keywords you use for data collection [6]. Furthermore, the bibliometric analysis is used when the amount of data is huge in number and the range of the bibliometric review is too broad for a manual review. But it suggested that the minimum amount of data to review is at least 200 publications when conducting bibliometric analysis [12].

A key step in bibliometric analysis is the selection of a suitable database for extracting the data. For this study, data was collected from the Scopus database at 12 February 2023 using keyword (TITLE-ABS-KEY(“Sandalwood Oil”)). For examine co-occurrences and co-authorship of the sandalwood oil research, the data retrieved from Scopus was analyzed using VOSviewer (version 1.6.18). Then, the results are visualized in map, chart and tabular form.

3. Results and Discussion

The keyword search on the Scopus database used to collect the data was (TITLE-ABS-KEY(“Sandalwood Oil”)). The data retrieved on 12 February 2023 from the database, consisted of 269 publications. The year of the data collected was from the interval of 1914 to 2023. And the data are gathered from the type of documents such as article, review, book chapter, conference, short survey, note, editorial, erratum, and letter. The publications are mostly written in English language. Out of 269 publications 257 are written in English and the rest are written in Germany, Japanese, Chinese, and Russian with the number of publications 10, 3, 2, and 1, sequentially.

3.1. Analysis of Annual Publication Performances

Fig. 1. depicts the rate of annual publication from 1914 to early 2023, with 269 publications in total gathered from the data. In the year of 1914, 1932, 1953, 1967, 1968, 1974, 1976, 1978, 1985, 1986, 1994, 1996, and 2002 there are just one in number of published study and the inactive year of publication was excluded. The most productive publication year are 2021 and 2022 with 17 publications. The annual publication gradually increased from year to year.

Until the early 2023, precisely 12 February 2023 when the data was gathered from Scopus there are only one publication about sandalwood oil has published.

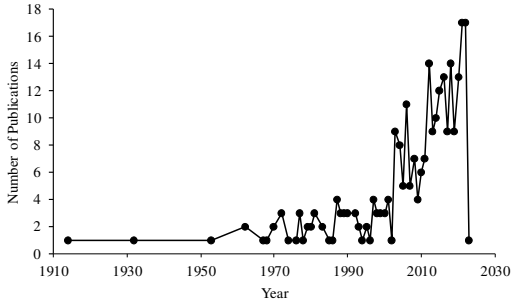

Fig. 1: Sandalwood oil annual publications performances from 1914 to 2023

3.2. Country Publication Performances

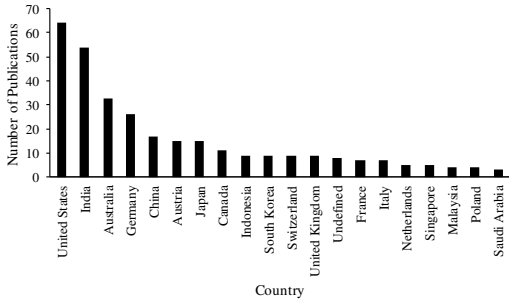

Fig. 2: The top 20 of most contributed country in sandalwood research from 1914 to 2023

There are 269 publications obtained from Scopus database and there are at least 52 countries contributed to sandalwood oil research and some of the publications has undefined country of origin. Fig. 2 presents the contribution of top 20 countries to the sandalwood oil research. The number of publications is shown in a bar chart. The chart shows that United States is the most contributed country with 64 publications, followed by India and Australia with 54 and 33 publications, respectively.

3.3. Institution Performances on Sandalwood Oil Research

The data gathered from Scopus shown that out of 493 publications on sandalwood oil, South Dakota State University and Universität Wien are the most productive institution in sandalwood oil research with 15 publications (4.46%), each. Then, followed by The University of Western Australia and The University of British Columbia with 10 publications (2.98%), each. Table 1 shows that not only universities have contributed to sandalwood oil research, but some companies are also contributing to the future of sandalwood oil applications.

Table 1: Top 20 most contributed institution on sandalwood oil research from 1914 to 2023

Rank	Institutions	Number of Publications	Percentage (%)
1	South Dakota State University	15	4.46
2	Universität Wien	15	4.46
3	Santalis Pharmaceuticals, Inc.	10	2.98
4	The University of Western Australia	10	2.98
5	The University of British Columbia	9	2.68
6	Wilkes University	8	2.38
7	Symrise AG	8	2.38
8	Michael Smith Laboratories	7	2.08
9	Institute of Wood Science and Technology IWST, Bangalore	7	2.08
10	Institut Teknologi Sepuluh Nopember	7	2.08
11	Indian Institute of Technology Kharagpur	6	1.79
12	Gyeongsang National University	5	1.49
13	Friedrich-Alexander-Universität Erlangen-Nürnberg	4	1.19
14	Firmenich SA	4	1.19
15	Fritzsche Dodge and Olcott Inc.	3	0.89
16	Forest Products Commission	3	0.89
17	Acdegroot Publishing	3	0.89
18	Universiti Sains Malaysia	3	0.89
19	Università Campus Bio-Medico di Roma	3	0.89
20	Università degli Studi di Messina	3	0.89

3.4. Publications' Subject Area

The Table 2 shown the top 15 subject area of the publication of sandalwood oil published between 1914 to 2023. Biochemistry, Genetics, and Molecular Biology take the first place of the highest rank with 93 publications (18.86%). Followed by Medicine with 90 publications (18.26%) and Chemistry (17.65%). That was indicated that the higher

percentage of the subject area, the closer relationship the subject area to sandalwood oil.

Table 2: Top 15 publications' subject area of sandalwood oil research from 1914 to 2023

Rank	Subject Area	Number of Publications	Percentage (%)
1	Biochemistry, Genetics and Molecular Biology	93	18.86
2	Medicine	90	18.26
3	Chemistry	87	17.65
4	Agricultural and Biological Sciences	61	12.37
5	Pharmacology, Toxicology and Pharmaceutics	61	12.37
6	Materials Science	19	3.85
7	Chemical Engineering	16	3.25
8	Engineering	14	2.84
9	Environmental Science	14	2.84
10	Multidisciplinary	10	2.03
11	Immunology and Microbiology	8	1.62
12	Physics and Astronomy	4	0.81
13	Economics, Econometrics and Finance	2	0.41
14	Energy	2	0.41
15	Neuroscience	2	0.41

3.5. Co-occurrences Analysis using Bibliometric Mapping

The full counting method was used for the co-occurrence mapping. The study also imposed some restrictions on the analysis. For example, a limiting factor was set at a minimum of five occurrences of a keyword. As a result, only 226 of the 3561 keywords from 269 articles met the threshold. Each keyword was examined using the VOSviewer, which computed the number of links, total link strengths, and co-occurrences of the keyword with other keywords. The co-occurrence of one keyword with another is referred to as a link, and the total link strength corresponds to the total cited references between one item and the others. Furthermore, the number of occurrences represents the number of articles that contained the keyword [13]. But this study only used network visualization for representing the co-occurrence analysis of the keywords.

Fig, 3 depicts the five groups formed by the 3493 keywords: cluster 1 (red), cluster 2 (green), cluster 3 (blue), cluster 4 (yellow), and cluster 5 (purple). The size of the circles and the prominence of the texts in each cluster reflect how frequent the associated keywords occur together. In contrast, the spacing between the items and the lines indicates how close the associated keywords are related and how they are linked. Furthermore, the distinguishable topics of each cluster's keywords were explored to discover the cluster's distinct theme.

Cluster 1 (red). Sandalwood oil, unclassified drug, and essential oil were the keywords with the highest co-occurrence with 131, 113, and 87 scores, respectively. In other words, for example, the 131 co-occurrences weight means that the keyword “sandalwood oil” appeared in 131 articles out of the 269 articles, or 48,7% of the total publications in the analysis. Based on the closer network visualization in VOSviewer, sandalwood oil was more strongly interlinked with 3 keywords: unclassified drug, essential oil, and human. These could be considered the hot topics in sandalwood oil research. Sandalwood oil is one of a type of essential oil. Essential oils are volatile molecules with complex blends of various derivatives namely terpenoids, aliphatic compounds, phenol derived compounds [14]. Sandalwood oil used by human since a long time ago, based on study one of the prospects of sandalwood oil in the future for human life is using it for anticancer. The natural product sandalwood oil from genus Santalum (Family *Santalaceae*) and its constituent alpha-santalol have been reported to exert chemopreventive effects against skin cancers as well as prostate, head and neck, and breast cancers [15].

Cluster 2 (green). In the second cluster the branch refers to the keyword article, Santalum, nonhuman, and sesquiterpenes. These are the keywords with the highest co-occurrences with 109, 76, 74 and 67 scores, respectively. Article is the type of documents of sandalwood oil that having the highest number out of the others type of the documents with 216 in number of documents. Santalum genus belongs to the family of *Santalaceae*, widespread in India, Australia, Hawaii, Sri Lanka, and Indonesia, and valued as traditional medicine, rituals, and modern bioactivities [3]. Whereas, alpha-santalol is a sesquiterpene found naturally in sandalwood oil. Its vast spectrum of health advantages has been related to the regulation of numerous signalling pathways involved in disease development [16].

Cluster 3 (blue). The third cluster shown that controlled study, priority journal, and antineoplastic agent are keywords with the highest co-occurrences with 57, 50 and 18 scores, respectively. Study found that α-santalol have anti-neoplastic effects against

both ER-positive and ER-negative breast cancer cells [17].

Cluster 4 (yellow). The fourth cluster shown that plant oils, vegetable oil and animals are keywords with the highest co-occurrences with 64, 51 and 32 scores, respectively. Based on study, sandalwood oil is one of plants oil that have adulticidal effects on house mosquitos (*Culex pipiens pallens*), sandalwood oil was used in spray form. The results shown that sandalwood oil have 85% efficacy and it's the highest results among the other comparative plant oil [18].

Cluster 5 (purple). The fifth cluster shown that plant extract, in vitro study and medicinal are keywords with the highest co-occurrences with 21, and 19 and 11 scores, respectively. The current best extraction method for obtaining sandalwood oil from sandalwood plant is air-hydrodistillation. It produced high quality of sandalwood oil with smaller amount of energy and time compared to traditional method [19]. Sandalwood oil applications in skin such as foot massage and body massage can significantly help with anxiety and depressions [20].

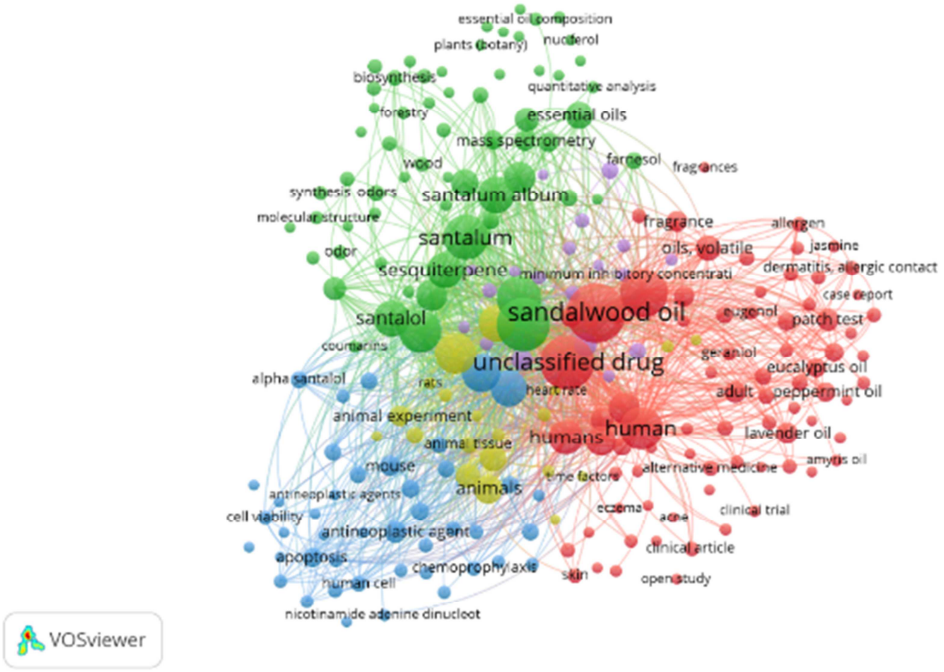

Fig. 3: Network visualizations of sandalwood oil research keywords using VOSviewer

3.6. Co-authorship Analysis using Bibliometric Mapping

There are 814 authors contributed to 269 publications of sandalwood oil research from 1914 to 2023. Using fractional counting method, with limitations such as maximum 25 authors per document and authors must publish at least 3 documents before, just 47 met the threshold and 10 of them shown in the map. Authors in the same cluster usually work in the same team [21]. Based on the Fig. 4 there are 3 clusters of authors in sandalwood oil research. The clusters represent by color, red for cluster 1, green for cluster 2, and blue for cluster 3. Based on Fig. 4, the line connecting one author to other shows that one author with another has conducted research in the same team. For example, Dwivedi, C. and Bommareddy, A. once published a joint study under the title "sandalwood oil", then in Fig. 4 these two authors are linked with a line of co-authorship [22]. It can also be concluded that, authors who are not connected to each other have never published research in the same team.

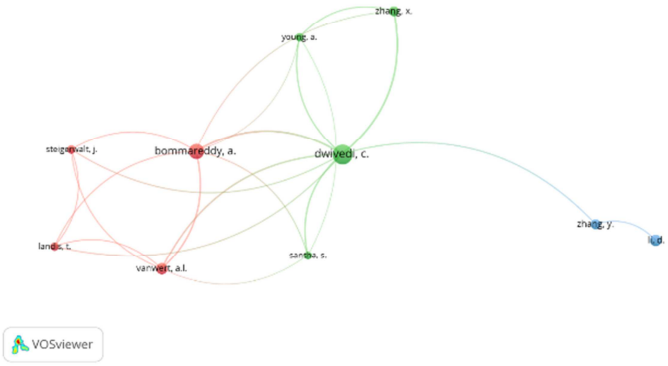

Fig. 4: Co-authorship mapping of sandalwood oil research from 1914 to 2023

4. Conclusions

Sandalwood oil has a significant economic potential in the cosmetics and dermatology industries due to its anti-aging properties. This bibliometric analysis examines the trend on research of sandalwood oil from 1914 to 2023. The Scopus data was analyzed and visualized the number of annual publications on sandalwood oil, the research subject area, the geographical distribution of research, and the co-occurrence and co-authorship of the research. Institutions that contribute the most on sandalwood oil research are South Dakota State University and Universität Wien. United states and India are the most contributed country in sandalwood oil research. The highest number of publications are published in the year 2021 and 2022. Finally, the comprehensive bibliometric analysis performed with VOSviewer software indicated steady increase in sandalwood oil research over the last century, highlighting its ongoing importance. The data highlighted significant contributions from leading countries and institutions, highlighting the important role of sandalwood oil in a variety of sectors ranging from biochemistry to dermatology. These findings collectively support sandalwood oil's long-term significance and potential, laying the groundwork for future study and industrial uses.

5. Conflicts of Interest

The authors declare that there is no conflict of interest.

6. References

[1] Bunney, E., McInerney, F. A., Dormontt, E., Malik, A., Welti, N., Wilkins, D., et al. Safeguarding sandalwood: A review of current and emerging tools to support sustainable and legal forestry. Plants People Planet (2022). https://doi.org/10.1002/ppp3.10349

[2] Tripathi, S., Kumar, P., Kumar Rout, P., Kumar Khare, S., Naik, S. Comparison of yield and quality of sandalwood oil extracted from heartwood of trees cultivated in different states of India. Mater Today Proc 57, 2400–2405 (2022). https://doi.org/10.1016/j.matpr.2021.12.536

[3] Sharifi-Rad, J., Quispe, C., Turgumbayeva, A., Mertdinç, Z., Tütüncü, S., Aydar, E. F., et al. Santalum Genus: Phytochemical constituents, biological activities and health promoting-effects. Zeitschrift Fur Naturforschung - Section C Journal of Biosciences 78, 9–25 (2023). https://doi.org/10.1515/znc-2022-0076

[4] Francois-Newton, V., Brown, A., Andres, P., Mandary, M. B., Weyers, C., Latouche-Veerapen, M., et al. Antioxidant and anti-aging potential of Indian sandalwood oil against environmental stressors in vitro and ex vivo. Cosmetics 8, (2021). https://doi.org/10.3390/cosmetics8020053

[5] Kolanthan, V. L., Brown, A., Soobramaney, V., Philibert, E. G., Newton, V. F., Hosenally, M., et al. Clinical Evaluation of Indian Sandalwood Oil and Its Protective Effect on the Skin against the Detrimental Effect of Exposome. Cosmetics 9, (2022). https://doi.org/10.3390/cosmetics9020035

[6] Tamala, J. K., Maramag, E. I., Simeon, K. A., Ignacio, J. J. A bibliometric analysis of sustainable oil and gas production research using VOSviewer. Clean Eng Technol 7, 100437 (2022). https://doi.org/10.1016/j.clet.2022.100437

[7] Gul, S., Nisa, N. T., Shah, T. A., Shah, M. U. A., Wani, A. B. (2015). Research output on Lavender, 2008–2012. Eur. J. Int. Med, 7(5), 460-466.

[8] Sisi, L. I. U., Changzhu, L. I., Rukuan, L. I. U., Zhihong, X. I. A. O., & Aihua, Z. H. A. N. G. (2021). Bibliometric Analysis of Domestic and Foreign Researches on Tea Saponin. Biomass Chem. Eng, 55(6), 10.

[9] Cardia, G. F. E., de Souza Silva-Comar, F. M., da Rocha, E. M. T., Silva-Filho, S. E., Zagotto, M., Uchida, N. S., ... & Cuman, R. K. N. (2021). Pharmacological, medicinal and toxicological properties of lavender essential oil: A review. Res. Soc. Dev., 10(5), e23310514933-e23310514933.

[10] Chidi, F., Bouhoudan, A., & Khaddor, M. (2020). Antifungal effect of the tea tree essential oil (*Melaleuca alternifolia*) against Penicillium griseofulvum and Penicillium verrucosum. J. King Saud Univ-Sci, 32(3), 2041-2045.

[11] Weerts, Z. Z. R., Masclee, A. A., Witteman, B. J., Clemens, C. H., Winkens, B., Brouwers, J. R., ... & Keszthelyi, D. (2020). Efficacy and safety of peppermint oil in a randomized, double-blind trial of patients with irritable bowel syndrome. Gastro, 158(1), 123-136.

[12] Rogers, G., Szomszor, M., Adams, J. Sample size in bibliometric analysis. Scientometrics 125, 777–794 (2020). https://doi.org/10.1007/s11192-020-03647-7

[13] Guo, Y.-M., Huang, Z.-L., Guo, J., Li, H., Guo, X.-R., Nkeli, M. J. Bibliometric Analysis on Smart Cities Research. Sustainability 11, 3606 (2019). https://doi.org/10.3390/su11133606

[14] Kashyap, N., Kumari, A., Raina, N., Zakir, F., Gupta, M. Prospects of essential oil loaded nanosystems for skincare. Phytomedicine Plus 2, 100198 (2022). https://doi.org/10.1016/j.phyplu.2021.100198

[15] Jain, R., Nair, S. Sandalwood Oil for the Chemoprevention of Skin Cancer: Mechanistic Insights, Anti-inflammatory, and In Vivo Anticancer Potential. Curr Pharmacol Rep 5, 345–358 (2019). https://doi.org/10.1007/s40495-019-00195-4

[16] Bommareddy, A., Brozena, S., Steigerwalt, J., Landis, T., Hughes, S., Mabry, E., et al. Medicinal properties of alpha-santalol, a naturally occurring constituent of sandalwood oil: review. Nat Prod Res 33, 527–543 (2019). https://doi.org/10.1080/14786419.2017.1399387

[17] Santha, S., Bommareddy, A., Rule, B., Guillermo, R., Kaushik, R. S., Young, A., et al. Antineoplastic Effects of α-Santalol on Estrogen Receptor-Positive and Estrogen Receptor-Negative Breast Cancer Cells through Cell Cycle Arrest at G2/M Phase and Induction of Apoptosis. PLoS One 8, (2013). https://doi.org/10.1371/journal.pone.0056982

[18] Kang, S.-H., Kim, M.-K., Noh, D.-J., Yoon, C., Kim, G.-H. Spray adulticidal effects of plant oils against house mosquito, Culex pipiens pallens (Diptera: Culicidae). J Pestic Sci 34, 100–106 (2009). https://doi.org/10.1584/jpestics.G08-45

[19] Kusuma, H. S., Mahfud, M. The extraction of essential oil from sandalwood (*Santalum album*) by microwave air-hydrodistillation method. Journal of Materials and Environmental Science 7, 1597–1606 (2016).

[20] Zhang, Y., Long, Y., Yu, S., Li, D., Yang, M., Guan, Y., et al. Natural volatile oils derived from herbal medicines: A promising therapy way for treating depressive disorder. Pharmacol Res 164, (2021). https://doi.org/10.1016/j.phrs.2020.105376

[21] Zheng, Q., Liu, K. Worldwide rapeseed (*Brassica napus* L.) research: A bibliometric analysis during 2011–2021. Oil Crop Science 7, 157–165 (2022). https://doi.org/10.1016/J.OCSCI.2022.11.004

[22] Bommareddy, A., McGlynn, D., Lewis, M., Lockus, L., Seward, J., Hong, K. L., et al. Akt/survivin pathway inhibition enhances the apoptotic cell death-induced by alpha-santalol in human prostate cancer cells. Fitoterapia 143, (2020). https://doi.org/10.1016/j.fitote.2020.104552