REVIEW ARTICLE

Therapeutic Potential of Cajeput Oil in Muscle Health: a Mini-review through a Bibliometric Approach.

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Abstract
Cajeput oil has been used in traditional medicine for its anti-inflammatory, analgesic, and antimicrobial properties. Recently, there has been increased interest in investigating its potential benefits for muscle health, including its ability to alleviate muscle pain, promote recovery, and enhance overall muscular function. This review provides a comprehensive analysis of the existing literature on cajeput oil and its applications in muscle health. Through a bibliometric analysis of research trends, citation networks, and key themes within this field, the review identifies the primary bioactive compounds in cajeput oil, such as 1,8-cineole, α-terpineol, α-pinene, and their roles in improving muscle health. The review emphasises the growing body of evidence that supports the effectiveness of cajeput oil in reducing muscle inflammation and soreness, while also discussing the limitations and gaps in current research. Additionally, the analysis highlights the need for more robust clinical trials and interdisciplinary studies to fully understand the therapeutic potential of cajeput oil in muscle health. These findings provide a foundation for future research and underline the importance of integrating traditional knowledge with modern scientific approaches to promote muscle health and overall well-being.

Keywords: *Bibliometric analysis, Essential oil, Melaleuca cajuputi,, Muscle health.*

Introduction

The muscle is an essential body component that is responsible for movement by contracting and relaxing the muscle fibres [1]. Although muscle is important for movement, overuse can cause soreness or strain. Muscle soreness or myalgia is a condition where there is discomfort or pain in the muscle [2]. This condition can arise from various causes, such as overexertion, infection, and injury. Common treatments for muscle soreness include ice therapy, heat therapy, massage, nonsteroidal anti-inflammatory drugs, rest and recovery [3,4]. Apart from these treatments, some resorted to herbal ailments as topical treatments due to their therapeutic properties, including cajeput oil.

Cajeput oil, also spelt as cajuput oil, is a volatile oil extracted through steam distillation from the leaves and twigs of the cajeput tree, specifically *Melaleuca leucadendron* and *Melaleuca cajuputi* [5,6]. They are originally from Southeast Asia, Australia, and several tropical countries. The interest in these plants has been focused mainly on their essential oil, which is extracted from their leaves and branches. Cajeput oil has been traditionally used for several conditions, such as pain in muscles and joints. Hence, it has become very useful as a natural remedy [7]. Its analgesic properties can alleviate pain from strains and injuries of muscles. Furthermore, the anti-inflammatory nature of the oil decreases swelling and hastens the process of wound healing [8,9]. Cajeput oil is rich in bioactive compounds and is renowned for its diverse therapeutic properties, particularly its antiseptic, analgesic, and anti-inflammatory effects [10]. One of the most notable benefits of cajeput oil is its strong antioxidant activity. Research indicates that extracts from cajeput oil can effectively scavenge free radicals, thereby protecting cells from oxidative stress and potential damage. This antioxidant capacity is largely due to the plant's high levels of phenolic compounds, which are crucial in combating oxidative damage linked to various chronic diseases.

Traditionally, cajeput oil has been used in various medicinal applications. It is commonly employed to alleviate respiratory issues, such as coughs and congestion, making it a popular choice in herbal remedies for colds and flu. In addition to that, cajeput is recognised for its antibacterial and anti-inflammatory effects [11–13]. Studies have demonstrated its efficacy against several strains of bacteria, including *Staphylococcus aureus* and *Bacillus cereus*, commonly used as topical ointment [14,15]. Recent studies have highlighted the potential of cajeput oil in modern applications, suggesting that it could serve as an effective alternative in managing muscle-related conditions [15,16]. However, while its benefits are promising, further research is necessary to fully understand the pharmacological mechanisms and safety profiles associated with its use in muscle therapy. This review discusses the potential use of cajeput oil as a natural muscle relaxant and remedy for muscle soreness. Based on a bibliometric methodology, the following review also examines cajeput oil's phytonutrients, physiological characteristics, and potential health advantages in muscle therapy.

Bibliometric analysis of cajeput oil over the past 20 years (2003-2023)

A bibliometric analysis was conducted using the Web of Science© (WOS) (www.webofknowledge.com) database to examine the global literature on cajeput oil. The term '*melaleuca cajuputi*', 'gelam', 'tea tree', 'cajuput tree', '*M. leucadendron*' and 'Cajeput oil' were used in the "topic item," including the title, abstract, keywords, and keywords plus of articles indexed in the Web of Science Core Collection (Figure 1). The search was performed to include only the last twenty years (2003–2023), English language, and scientific articles. A total of 2099 publications were retrieved and extracted for publication numbers, top authors, affiliations, countries, and 50 most frequently used keywords.

Publication numbers and categories analysis

The examination of publications constitutes a performance analysis, offering distinct perspectives and intriguing data regarding the output. This analysis aids readers in comprehending the study field and its evolution over the years [17]. As shown in Figure 2, the number of publications involving cajeput oil has shown an increasing trend over the years, with notable peaks in 2008, 2012, and 2022. However, it has experienced some oscillations throughout the years, especially in 2005 to 2007, 2008 to 2010, and 2012 to 2014. These oscillations can be associated with the findings regarding the use of cajeput essential oil in the phytochemicals study. The year 2022 showed the highest number of publications recorded, with the findings regarding cajeput oil, either extracted or essential oil, used as an antimicrobial agent for many health applications [12,18], nanoparticles [19,20], and incorporation with other food products [21–23].

According to the WOS, the publication was allocated to 137 categories. For this review, only the five most relevant categories were presented, as illustrated in Figure 2, due to their high number of publications. It was noted that cajeput oil is quite versatile, given the large number of research areas it encompasses. The Food Science Technology category is highlighted among the others, presenting 266 publications throughout the 20 years, with an average of 10.07 publications yearly, associated with several applications of cajeput oil (essential oil) in foods. The Pharmacology Pharmacy category presented 242 publications with an average of 9.5 articles per year, researching cajeput oil predominantly for its health benefits toward both human and animal applications. The other three categories are related to biotechnology, microbiology, and plant sciences. The interest of these fields in cajeput oil is strongly associated with production, as the microbial route is preferable and more advantageous.

Analysis of highest-ranking authors, affiliations, countries, and keywords

Table 1 shows the most productive research, organisations, and countries responsible for the high number of publications concerning cajeput oil throughout the 20 years. This information forms what is known as bibliometric or science mappings. According to a study, these analyses involve thorough research into the characteristics of published literature, exploring the connections between research elements (such as authors, organisations, and countries) and their significance to science [24]. Additionally, they uncover emerging trends, highlight the academic impact of major works, and track the advancement of specific topics.

Thomas V Riley (Riley TV), Christine F Carson (Carson CF), and Catherine A. Hammer (Hammer CA) are the first (43 publications), second (38 publications) and third (30 publications) most productive authors, respectively focusing more the antimicrobial and antifungal effect of *Melaleuca* oil against multiple types of bacteria including *Staphylococcus aureus*, *Candida* sp., *Saccharomyces cerevisiae*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Malassezia species* and some *in vitro* work using cell culture analysis. Juergen Reichilng (Reichilng J), Matheus Dellaméa Baldissera (Baldissera MD) and Xingfeng Shao (Shao XF), with 23, 21 and 21 publications, respectively, research more on the antiviral properties of cajeput oil and its applications towards infected plants and farm animals.

According to Table 1, the most productive organisation in producing scientific articles related to cajeput oil is the University of Western Australia, which is the affiliation of the first, second and third most productive authors. Apart from that, several other universities and organisations from Australia were included in the list, including Southern Cross University, University of Queensland, and Queen Elizabeth II

Medical Centre. This also reflects Australia (323 publications) being the second most productive country in the field of cajeput oil, after China, with 397 publications. Apart from that, the United States of America, Brazil, Italy, and Malaysia are the top third, fourth, fifth and sixth most productive countries in producing research articles relating to cajeput oil.

To better understand the current research interests, a keyword analysis was conducted to identify trends associated with cajeput oil. The WOS database features two types of keywords: author keywords (AKs) and keywords plus (KP), both of which are significant in bibliometric studies [24,25]. In this analysis, we focus exclusively on the most frequently cited AKs to highlight the key trends emphasised by researchers. Analysis of the most cited keywords can uncover research's hot topics and trends by examining the frequency of specific terms [26]. This analysis can also provide insights into a subject's focus areas within a certain region or time period.

From 2003 to 2023, 9,794 different keywords were found in the 2,321 analysis publications. This review highlights the 50 most frequent keywords (Figure 3). The size of the nodes in Figure 3 represents the number of times the keywords are used. In contrast, the thickness of the lines connecting the nodes represents connections between the keywords. The terms 'tea tree oil', 'antimicrobial activity', 'antibacterial activity', and '*in vitro*' were identified as the most frequently cited author keywords, each appearing more than 40 times. This suggests that most articles concentrate on applying cajeput oil's antimicrobial and antibacterial properties to multiple research fields. Moreover, Figure 3 also showed the trends of recent popular keywords (in yellow), such as antioxidant, antibacterial, nanoparticles, electrospinning, nanoemulsion, and biofilm, highlighting the potential direction of cajeput oil research towards nanotechnology and antibacterial. In conclusion, the clusters identified, along with the bibliometric analysis described earlier, provide a foundation for identifying and prioritising key topics related to the therapeutic effects of cajeput oil on muscle health, which are further explored in this study.

Physicochemical and pharmacological analysis of cajeput oil relating towards muscle health

According to the literature from bibliometric analysis, most of the bioactivity studies of cajeput used different parts of the plant. A review from 2023 stated that the majority of the cajeput study used essential oils (80%), followed by leaves (40%), flowers (10%) and then stem (10%) [6,27]. Cajeput is renowned for its essential oil, which is rich in phytochemicals in the class of monoterpenes, sesquiterpenes, flavonoids, and phenolic compounds [5,27]. These bioactive components contribute to the oil's significant antioxidant, antibacterial, and anti-inflammatory properties, making it a valuable remedy in traditional medicine. The physicochemical content of cajeput oil varies depending on multiple factors, such as part of the plant, geographical location, and seasons [14,27]. Table 2 shows some of the commonly studied components of *Melaleuca cajaputi*.

Overall, there were slight variations in the proportions of the components but no significant differences in the major components, particularly 1,8-cineole. This monoterpenoid compound is also known as eucalyptol and is characterised by its colourless camphor-like odour [28]. This compound is crucial for assessing the quality of essential oil from cajeput oil leaves. Numerous studies have shown that 1,8-cineole is typically present in high cajeput oil leaf essential oil yields, ranging from 44.8 to 60.2% [5,27]. According to the study, many of these cajeput oil's constituents can be used to maintain muscle health. 1,8-cineole, apart from being the major compound in cajeput oil essential oil and primarily determining its biological activity, has anti-inflammatory and

analgesic (pain-relieving) properties that can help soothe muscle pain and inflammation [6].

A study by Nozohour et al. (2022) researched the use of 1,8-cineole on the effect of contraction and relaxation of the bovine ileum's smooth muscle [29]. The results from the findings show that the active compound significantly inhibits spontaneous muscle contractions and contractions induced by spasmogens such as carbachol, barium chloride, and potassium chloride bovine ileum, indicating muscle relaxation. The antispasmodic action of 1,8-cineole is mainly mediated through the blockade of calcium channels in smooth muscle. Inhibiting these channels, 1,8-cineole reduces calcium influx, which is necessary for muscle contraction. Calcium channels play an important role in muscle function: These channels promote excitation-contraction coupling in skeletal muscles, regulate cardiac contraction in cardiac muscles, and contribute to smooth muscle contraction. Modulations on these channels can reduce both spontaneous and stimulated contraction, thereby decreasing pain and promoting relaxation.

Another study on the effect of 1,8-cineole on tracheal smooth muscle indicated that it blocks the L-type voltage-gated calcium channels (VGCC) activity [30]. This blockade reduces calcium influx, which is necessary for muscle contraction. It also indicates that 1,8-Cineole has a dual-effect on muscle contraction. At lower concentrations, it induces muscle contraction, while at higher concentrations, it relaxes muscle contraction. Given its spasmolytic and myorelaxant properties, 1,8-cineole may have the potential for therapeutic use in respiratory conditions characterised by smooth muscle contraction, such as asthma or bronchospasm [30].

In an *in-vivo* study, 1,8-cineole showed a significant anti-inflammatory and analgesic effect in Albino Wistar rats [28]. In combination with flurbiprofen, it enhanced anti-inflammation and analgesia regarding the efficacy for inflammation and pain, so it played a very critical role in the management of muscle soreness. This mechanism involved the downregulation of pro-inflammatory cytokines, TNF-α and IL-4, which were the cytokines involved in muscle inflammation and perception of pain.

β-pinene is a bicyclic monoterpene that has a colourless, woody, pine-like aroma liquid. This compound is known to exhibit anti-inflammatory properties that can help to reduce swelling and pain in muscles [31]. It also has shown an analgesic effect in some studies, thus able to modulate pain perception, which somehow can help alleviate muscle spasms and cramps [31,32].

Another component that can help alleviate muscle pain is limonene. Limonene is an aliphatic hydrocarbon classified as a cyclic monoterpene. In a study using chronic musculoskeletal pain, mice models showed that D-limonene was able to reduce pain [33]. The study found that the compound possesses an antihyperalgesic effect, which reduces muscle pain through the reducing Fos protein (pain receptor). These actions can only be made possible by the anti-inflammatory, analgesic, and muscle relaxation action of limonene [33].

β-Caryophyllene, or (−)-β-caryophyllene, is a bicyclic natural sesquiterpene found in many essential oils, including cajeput oil. It possesses anti-inflammatory properties, which can be beneficial in alleviating muscle pain. In a study using liposomal β-caryophyllene, researchers assessed its effectiveness in reducing delayed onset muscle soreness in humans [34]. This randomised placebo-controlled study showed improvement in the treatment group compared to the placebo group. The improvements were seen in terms of muscle recovery, pain reduction, lower muscle fatigue, and better aerobic function, indicating the potential for liposomal β-caryophyllene to reduce muscle pain.

Another randomised placebo-controlled study used liposomal β-caryophyllene to evaluate its effect on delayed onset muscle soreness (DOMS) in healthy human subjects [35]. The treatment group that received liposomal β-caryophyllene showed a significant reduction in DOMS as compared to the placebo group. It was

demonstrated that the treatment improved aerobic function, reduced muscle fatigue, enhanced endurance, and improved muscle energy supply [35]. Additionally, the study indicated that liposomal β-caryophyllene reduced inflammation and enhanced neuromuscular activation, leading to improved muscle health. Other compounds, such as α-terpineol, have been shown to have anti-inflammatory and antioxidant effects, which can aid in muscle recovery and reduce soreness [5,27]. Besides, linalool, from the monoterpene alcohol, has been found to have muscle relaxant and analgesic effects, which can help alleviate muscle tension and pain [6].

Limitations and future planning

Cajeput oil is known for its ability to alleviate muscular aches and spasms, particularly in Southeast Asian countries like Malaysia, Indonesia, and Thailand. However, there are some important precautions to consider. This oil can irritate the skin or cause allergic reactions in some individuals, especially if it is not properly diluted with a carrier oil. Additionally, there is a concern that cajeput oil may interact with certain medications, such as those for diabetes. Therefore, anyone taking prescription or over-the-counter medications should consult a doctor before using them.

Despite its widespread availability and frequent claims of relieving muscle pain, cajeput oil has limited scientific literature to support these assertions. In contrast to other essential oils like eucalyptus, lemon, and peppermint, which have substantial research backing their benefits, cajeput oil presents an opportunity for further scientific exploration. While it is commonly used to relieve muscle pain in Southeast Asian countries and has shown potential benefits, more evidence is needed to validate these claims. Traditional uses of cajuput oil include applications as a muscle relaxant and for alleviating muscle pain; there is a lack of rigorous clinical studies specifically for these purposes, particularly in controlled environments. Most studies focus on its antioxidant and antibacterial properties rather than direct effects on muscle health or recovery [14]. Additionally, the variability in the chemical composition of cajuput oil based on extraction methods and geographical sources complicates the establishment of standardised dosages and formulations for therapeutic use [13]. Overall, these limitations highlight the need for targeted research to fully understand the potential benefits of *Melaleuca cajuputi* for muscle health.

Furthermore, this opens up opportunities for additional *in-vivo* and *in-vitro* studies to scientifically validate the effectiveness of cajeput oil in alleviating muscle pain. These studies could involve conducting large-scale randomised controlled trials to determine the safety, efficacy, and optimal dosage of cajeput oil for various muscle pain conditions. Investigating the underlying mechanisms responsible for the analgesic and anti-inflammatory properties of cajeput oil could also prove to be valuable. This research could lead to more scientific exploration, not only in this field but also in others. Overall, cajeput oil has untapped potential that warrants further investigation to enhance human health.

Conclusion

In summary, this mini-review explores the potential therapeutic benefits of cajeput oil for enhancing muscle health. Additionally, this mini-review utilises bibliometric analysis to observe the existing trends in cajeput oil literature. There is a growing body of literature on cajeput oil research each year. However, the bibliometric analysis also indicates a deficiency in literature focusing on the effects of cajeput oil on muscle health, highlighting the need for further scientific studies to expand our understanding beyond anecdotal evidence. Cajeput oil may enhance muscle health due to its phytochemicals, such as 1,8-cineole, limonene, and β-caryophyllene, which have anti-inflammatory and analgesic properties that can reduce muscle soreness. Despite claims in the market regarding the oil's

efficacy in relieving muscle pain, scientific evidence is still limited despite widespread consumer use, underscoring the necessity for additional scientific research in the future. Nevertheless, cajeput oil has huge potential to become one of the important ingredients that can be used to alleviate muscle soreness in the future, with enough scientific evidence.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Conflict of interest:

The authors have no conflict of interest to declare.

Authors' contribution:

M.F.Z: Formal analysis, Writing - Review & Editing M.A.A.M.: Software, Formal analysis, Methodology, Writing - Original Draft; M.N.M.B.: Review & Project planning; N.H.C.B.: Review & Project planning; P. M. R.: Writing - Review & Editing, Project administration.

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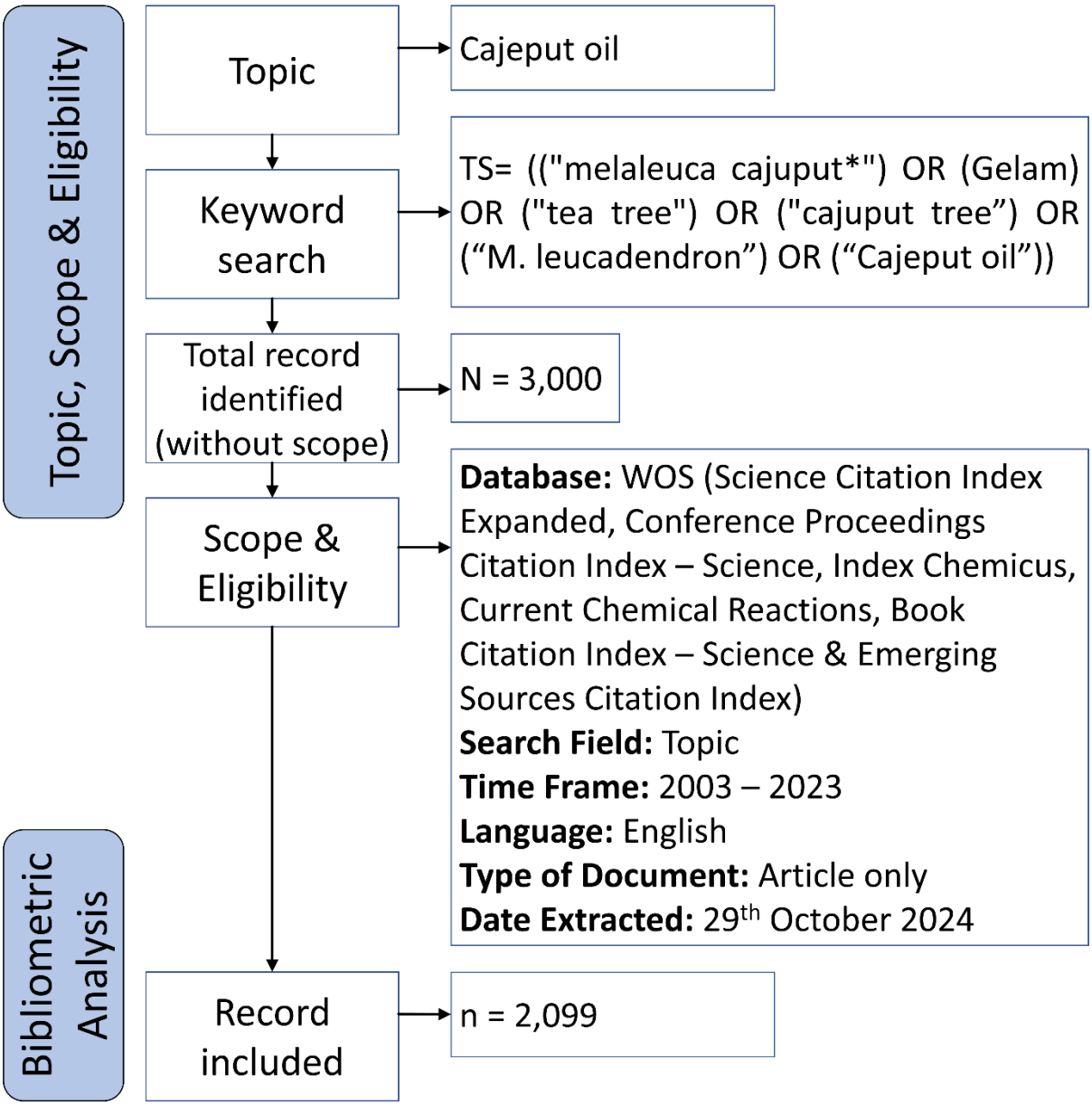

Figure 1. Flowchart for research structure on cajeput oil literature in the world focused on the WOS database.

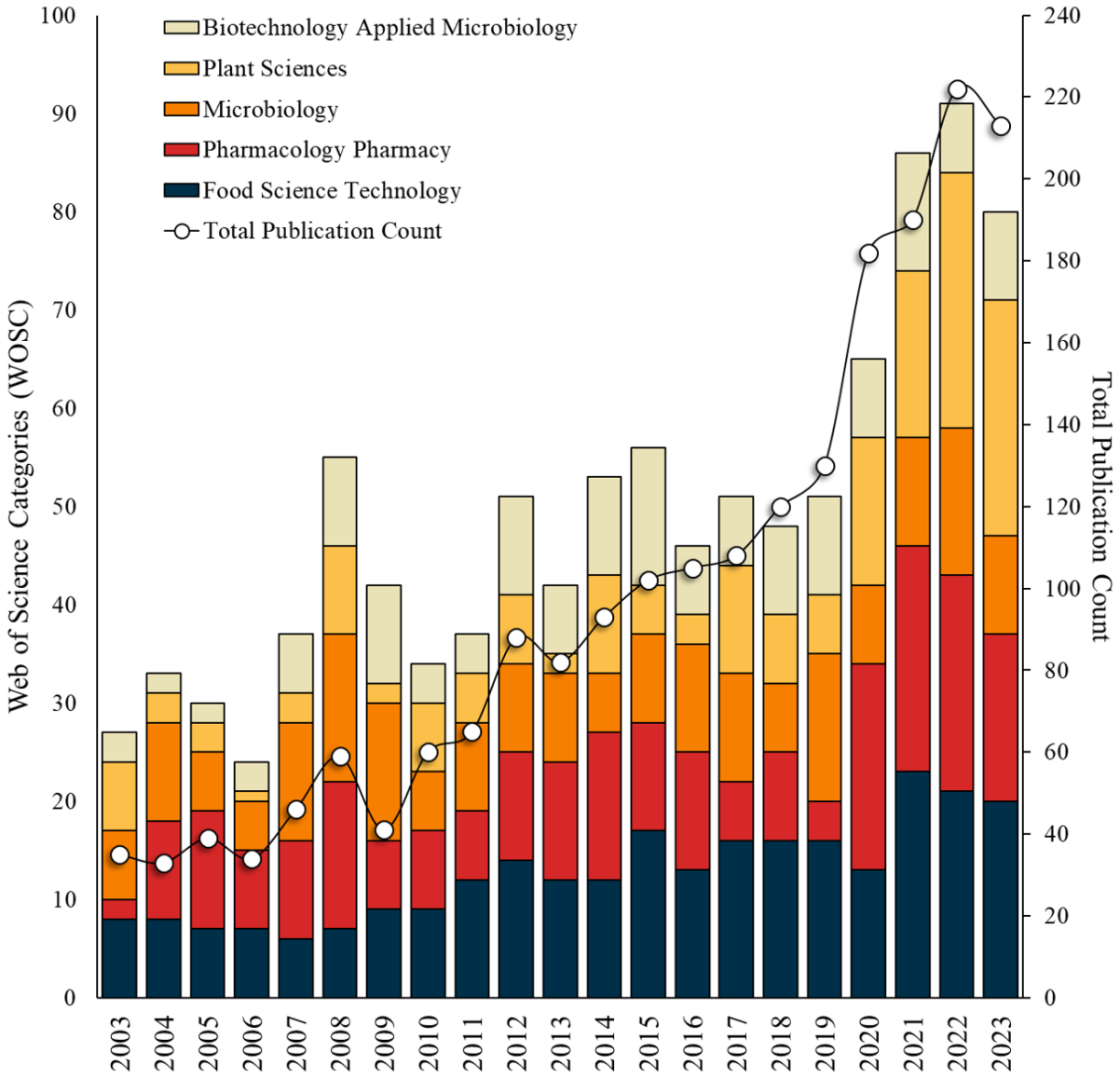

Figure 2. Number of publications and WOS categories

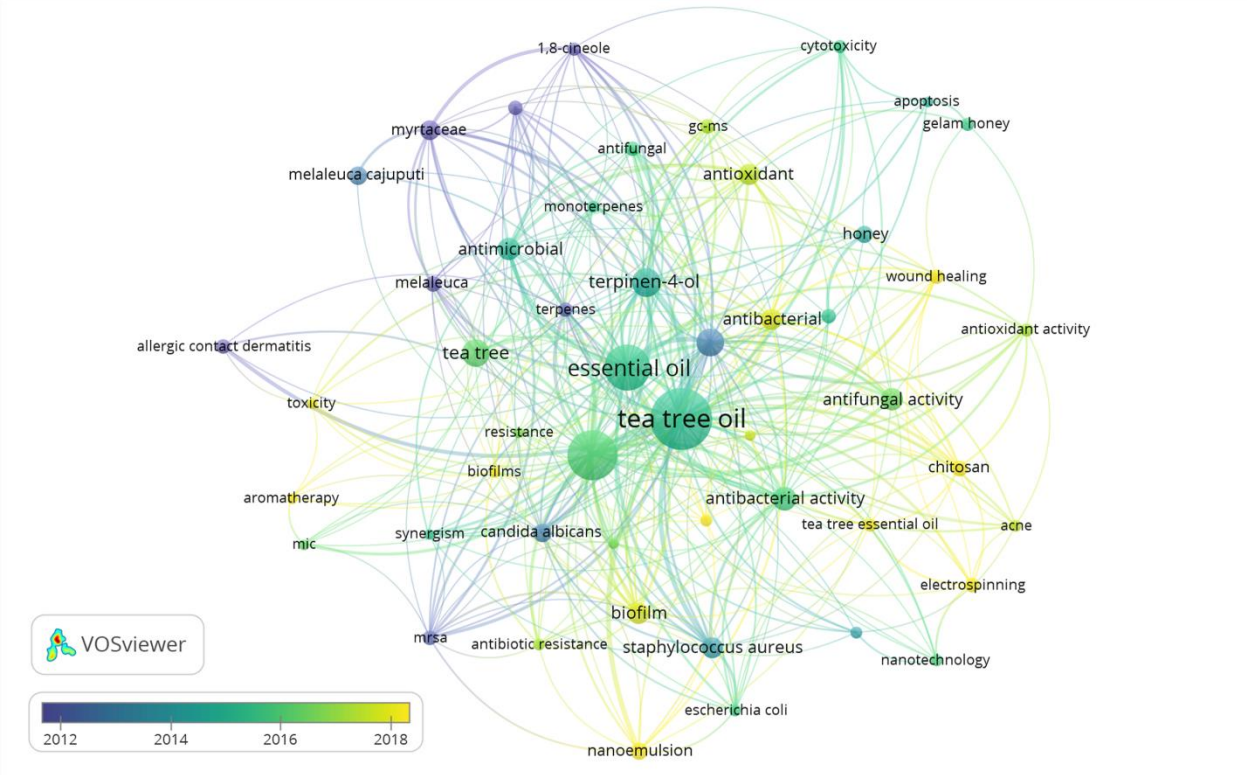

Figure 3. Network visualisation of top 50 most used keywords related to cajeput oil.

Table 1. Most productive researchers, organisations, and countries

Authors		
Names	Record count	% of 2,321
Riley TV	43	1.853
Carson CF	38	1.637
Hammer KA	30	1.293
Reichling J	23	0.991
Baldissera MD	21	0.905
Shao XF	21	0.905
Affiliations		
Names	Record count	% of 2,321
University of Western Australia	54	2.237
Egyptian Knowledge Bank (EKB)	51	2.197
Universidade Federal De Santa Maria	43	1.853
Southern Cross University	38	1.637
University of Queensland	33	1.422
Queen Elizabeth II Medical Centre	31	1.336
Country/region		
Names	Record count	% of 2,321
China	397	17.105
Australia	323	13.916
United States of America	248	10.685
Brazil	187	8.057
Italy	141	6.075
Malaysia	118	5.084

Table 2. Bioactive compound in cajeput oil [27,30].

Compound	Approximate proportion (%)	Properties	Reff
1,8-cineole (Eucalyptol)	44.8–60.2	Analgesic and anti-inflammatory actions, when applied locally, significantly reduce pain and inflammation. The warming sensation produced may improve blood circulation to the affected area, contributing to pain relief.	[27,30]
β-pinene	5.4–8.9	Possesses anti-inflammatory and analgesic effect	[27,30]
Limonene	4.5–13.5	Enhanced the general soothing effect of cajeput oil in the management of muscle pains.	[27]
α-terpineol	4–12.5	It has anti-inflammatory properties and thus can help reduce muscular pains and increase relaxation.	[30]
α-pinene	3–12	Alleviate muscle soreness and tension, hence beneficial for massage applications.	[27,30]
β-caryophyllene	3.8–7.6	Have analgesic and anti-inflammatory properties.	[30]
γ-terpinene	3.5–7.9	Have antinociceptive (pain-relieving), analgesic and anti-inflammatory properties.	[27]

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