Journal of Experimental Pharmacology
Dovepress
Taylor & Francis Group
Open Access Full Text Article
ORIGINAL RESEARCH

Comparison of Essential Oil Extraction Techniques and Their Therapeutic Applications in Dentistry: Focus on *Candida albicans* Inhibition

Katherine Cuenca-León[1–4], Jéssica María Sarmiento-Ordóñez[1,2], Edisson-Mauricio Pacheco-Quito[1,2], Samantha Miriam Benavides-Túlcan[1], Nicole Alejandra Castro[1], Aránzazu Zarzuelo-Castañeda[3]

[1]Unidad Académica de Salud y Bienestar, Carrera de Odontología, Universidad Católica de Cuenca, Cuenca, Ecuador; [2]Grupo de Investigación Innovación y Desarrollo Farmacéutico en Odontología, Jefatura de Investigación e Innovación, Universidad Católica de Cuenca, Cuenca, Ecuador; [3]Department of Pharmaceutical Sciences, University of Salamanca, Salamanca, Spain; [4]Red Ecuatoriana de Mujeres Científicas (REMCI) Nodo Univrsidad Católica de Cuenca, Quito, Ecuador

Correspondence: Katherine Cuenca-León, Email kcuencal@ucacue.edu.ec

Background: In this study, the efficacy of three essential oil extraction techniques steam entrainment, Soxhlet extraction, and supercritical fluid extraction (SCF) was evaluated.

Aim: Determine the most effective method for obtaining bioactive compounds from *Cymbopogon citratus, Origanum vulgare*, and *Coriandrum sativum*, plant species recognized for their antimicrobial and anti-inflammatory properties with potential applications in dentistry. The selected plants, identified based on scientific evidence, were certified and lyophilized prior to extraction. The efficiency of each technique was assessed in terms of essential oil yield, purity, and biological activity.

Methodology: The plant species were selected for their therapeutic properties based on scientific reports, certified, and lyophilized before proceeding with the different extraction methods. The efficacy of each technique was compared in terms of the purity and yield of the essential oils obtained. The statistical analysis was performed using SPSS version 25.

Results: It was shown that FSC extraction is the method that allows obtaining essential oils with the highest purity and yield, followed by steam entrainment, with the Soxhlet method being the least efficient. However, in the microbiological analysis, the essential oil obtained by steam entrainment showed a greater inhibitory effect against *Candida albicans* ATCC 90028.

Conclusion: In this study, the FSC and steam entrainment techniques are the most suitable for obtaining essential oils for therapeutic applications in dentistry, since they allow better preservation of the bioactive components and reduce the environmental impact. These results position FSC and vapor entrainment extraction as promising options for the development of therapeutic products in dentistry.

Keywords: essential oil, extraction methods, odontology, *Cymbopogon citratus*, *Origanum vulgare*, *Coriandrum sativum*

Introduction

Essential oils (EOs) are liquid extracts with a consistency similar to that of fatty oils, yet they are distinguished by their volatility, which allows them to evaporate without leaving residues.[1,2] They are derived from various parts of plants, including leaves, seeds, bark, roots, flowers, and fruits.[3,4] The aroma and color characteristics of EOs are determined by the composition and proportion of their active compounds. These oils are complex mixtures that may contain up to 100 active components, such as low-molecular-weight aliphatic, terpenoids, monoterpenes, sesquiterpenes, and phenylpropanes.[5,6]

EOs have broad applications across various industries, including pharmaceuticals, food, and cosmetics. They are used in the manufacture of perfumes, flavorings, and acaricidal and insecticidal agents, owing to their anti-inflammatory, antioxidant, and antimicrobial properties, among others.[7,8] In dentistry, EOs could be formulated into mouthwashes, gels, or toothpaste to enhance their stability and efficacy.[9] Compared to conventional antifungals such as azoles and polyenes, EOs offer multiple mechanisms of action and a lower risk of resistance, although their clinical effectiveness still requires validation in clinical trials.[10]

Received: 8 March 2025
Accepted: 16 May 2025
Published: 3 July 2025

EOs have demonstrated antifungal properties through mechanisms such as disrupting fungal cell membranes, inhibiting ergosterol synthesis, and preventing biofilm formation.[11,12] Compounds such as thymol and eugenol destabilize the cell membrane of *Candida albicans*,[13] while others induce oxidative stress, leading to cellular apoptosis.[14] These characteristics position them as promising alternatives for the treatment of oral infections. However, their volatility and potential toxicity necessitate detailed studies to ensure their safety and optimal dosage. For clinical implementation, it is crucial to evaluate their safety profile, develop controlled-release systems, and conduct comparative studies with existing treatments. Future research should focus on the standardization of bioactive components and their synergistic potential with conventional antifungals.[15]

To ensure the optimal quality of EOs, several factors influencing their composition must be considered, ranging from intrinsic plant characteristics to environmental and methodological aspects.[5,8,16,17] The extraction method is a key factor in EO quality and depends on both the technique employed and the specific conditions of analysis and solvents used.[16] Choosing the appropriate extraction method is essential to preserve the oil's bioactive properties and meet required quality standards.[16] In the pharmaceutical industry, EO extraction methods are fundamental for drug formulation and development, as they enable the isolation of bioactive components from plants with therapeutic properties. Among the most commonly used methods is steam distillation. However, more advanced and sustainable techniques include Clevenger trap hydrodistillation, ultrasound-assisted extraction, supercritical fluid extraction, and Soxhlet extraction.[16,18]

The present study aimed to compare three methods of essential oil extraction from *Origanum vulgare* (Oregano), *Cymbopogon citratus* (Lemon Verbena), and *Coriandrum sativum* (Coriander). These plant species are widely distributed across Ecuador, where they are traditionally cultivated and used for both medicinal and culinary purposes. *Cymbopogon citratus* thrives in tropical and subtropical regions, particularly along the Ecuadorian coast and in the Amazon, where it is highly valued for its applications in infusions and natural medicine. *Origanum vulgare* flourishes in the temperate zones of the Andean highlands, where it plays a prominent role in local gastronomy and is often incorporated into herbal remedies. Similarly, *Coriandrum sativum* is commonly found throughout Ecuador, particularly in the Coast and Sierra regions, where it is a staple in traditional cuisine and is known for its digestive and antimicrobial properties.[19,20]

The efficacy of each extraction method was evaluated in terms of purity, yield, and effectiveness, focusing on bioactive compounds known for their antimicrobial properties, such as carvacrol, thymol, α-citral, and others. This analysis serves as a preliminary phase for future research in dentistry, aimed at developing pharmaceutical formulations based on these oils, which have demonstrated potential in inhibiting the growth of *Candida albicans* and other pathogenic microorganisms. The results from this study will contribute to understanding the potential of these essential oils as natural alternatives in dental applications.

Materials and Methods

This was a longitudinal laboratory study and was performed under the permission of the Bioethics Committee of the Catholic University of Cuenca under the category of exempt, with code 108–2024. The objective of this study was to identify the most effective extraction method for the three plant species: lemon verbena, coriander and oregano; in order to test the antifungal effect of these plant species in the field of dentistry.

Selection of Plant Species

The plant species studied are widely distributed in Ecuador, where they are traditionally cultivated and utilized for their medicinal and culinary properties. *Cymbopogon citratus* thrives in tropical and subtropical regions, particularly along the Ecuadorian coast and in the Amazon, where it is highly valued for its use in infusions and natural medicine. *Origanum vulgare* flourishes in the temperate zones of the Andean highlands, where it is widely incorporated into gastronomy and herbal remedies. Coriandrum sativum is commonly found throughout the country, especially in the Coast and Sierra regions, where it is an essential component of traditional cuisine and is attributed with digestive and antimicrobial properties.[19]

These species were selected for this study due to their well-documented antimicrobial activity, which is attributed to the presence of chemical compounds such as carvacrol, thymol, α-citral, myrcenol, β-citral, citral, γ-myrcene, linalool, geraniol, borneol, and linoleic acid,[16,21] as well as their traditional use in Ecuadorian folk medicine. Previous studies have demonstrated that the essential oils and extracts of these plants contain bioactive compounds with antifungal properties. Specifically, their efficacy against *Candida albicans*, an opportunistic fungus responsible for infections in humans, was investigated to explore natural alternatives for controlling this pathogenic yeast.[7,17]

Botanical Certification

To ensure the authenticity and accurate identification of the plant species used in this study—*Cymbopogon citratus* (lemongrass), *Origanum vulgare* (oregano), and *Coriandrum sativum* (coriander) a rigorous botanical certification process was carried out. This certification was conducted by a specialized expert in plant taxonomy with extensive experience in species identification. (Professor Verónica Vivar- Ciencias Agropecuarias Universidad Católica de Cuenca)

The process involved a detailed morphological examination of the samples, comparing their characteristics with standard botanical identification keys and reference herbarium specimens. Additionally, the samples were cross-verified against specialized botanical literature to confirm their classification. This multi-step verification ensured that each sample matched established botanical descriptions, guaranteeing the accuracy of species identification.

Obtaining and Selecting the Plant Species

Representative samples of the plant species lemon verbena (*Cymbopogon citratus*), oregano *(Origanum vulgare*) and coriander *(Coriandrum sativum*) were collected from various sources, including specialized nurseries and identified wild areas. Plants were selected in good health and free of visible diseases.

In addition, special attention was paid to the phenological stage of the plants, collecting the leaves of lemon verbena and oregano during their vegetative phase and the mature seeds of coriander. This procurement process ensured the availability of high-quality samples, essential for the investigation of essential oils and their antifungal properties.

The selection of lemon verbena and oregano leaves was carefully made during the vegetative growth stage of the plants, when the essential oils are presumably at their highest concentration. Mature, healthy leaves were chosen, avoiding those that showed signs of insect damage, disease or environmental stress. In addition, attention was paid to the uniformity of size and shape of the selected leaves, ensuring the homogeneity of the sample. For coriander, in addition to leaves, mature seeds were collected, as they contain a significant number of essential oils with antifungal properties. This rigorous selection process ensured that high quality and homogeneous samples were obtained, which are essential to obtain reliable results in the study of essential oils.

Extraction Methods

The selection of methods such as steam entrainment, supercritical fluid extraction (SFE), and Soxhlet extraction for obtaining essential oils is based on their specific advantages in terms of efficiency, selectivity, and the quality of the final product. The choice among these methods depends on factors such as the nature of the plant, the desired composition of the essential oil, and economic and environmental considerations. SFE, in particular, stands out for its ability to obtain high-quality extracts in a sustainable manner.

Supercritical Fluid Extraction (SFE)

The supercritical state is reached by equilibrium between temperature and pressure, where a gas can condense into a liquid by increasing the pressure to its maximum value, while a liquid can vaporize by increasing the temperature to its upper limit.

First, it is imperative to perform the process of drying and grinding the sample in order to enlarge its surface area and thus facilitate the interaction with the supercritical fluid. Subsequently, this prepared sample is introduced into the extraction column of the device. The configuration of the thermo-pressurized conditions of the system is carried out according to the particular specifications required for the selected supercritical fluid. Then, the controlled injection of the supercritical fluid is carried out using a high-pressure pump.

The liquid comes in contact with the sample, performing the function of a solvent by extracting the constituents of interest from the sample. The soluble compounds will be dissolved in the liquid and transported out of the extraction column.

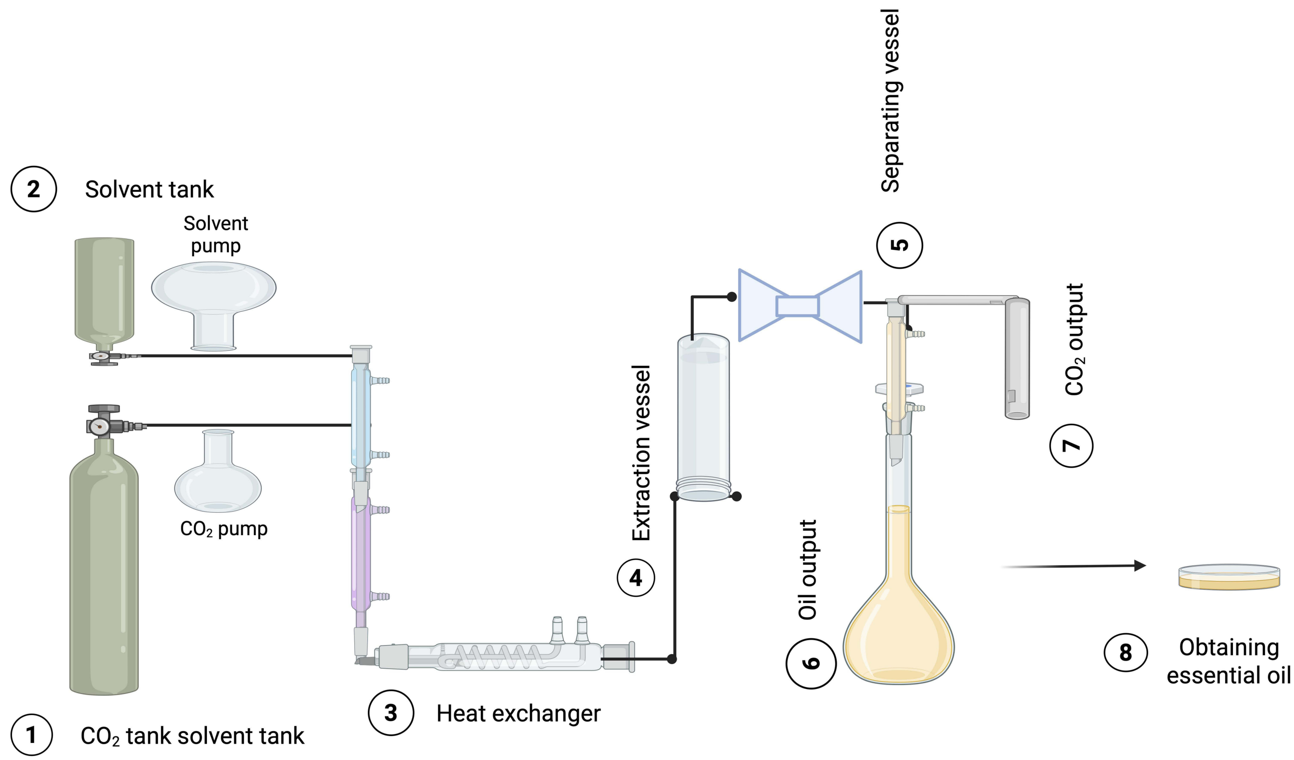

Figure 1 Supercritical fluid extraction method. Created in BioRender. Benavides, S. (2025) https://BioRender.com/kgt0ck9.

Pressure and temperature are regulated by a valve to proceed with depressurization and separation, where the extract is separated from the remaining supercritical fluid by a process of decompression and evaporation. This approach allows selective extraction of the desired compounds, since their solubilities are affected by temperature and pressure, and is advantageous due to the use of a non-harmful solvent, as shown in Figure 1.[22]

Steam Entrainment

This steam entrainment process is used to achieve complete recovery of the essential oil. It is a distillation process that avoids the direct use of heat on the selected sample, which helps to preserve both the quality and the integrity of the sample. As a result, a high purity essential oil is obtained, as the volatile components are efficiently extracted by steam.[23]

The distillation flask is filled with water, while the respective samples are placed in the boiling vessel, which is positioned in the distillation flask. The process is started by heating the distillation flask to generate steam. This steam carries with it the volatile compounds in the samples. The essential oils then condense and, being less dense than water, float to the surface, as shown in Figure 2. [23,24]

Extraction by Soxhlet Method

The Soxhlet extraction method is a widely used technique in analytical chemistry and phytochemistry for the efficient separation of organic compounds from solid matrices. This method employs an apparatus designed to perform a continuous reflux extraction process, in which a volatilized solvent condenses and recirculates through a cartridge containing the sample.[25] The fundamental principle of this technique lies in the selective solubilization of the target compounds in a suitable solvent, ensuring thorough extraction by repeated exposure of the sample to the fresh, pure solvent dripping from the condenser.[26]

The heated solvent in the Soxhlet flask evaporates, rises through a side tube and condenses at the top of the system thanks to the cooling provided by the condenser. The condensed liquid flows into the cartridge, where it extracts the soluble compounds from the solid matrix. Once the solvent level in the cartridge reaches a critical point, the integrated siphon empties the contents back into the flask, where the cycle begins again. This cyclic process allows maximizing efficiency by using controlled amount of

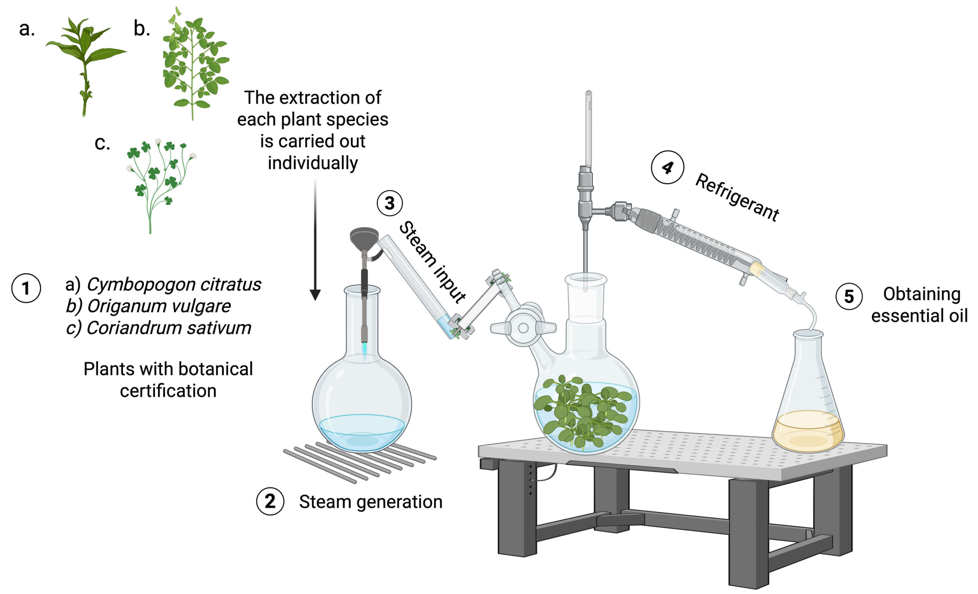

Figure 2 Extraction method steam distillation. Created in BioRender. Benavides, S. (2025) https://BioRender.com/31eat5j.

solvent, while maintaining a balance between the cost and performance of the method.[27] The Soxhlet method is especially useful for complex samples where the analytes of interest are present in low concentrations or heterogeneously distributed in the matrix, as shown in Figure 3.[26,28]

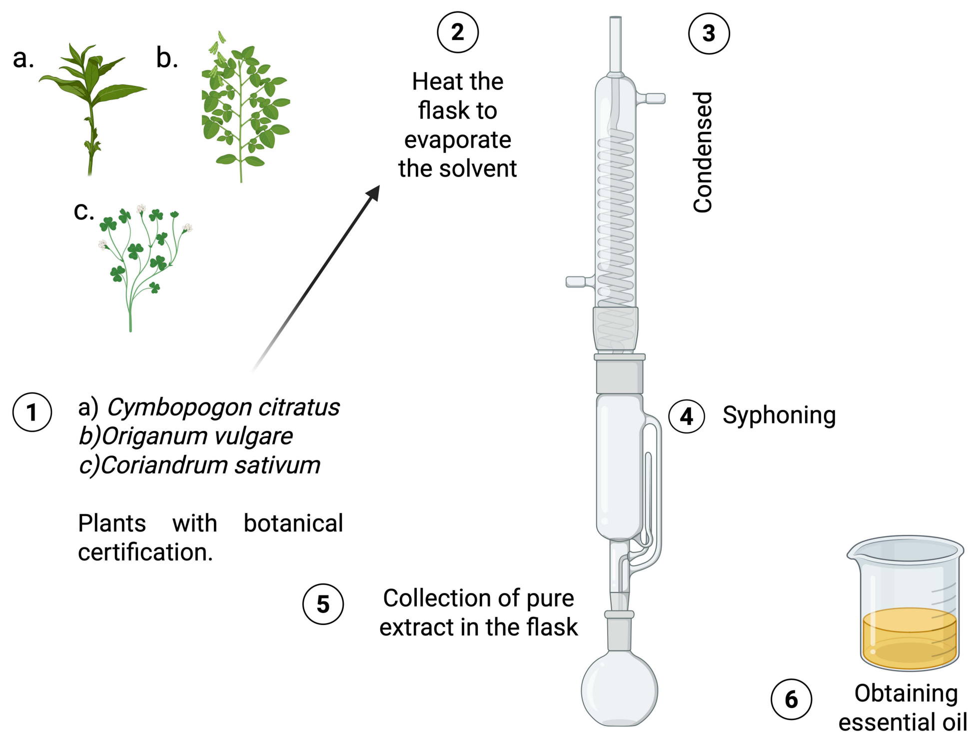

Figure 3 Soxhlet method. Created in BioRender. Benavides, S. (2025) https://BioRender.com/c34rvzx.

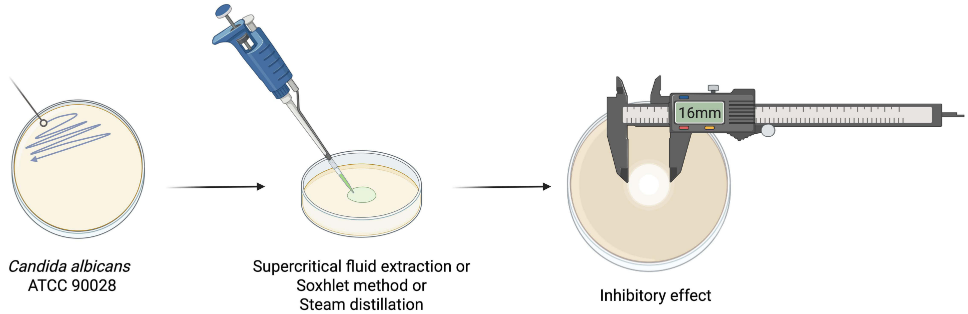

Figure 4 Inhibitory effect of essential oil by each type of extraction using strains of *C. albicans*. Created in BioRender. Pacheco, E. (2025) https://BioRender.com/nte40ym.

Analysis of Essential Oils

The purity of the essential oils was assessed using gas chromatography coupled with mass spectrometry (GC-MS), enabling the identification and quantification of key bioactive compounds such as carvacrol, thymol, citral, and linalool. Purity was determined based on the relative percentage of these compounds in relation to the total components detected. Supercritical fluid extraction (SFE) achieved the highest purity (>90%), followed by the Soxhlet method (88%) and steam distillation (85%).

Microbiological Analysis of Essential Oils

The antifungal activity of the essential oils was tested against synthetic strains ATCC 90028 of *C. albicans*, without any dilution, obtaining a maximum inhibitory halo in the 3 species, as shown in Figure 4. Further studies against bacterial strains are planned for the future.

Statistical Analysis

A comparative analysis was conducted to evaluate the concentrations of essential oils obtained through three extraction methods: steam entrainment, supercritical fluid extraction (SFE), and the Soxhlet method. To determine statistically significant differences between these techniques, an analysis of variance (ANOVA) was performed using Welch's test, given the heterogeneity of variances.

Due to the limited sample size, the Shapiro–Wilk test was exclusively employed to assess data normality, yielding a statistic of 0.858 and a p-value of 0.091. These results indicate no significant deviations from normality, thereby justifying the application of ANOVA for mean comparisons.

The ANOVA results ($F = 7.52$, $p = 0.045$) revealed statistically significant differences in essential oil concentrations across the plant species analyzed. These findings suggest that the intrinsic chemical composition of each species plays a critical role in determining essential oil yield.

Results

Analysis of the Concentration of Essential Oils in Lemon Verbena, Cilantro, and Oregano: Comparison of Extraction Methods

The analysis of essential oil concentrations extracted from Lemon Verbena, Cilantro, and Oregano demonstrated that the Supercritical Fluid Extraction (SFE) method is the most efficient in terms of yield. Compared to Soxhlet and steam entrainment methods, SFE consistently yielded higher concentrations across all evaluated plant species. The specific data for each method and plant are presented in Table 1.

These findings suggest that the choice of extraction method should be made according to specific priorities—whether to maximize yield or to balance costs and process complexity. The SFE method, though more complex and costly, provides the highest yield, while vapor entrainment offers a more affordable solution at the cost of lower concentrations.

Table 1 Analysis of the Concentration of Essential Oils in Lemon Verbena, Cilantro, and Oregano: Comparison of Extraction Methods

Extraction Method	Lemon Verbena (%)	Cilantro (%)	Oregano (%)
Supercritical fluid extraction (SFE)	2	1.2	1.6
Soxhlet Extraction	1.8	1	1.4
Steam entrainment	1.5	0.8	1.2

The cost analysis in this case was carried out by evaluating the operational and infrastructure costs associated with each extraction method, comparing them with the yield in terms of essential oil concentration obtained. The supercritical fluid extraction (SFE) method was the most expensive due to the investment in specialized high-pressure equipment and the consumption of CO_2, which entails high costs both in installation and operation. The Soxhlet method, while more economical, also incurs operational costs due to the use of solvents, but these are lower compared to SFE, making it more accessible. Lastly, steam distillation proved to be the most cost-effective due to its simplicity and low operational costs; however, its lower yield required more raw material to obtain a similar amount of oil, affecting overall efficiency. The cost analysis focused on the relationship between initial investment, operational costs, and the volume of essential oil produced.

Figure 5 illustrate the mean concentrations of essential oils for each plant species and extraction method, along with their respective 95% confidence intervals. As shown in the graph, there were no significant differences in the concentration of oils obtained by each extraction method, which aligns with the results of the ANOVA analysis.

For the Lemon Verbena plant, the average concentration was 1.77%, with a standard deviation (SD) of 0.252 and a standard error (SE) of 0.145, based on a sample of three extractions. Cilantro yielded an average concentration of 1.00%, with a SD of 0.200 and an SE of 0.115, also from three extractions. Oregano's mean concentration was 1.40%, with a SD of 0.200 and an SE of 0.115, derived from three samples.

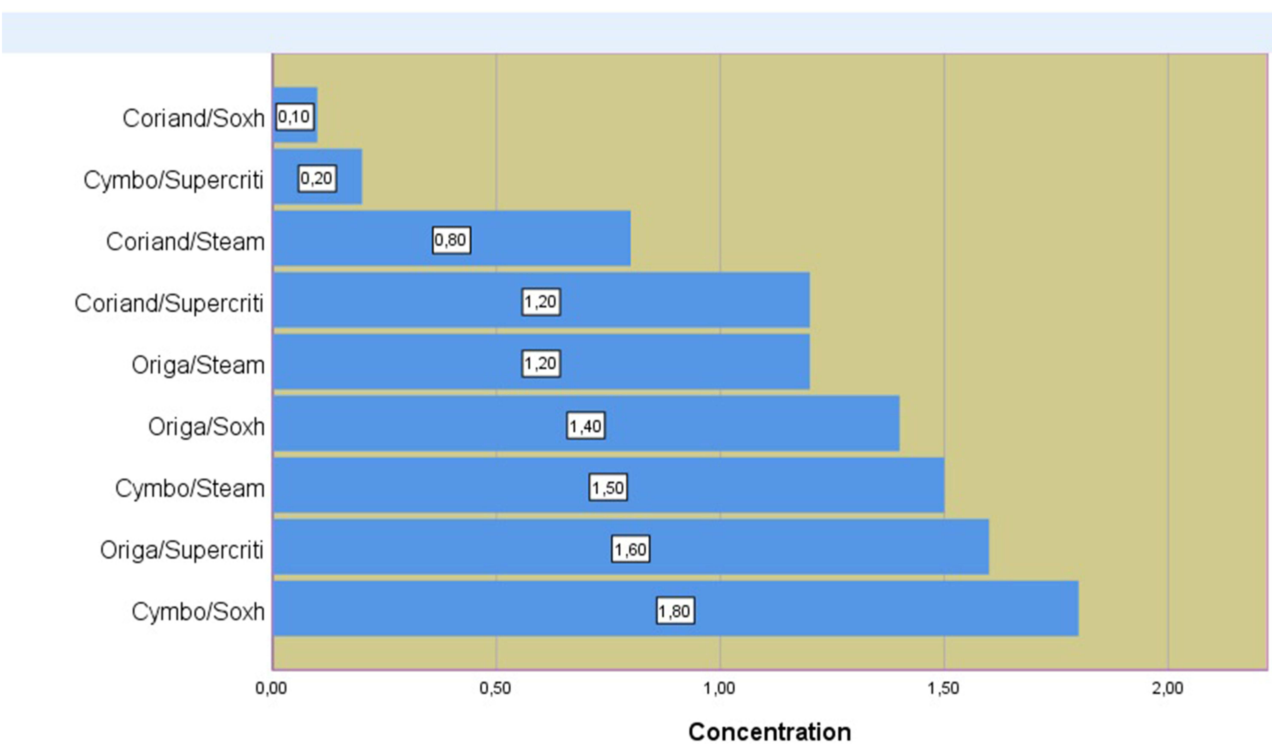

Figure 5 Analysis of the extraction method - concentration.

The graph presents the average concentrations for each plant along with their confidence intervals, which provide insights into the variability of the samples and the precision of the estimated means. Notably, the variability in concentrations was higher for Lemon Verbena compared to the other two plants, indicating a greater variation in its essential oil yield.

The ANOVA analysis yielded an F-value of 7.52 and a p-value of 0.045, indicating that there are significant differences in the concentrations of the essential oils among the plant species. This suggests that the type of plant plays a significant role in determining the concentration of essential oils, and the observed differences are not due to random chance.

It is important to note that while the graph shows the average concentrations of each plant, the differences in these concentrations may be influenced by both the intrinsic properties of the plants and the analysis methods employed. Variations in the sensitivity and precision of the extraction techniques could contribute to these differences.

These results suggest that while different extraction methods were used, there were no significant differences in the final concentrations of essential oils across methods, providing a useful foundation for future studies in this area.

Extraction Method Parameters Analysis

As summarized in Table 2, the supercritical fluid extraction method emerged as the most efficient in terms of both purity and yield. However, the Soxhlet method showed some drawbacks, particularly its longer extraction time, which could be a limiting factor in large-scale applications.

Antifungal Effects of Essential Oils from Different Extraction Methods

The antifungal effects of essential oils extracted using three methods are summarized in Table 3. The Soxhlet extraction showed minimal activity, with inhibition zones smaller than 6 mm. The SFE method exhibited moderate activity, while the steam entrainment method demonstrated the highest efficacy, with inhibition zones greater than 6 mm.

Table 2 Performance of Extraction Methods: Oil Quantity, Purity and Cost

Extraction Method	Plant	Advantages	Disadvantages
Steam Distillation	*Cymbopogon citratus*	- Low operating cost - Simple process - Good yield with high purity	- Long extraction time - May degrade sensitive compounds
	Coriandrum sativum	- Efficient for volatile compounds - Widely accepted commercially	- Produces less oil compared to other methods
	Origanum vulgare	- Low toxicity and process safety - Good yield in terms of purity	- Requires large amounts of raw material
Supercritical Fluids	*Cymbopogon citratus*	- High purity and yield - Preserves sensitive compounds	- High operating cost - Requires expensive specialized equipment
	Coriandrum sativum	- Excellent for thermolabile compounds - High extraction efficiency	-Complex process - Longer extraction time
	Origanum vulgare	- Produces oils with a complete aroma profile - Requires fewer solvents	- Requires advanced technical knowledge
Soxhlet	*Cymbopogon citratus*	- Good extraction efficiency - Equipment is readily available in standard laboratories	- High solvent consumption - Long process duration
	Coriandrum sativum	Continuous process with good oil recovery - Well established method	- Risk of thermal degradation - Requires prior degreasing
	Origanum vulgare	- High reproducibility - Allows the use of different solvents	- High energy consumption - Solvents may leave residues

Table 3 Antifungal Effects of Essential Oils from Different Extraction Methods

Extraction Method	Inhibition Zone (mm)	Antifungal Activity	Conclusion
Soxhlet Extraction	< 6 mm	Minimal activity	Limited antifungal effect
Supercritical Fluid Extraction (SFE)	Below expected threshold	Moderate activity	Antifungal effect, but below expected levels
Steam Entrainment	> 6 mm	High activity	Most effective method for antifungal applications

Table 4 Comparison of Extraction Methods Based on Essential Oil Yield and Characteristics

Plant Species	Supercritical Fluid Extraction (SFE)	Soxhlet Extraction	Steam entrainment
Lemon Verbena	2.00%	1.80%	1.50%
Cilantro	1.20%	1.00%	0.80%
Oregano	1.60%	1.40%	1.20%

Comparison of Extraction Methods Based on Essential Oil Yield and Characteristics

In Table 4, a detailed comparison of the steam entrainment, supercritical fluid, and Soxhlet methods is presented. This comparison outlines the advantages and limitations of each technique in relation to the particular characteristics of the plants studied. This analysis serves as a basis for selecting the most appropriate extraction method, depending on the specific quality requirements for essential oils, particularly in applications such as dental treatments.

These comprehensive results underscore the importance of selecting the right extraction method to achieve optimal yield and quality of essential oils for various applications, including therapeutic uses.

Discussion

Although essential oils can be obtained using different methods, such as solvent extraction, steam entrainment, and supercritical fluid extraction, the most widely used method—both on a small and large scale—is steam entrainment. This method is preferred because it yields a higher proportion of various essential oils.[14,29] This is supported by the data in Table 2, which shows that steam entrainment resulted in 2.5 g of oil with 85% purity in 4 hours, at a low operational cost. In contrast, supercritical fluid extraction yielded 3.2 g in 6 hours with 90% purity but at a higher economic cost. The Soxhlet method, meanwhile, produced 2.8 g with 88% purity in 8 hours, at a medium operational cost.

The antifungal activity of the extracted essential oils was evaluated by measuring their growth-inhibitory capacity against *Candida albicans ATCC*® 90028. The best results were obtained with the essential oil extracted via steam entrainment. It is important to note that this study specifically examined the efficacy against *C. albicans ATCC*® 90028, which is a crucial aspect to clarify, as this research is considered preliminary for the development of therapeutic applications. Previous studies have indicated that oregano essential oil can inhibit the growth of other strains, such as *Staphylococcus aureus* and *Pseudomonas aeruginosa*, by altering the permeability of the cell membrane.[30] However, conflicting research suggests that this essential oil may not be effective against these microorganisms. These discrepancies may be attributed to variations in the composition of the essential oils used, which can significantly affect their antifungal activity. It is generally accepted that phenolic compounds, such as thymol and carvacrol, have hydroxyl groups that cause considerable structural and functional damage at the plasma membrane level.[13,14]

By comparing and evaluating extraction methods, their advantages and disadvantages, the following points of discussion can be derived from certain authors. Several studies highlight that essential oils (EOs) have diverse applications in the pharmaceutical industry, as preservatives in the food industry, and as promoters and regulators of intestinal health in animal feed, due to their antimicrobial and antioxidant properties.[15,31] Steam entrainment extraction has been identified as the most common method for obtaining essential oils used in multiple sectors. However, solvent extraction has been shown to generate residues and cause losses of essential oils.[21,23] Several authors have concluded that steam distillation is preferable because it operates outside the system, maintaining a lower internal temperature and thus reducing the rate of deterioration compared to water distillation. However, a major challenge of this method is the precise regulation of steam flow and pressure.[8,21,24,26]

Moreover, a study comparing the extraction efficiency of essential oils from grapefruit peels found that steam distillation was the most successful method, with yields up to 60 times higher than hydrodistillation. The authors of this study noted that these results were consistent with those reported in the literature, and attributed this success to the hydrophilic and non-volatile nature of the essential oils extracted from citrus fruits.[23]

It can be mentioned that other authors reached similar conclusions, with steam entrainment yielding more accurate results compared to what has been documented in the literature. In this context, steam entrainment was demonstrated to be the most efficient method for obtaining essential oils, compared to the Soxhlet method using organic solvents, due to its ability to produce a product with fewer impurities.[28,29]

Additionally, the importance of this study in the field of phytotherapy cannot be overstated, as it represents the first stage of research for the formulation of therapeutic applications. Phytotherapy, an alternative to conventional pharmacological treatments, requires precise and efficient methods for extracting bioactive components from plants. This study focuses on comparing different extraction techniques to determine the most suitable one in terms of purity, yield, and efficacy. The ultimate goal is to develop formulations that can be applied in the dental field, particularly for combating *Candida albicans* infections, a common fungus in the oral cavity. Furthermore, this research aims to lay a solid foundation for future studies that will optimize the formulation of phytotherapeutic products.[4]

Comparing the efficacy of essential oils (EOs) with conventional antifungal agents used in dentistry, such as azoles and polyenes, is crucial for determining their viability as alternatives or adjuvants in the treatment of oral infections. Recent studies have shown that compounds like thymol and eugenol exhibit significant antifungal activity against *Candida albicans*, comparable to drugs like fluconazole, although with distinct mechanisms of action that could help reduce the risk of resistance. Additionally, some essential oils have shown synergistic effects when combined with conventional antifungals, enhancing their efficacy and reducing the toxicity associated with these treatments. However, the variability in EO composition and the lack of standardization in their clinical use call for further trials to assess their effectiveness in vivo and their long-term safety. Well-designed comparative studies would help define the role of EOs in dentistry, optimize their formulation, and determine appropriate dosages for clinical use.[31,32]

It is crucial that future research investigates the effectiveness of these oils on a wider range of oral pathogens, as well as their potential toxicity and long-term stability in dental preparations. This analysis lays the foundation for future research to confirm the use of essential oils obtained through FSC and vapor entrainment in the creation of new phytotherapeutic treatments in dentistry, drawing attention to sustainable and effective options for antimicrobial resistance. In consequence, the choice of extraction method should be based on a thorough evaluation that takes into account purity, yield, operating costs, preservation of bioactive components and microbiological analysis.

Conclusions

This study compared three methods of essential oil extraction steam distillation, supercritical fluid extraction (SFE), and Soxhlet extraction using *Cymbopogon citratus, Origanum vulgare*, and *Coriandrum sativum*. SFE proved to be the most efficient in terms of both yield and purity, reaching over 90% bioactive compound content. Although steam distillation showed slightly lower purity levels, it demonstrated the highest antifungal efficacy against *Candida albicans*, making it a strong candidate for dental applications where antimicrobial effectiveness is essential.

Economically, SFE requires greater investment and operational costs due to the need for high-pressure equipment and CO_2, but its elevated yield makes it suitable for clinical applications that demand high standards. In contrast, steam distillation, with its lower complexity and reduced costs, presents a sustainable and accessible alternative, especially for broader therapeutic use. Soxhlet extraction, while effective, is less favorable due to longer processing times and solvent-related limitations.

In conclusion, selecting an appropriate extraction method must involve a comprehensive evaluation of yield, purity, efficacy, cost, and sustainability. Based on these criteria, both SFE and steam distillation emerge as the most suitable options for producing high-quality essential oils with potential therapeutic applications in dentistry.

Acknowledgments

Special mention goes to Professor Verónica Vivar, research professor of Agricultural Sciences at the Catholic University of Cuenca, for her contribution to the certification of plant species, and to Professor Juan Carlos González for his collaboration in the preparation phase of the plant species. We also thank Edisson-Mauricio Pacheco-Quito and Katherine Cuenca-León, who are part of the Research Group: Innovación y Desarrollo Farmacéutico en Odontología, Facultad de Odontología, Jefatura de Investigación e Innovación, Universidad Católica de Cuenca, Cuenca, Ecuador.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

The APC was funded by Universidad Católica de Cuenca, Cuenca, Ecuador, it is anchored to the project called: “Desarrollo de formulaciones bucales basadas en componentes activos de origen vegetal para el control de microorganismos orales” approved under code: PICTMS24-05.

Disclosure

The authors declare no conflicts of interest in this work.

References

1. Oniga I, Pus C, Silaghi-Dumitrescu R, et al. Origanum vulgare ssp. vulgare: chemical composition and biological studies. *Molecules*. 2018;23(8):2077. doi:10.3390/molecules23082077
2. Handschuh Briones RA, Silva Arcos EN, Urrutia M, Godoy-Martínez P. Actividad antifúngica de los enjuagues bucales frente a Candida albicans y Rhodotorula mucilaginosa: un estudio in vitro. *Rev Iberoam Micol*. 2020;37(2):47–52. doi:10.1016/j.riam.2019.10.006
3. Sturabotti E, Moldoveanu VG, Camilli A, et al. Thymol-functionalized hyaluronic acid as promising preservative biomaterial for the inhibition of candida albicans biofilm formation. *ACS Macro Lett*. 2023;12(8):1079–1084. doi:10.1021/acsmacrolett.3c00208
4. Shafiee F, Moghadamnia AA, Shahandeh Z, Sadighian F, Khodadadi E. Evaluation of the antibacterial effects of aqueous and ethanolic leaf extracts of Aloysia Citriodora (Lemon verbena) on Streptococcus mutans and Streptococcus sobrinus. *Electron Physician*. 2016;8(12):3363–3368. doi:10.19082/3363
5. Al-Maharik N, Salama Y, Al-Hajj N, et al. Chemical composition, anticancer, antimicrobial activity of Aloysia citriodora Palau essential oils from four different locations in Palestine. *BMC Complement Med Ther*. 2024;24(1). doi:10.1186/s12906-024-04390-9.
6. Barrientos Ramírez L, Silva Guzmán JA, Osorio Muñoz EA, et al. Chemical composition, antioxidant properties, and antibacterial activity of essential oils of Satureja macrostema (Moc. and Sessé ex Benth.) Briq. *Molecules*. 2023;28(12):4719. doi:10.3390/molecules28124719
7. Barbosa DHX, Gondim CR, Silva-Henriques MQ, et al. Coriandrum sativum L. essential oil obtained from organic culture shows antifungal activity against planktonic and multibiofilm Candida. *Brazilian J Biol*. 2023;83:e264875.
8. Machado CA, Oliveira FO, de Andrade MA, Hodel KVS, Lepikson H, Machado BAS. Steam distillation for essential oil extraction: an evaluation of technological advances based on an analysis of patent documents. *Sustainability*. 2022;14(12):7119. doi:10.3390/su14127119
9. Gomes DB, Serpa PZ, Miorando D, et al. Involvement of anti-inflammatory and stress oxidative markers in the antidepressant-like activity of Aloysia citriodora and verbascoside on mice with bacterial lipopolysaccharide- (LPS-) induced depression. *Evidence-Based Complementary Alternative Med*. 2022;2022:1–18. doi:10.1155/2022/1041656
10. Al Hafi M, El Beyrouthy M, Ouaini N, Stien D, Rutledge D, Chaillou S. Chemical composition and antimicrobial activity of Origanum libanoticum, Origanum ehrenbergii, and Origanum syriacum growing wild in Lebanon. *Chem Biodivers*. 2016;13(5):555–560. doi:10.1002/cbdv.201500178
11. Jaradat N, Hawash M, Abualhasan MN, et al. Spectral characterization, antioxidant, antimicrobial, cytotoxic, and cyclooxygenase inhibitory activities of Aloysia citriodora essential oils collected from two Palestinian regions. *BMC Complement Med Ther*. 2021;21(1). doi:10.1186/s12906-021-03314-1.
12. F MA-L, Ainane A, El Yaacoubi A. Antimicrobial activities of the essential oil and methanolic extract of Moroccan Coriandrum sativum Available from: https://www.researchgate.net/publication/357935743. Accessed June 14, 2025.
13. Mohamad R, Mussa R, Suslina SN. Prospects for using Origanum Syriacum (L.) as a source of antimicrobial agents. *J Adv Pharmaceut Technol Res*. 2021;12:340–344. doi:10.4103/japtr.japtr_106_21

14. Sharifi-Rad M, Varoni EM, Martorell M, et al. Carvacrol and human health: a comprehensive review. *Phytother Res*. 2018;32:1675–1687. doi:10.1002/ptr.6103
15. Hao Y, Li J, Shi L. A carvacrol-rich essential oil extracted from oregano (Origanum vulgare "Hot & Spicy") exerts potent antibacterial effects against Staphylococcus aureus. *Front Microbiol*. 2021;12. doi:10.3389/fmicb.2021.741861
16. Haryalchi K, Kazemi Aski S, Mansour Ghanaie M, et al. Effects of the aroma of lemone verbena (Aloysia citriodora Paláu) essential oil on anxiety and the hemodynamic profile before cesarean section: a randomized clinical trial. *Health Sci Rep*. 2023;6(5). doi:10.1002/hsr2.1282.
17. Al-Khayri JM, Banadka A, Nandhini M, Nagella P, Al-Mssallem MQ, Alessa FM. Essential oil from Coriandrum sativum: a review on its phytochemistry and biological activity. *Molecules*. 2023;28:696. doi:10.3390/molecules28020696
18. Hirondart M, Rombaut N, Fabiano-Tixier AS, Bily A, Chemat F. Comparison between pressurized liquid extraction and conventional Soxhlet extraction for rosemary antioxidants, yield, composition, and environmental footprint. *Foods*. 2020;9(5):584. doi:10.3390/foods9050584
19. Azuero A, Carmita J, Diana J, Martín HS. Análisis del efecto antimicrobiano de doce plantas medicinales de uso ancestral en Ecuador. *UNEMI*. 2016;9(20):11–18. doi:10.29076/issn.2528-7737vol9iss20.2016pp11-18p
20. Santillán-Espinosa R, Gómez M, López F. Coriandrum sativum y sus propiedades farmacológicas en la medicina tradicional ecuatoriana. *Revista Ecuatoriana de Ciencias Agrícolas y Naturales*. 2021;33:45–53.
21. Akdağ A, Ozturk E. Distillation methods of essential oils. 2019. Available from: https://www.researchgate.net/publication/332801584. Accessed June 14, 2025.
22. Uwineza PA, Waśkiewicz A. Recent advances in supercritical fluid extraction of natural bioactive compounds from natural plant materials. *Molecules*. 2020;25(17):3847. doi:10.3390/molecules25173847
23. Colina-Márquez JÁ, Contreras E, Ruiz J, Monroy L. Comparación de dos métodos de extracción para el aceite esencial de la cáscara de pomelo (Citrus maxima). *Revista Ing-Nova*. 2022;1(1):85–98. doi:10.32997/rin-2022-3729
24. Chi W, Mak W, Mak K. Title: comparisons between the hydro distillation and the steam distillation in the extraction of volatile compounds from and the anti-oxidative activity of Prunella vulgaris. Available from: https://www.researchgate.net/publication/361828344. Accessed June 14, 2025.
25. Peron G, Ferrarese I, Carmo Dos Santos N, et al. Sustainable extraction of bioactive compounds and nutrients from agri-food wastes: potential reutilization of berry, honey, and chicory byproducts. *Appl Sci*. 2024;14(23):10785. doi:10.3390/app142310785
26. Koon F, Sorensen E, Gavriilidis A. Lam 1 ES 1, AG 1. Review on gas–liquid separations in microchannel devices. *Chem Eng Res Design*. 2013;91 (10):1941–1953. doi:10.1016/j.cherd.2013.07.031
27. Chemat F, Abert Vian M, Fabiano-Tixier AS, et al. A review of sustainable and intensified techniques for extraction of food and natural products. *Green Chem Royal Soc Chem*. 2020;22:2325–2353. doi:10.1039/C9GC03878G
28. Cedeño A, Moreira C, Muñoz J, Muñoz A, Pillasaguay S, Riera MA. Comparación De Métodos De Destilación Para La Obtención De Aceite Esencial De Eucalipto. *Revista Colón Ciencias Tecnología y Negocios*. 2019;6(1):1–13.
29. Cuenca-León K, Pacheco-Quito EM, Granda-Granda Y, Vélez-León E, Zarzuelo-Castañeda A. Phytotherapy: a solution to decrease antifungal resistance in the dental field. *Biomolecules*; 2022;12:789.
30. Cardona LFV, Díaz JCQ. Extracción y caracterización de aceite esencial de orégano, especie Plectranthus amboinicus, a partir de cultivos orgánicos del Magdalena Medio en Colombia / Extração e caracterização do óleo essencial de orégano, espécie Plectranthus amboinicus, de cultivos orgânicos de Magdalena Medio na Colômbia. *Braz J Animal Environ Res*. 2022;5(1):550–563.
31. Freire JCP, Júnior JKDO, Silva DDF, De SJP, Guerra FQS, De Oliveira Lima E. Antifungal activity of essential oils against candida albicans strains isolated from users of dental prostheses. *Evidence-Based Complementary AlternMed*. 2017;2017. doi:10.1155/2017/7158756
32. Wińska K, Mączka W, Łyczko J, Grabarczyk M, Czubaszek A, Szumny A. Essential oils as antimicrobial agents—myth or real alternative? *Molecules*. 2019;24(11):2130. doi:10.3390/molecules24112130