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Exploring the antioxidant properties of rosmarinus officinalis essential oil and its traditional applications: scope review

Explorando as propriedades antioxidantes do óleo essencial de Rosmarinus officinalis e suas aplicações tradicionais: revisão de escopo

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Abstract

The ethnopharmacology of rosemary and the historical recognition of its medicinal properties have proven to be crucial for scientifically validating its traditional use and exploring its therapeutic potential in public health for various diseases. In the current context of seeking new natural and alternative therapies, it is crucial to explore the medicinal properties of plants like rosemary, which has been used for centuries for therapeutic purposes. This study aimed to conduct an analysis of the antioxidant activity of Rosmarinus officinalis essential oil. To achieve this goal, we followed the protocol established by the Joanna Briggs Institute Reviewer's Manual, ensuring the methodological quality of the research and protocol transparency by registering the study on the Open Science Framework (OSF). The research findings revealed 31 studies with antioxidant activity in essential oils, highlighting Morocco and Tunisia as regions with the most studies on rosemary and antioxidant activity, with the compounds 1,8-cineole and alpha-pinene being the main responsible for this activity. These findings not only corroborate the ethnofarmacological tradition associated with rosemary but also provide valuable information for future investigations into its therapeutic potential. The need to explore the medicinal properties of rosemary in a contemporary context is emphasized by the growing demand for natural and alternative therapies, as well as the importance of scientifically validating traditional knowledge about the use of medicinal plants. Furthermore, gaining a better understanding of the therapeutic properties of rosemary and its active compounds can significantly contribute to public health in the pursuit of new therapies.

Keywords: Antioxidants; ethnopharmacology; Plants; Rosmarinus officinalis L; Therapeutics.

Resumo

A etnofarmacologia do alecrim e o reconhecimento histórico de suas propriedades medicinais são fundamentais para validar cientificamente sua utilização tradicional e explorar seu potencial terapêutico na saúde pública para diversas doenças. Em um contexto de busca por novas terapias naturais e alternativas, é crucial explorar as propriedades medicinais de plantas como o alecrim, utilizado há séculos com propósitos terapêuticos. Este estudo teve como objetivo analisar a atividade antioxidante do óleo essencial de Rosmarinus officinalis. Para alcançá-lo, seguimos o protocolo estabelecido pelo Manual do Revisor do Instituto Joanna Briggs, garantindo a qualidade metodológica da pesquisa e o registro no Open Science Framework (OSF). Os resultados revelaram 31 estudos com atividade antioxidante em óleos essenciais, destacando Marrocos e Tunísia como regiões com maior estudo do alecrim e atividade antioxidante, sendo o 1,8-cineol e o alfa-pineno os principais responsáveis por essa atividade. Esses achados corroboram a tradição etnofarmacológica associada ao alecrim e fornecem informações valiosas para futuras investigações sobre seu potencial terapêutico. A necessidade de explorar as propriedades medicinais do alecrim em um contexto contemporâneo é enfatizada pela crescente demanda por terapias naturais e alternativas, bem como pela importância de validar cientificamente o conhecimento tradicional sobre o uso de plantas medicinais. Além disso, compreender melhor as propriedades terapêuticas do alecrim e de seus compostos ativos pode contribuir significativamente para a saúde pública na busca por novas terapias.

Palavras-chave: *Antioxidantes; etnofarmacologia; Plantas; Rosmarinus officinalis L; Terapêutica.*

1 Introduction

Essential oils derived from plants are crucial in the quest for innovative therapeutic agents (Firenzuoli et al., 2014). These oils contain abundant terpenes and non-terpenoid compounds, renowned for their antibacterial, antifungal, antiviral, and notably, antioxidant characteristics (Zulhendri et al., 2021.). Among these, the essential oil extracted from Rosmarinus officinalis L., commonly known as rosemary and originating from the Mediterranean area, stands out due to its exceptional bioactive properties (Borges et al., 2019). Traditionally esteemed for its antibacterial, neuroprotective, antioxidant, and potentially anticancer effects (Rafie et al., 2017), rosemary serves as a prominent illustration of the myriad benefits offered by nature-derived products (Aziz et al., 2022).

The interest in rosemary's antioxidant properties is considerable, especially concerning its ability to inhibit angiogenesis, modulate immune responses, and reduce inflammation (Degner; Papoutsis; Romagnolo, 2009). This essential oil, predominantly containing monoterpenes like camphene, 1,8-cineole, α-pinene, myrcene, limonene, and camphor (Becer et al., 2023), exhibits a composition that varies based on environmental conditions and extraction techniques. The exploration of its anti-tumor effectiveness has reinforced the link between its antioxidant attributes and potential therapeutic uses (Becer et al., 2023).

The importance of essential oils in ethnopharmacology is notable, underscored by their traditional utilization across diverse cultures (Pirintsos et al., 2022). Human societies, over generations, have leveraged the medicinal benefits of oils such as rosemary, derived from aromatic and medicinal plants (González-Minero; Bravo-Díaz; Ayala-Gómez, 2020). This traditional knowledge, often transmitted orally, is deeply rooted in local cultural practices and has been progressively validated by modern scientific research (Michael et al., 2009). By identifying active compounds and elucidating mechanisms of action, modern science offers new insights into these ancient practices (Yuan et al., 2016).

Scientific research on the benefits of rosemary essential oil has gained prominence due to its antioxidant properties and its relevance in traditional medicine. These studies address both the therapeutic properties of the oil and its use in various cultures throughout history. Understanding these aspects is crucial to explore the full therapeutic potential of rosemary and its application in contemporary health. Therefore, a focused review on this topic is essential to synthesize existing knowledge and identify areas that require further investigation, aiming to maximize the benefits of this oil in integrative medicine. The focused review specifically centers on the essential oil of Rosmarinus officinalis L, a subject that is attracting increasing scientific attention due to its remarkable antioxidant attributes and its importance in the traditional medicine of various societies. Throughout this examination, we delve into a spectrum of scientific studies focused on the antioxidant properties of rosemary oil, encompassing both laboratory experiments and clinical trials. Concurrently, the review addresses ethnopharmacological research, seeking to synthesize existing knowledge on the applications and benefits of Rosmarinus officinalis essential oil, while also identifying pathways that require further exploration. Our goal is to underscore the therapeutic potential of rosemary, emphasizing the relevance of its traditional practices in the context of contemporary health and integrative medicine.

2 Materials and methods

The research entitled rigorously followed the protocol established by the Joanna Briggs Institute Reviewer's Manual (Aromataris et al, 2024). This process included the steps: (1) Search Strategy, (2) Inclusion Criteria, (3) Exclusion Criteria, (4) Study Selection, (5) Data Extraction, and (6) Synthesis of Results. To ensure the quality and reliability of this study, we used the checklist known as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018) as an essential guide throughout the review process and writing of the article. This checklist is widely recognized for its ability to ensure methodological integrity in systematic reviews and scoping reviews. Additionally, it is important to highlight that this study was duly registered in the Open Science Framework (OSF) to promote transparency and enable public access to the data, methods, and results obtained throughout the research. The registration can be accessed through the link https://osf.io/dqjf5/, reinforcing our commitment to open disclosure and the dissemination of scientific knowledge.

3 Theoretical reference

3.1 Botanical description

Rosmarinus officinalis L., commonly known as rosemary, belongs to the Lamiaceae family, formerly referred to as Labiatae (Ribeiro-Santos et al., 2015). officinalis is a plant native to the Mediterranean region and is extensively studied due to its highly valued essential oil (EOs), phenolic content, and outstanding antioxidant properties (Zaouali; Bouzaine; Boussaid, 2010). This plant can grow up to 2 meters tall. Its bark is dark gray with irregular fissures and a flaky texture. Young branches are densely covered with white, star-shaped tomentum. Rosmarinus officinalis leaves are arranged along the branches, varying from sessile to slightly petiolate. The leaf blade measures 1-2.5 cm × 1-2 mm and has a leathery texture. The upper surface of the leaves is somewhat glossy and nearly hairless, while the underside is densely white and star-tomentose. The leaves have a tapering base, a smooth rolled margin, and a blunt apex (Rosmarinus, 2023).

This shrub, reaching heights of up to 1 meter, has leaves measuring 10-20 x 1-2 mm, dark green in color, grouped together and aromatic. The upper side of the leaves is smooth, while the underside has a star-shaped-canescent texture. The shrub's inflorescence is briefly pedunculated, bearing about 10-15 flowers in axillary clusters, accompanied by small bracts. The calyx is approximately 4 mm long, finely tomentose, star-shaped, and dotted with glands. The corolla is light blue, measuring around 10 mm. The nuts are approximately 2.5 x 1.5 mm and become mucilaginous when wet (Rosmarinus,2023). The Lamiaceae family, as described by (Andrade et al., 2018) , is one of the largest and most distinctive flowering plant families, comprising approximately 236 genera and 6,900 to 7,200 species worldwide. Lamiaceae is renowned for its biologically active essential oils, a trait shared by many of its members. Furthermore, the family includes various ornamental and culinary herbs, such as basil, lavender, mint, rosemary, sage, and thyme, renowned for their diverse applications and aromatic characteristics. There are over 20 documented variations of Rosmarinus officinalis that can be distinguished based on specific morphological characteristics, such as the calyx, the corolla, leaf dimensions, the arrangement of the inflorescence, and the presence of glandular trichomes (Ribeiro-Santos et al., 2015).

Rosemary essential oil ranges in color from colorless to pale yellow, is insoluble in water, and is characterized by its distinctive camphor scent (Atti-Santos et al., 2005). The primary components of rosemary essential oil include camphor, accounting for 5.0–21% of its composition, 1,8-cineol present in 15–55%, α-pinene representing 9.0–26%, and Borneol comprising 1.5–5.0%. Additionally, it contains camphene (2.5–12%), β-pinene (2.0–9.0%), and limonene (1.5–5.0%). The proportions of these constituents in rosemary essential oil vary depending on the plant's growth stage and environmental conditions (Andrade et al., 2018).

3.2 Mechanism of antioxidant action

Since the 1990s, there has been a substantial expansion in antioxidant research, driven by the perceived health benefits and potential for disease prevention associated with antioxidants. The antioxidant properties of individual compounds, as well as those found in foods and dietary supplements, have been extensively investigated across a range of biological systems, including cell cultures, animal models, and clinical trials (Lü et al., 2010).

Antioxidant substances possess the ability to counteract free radicals by either accepting or donating electrons. This action helps restore the balance of radicals (Vona et al., 2021). These antioxidant molecules directly interact with active radicals to neutralize them, potentially forming new, less reactive free radicals that are more stable and less harmful than their predecessors (Pham-Huy; He; Pham-Huy, 2008). These newly formed radicals can then be neutralized by other antioxidants or processes, effectively ending their reactive state (Nimse; Pal, 2015) .

Various antioxidants, including those containing aromatic ring structures, have the ability to redistribute electrons in both aqueous and lipid environments. Vitamins C (AscH−) and E (TOH) can directly react with or neutralize radicals such as hydroxyl, alkoxyl, and lipid peroxyl (ROO•), resulting in the formation of water, alcohol, and lipid hydroperoxides. Vitamin E can convert into a less reactive phenolic radical, while vitamin C can form a highly stable radical (Asc−•) due to its rearranged structure (Figures 1 A and B). Additionally, vitamin C can counteract the radical form of other antioxidants, such as the glutathione radical and the vitamin E radical, restoring the functionality of these antioxidants (Figure 1 C). Vitamin C can be easily regenerated from Asc−• using NADH (Nicotinamide Adenine Dinucleotide) or NADPH-dependent reductases. Many antioxidants have the ability to directly interact with reactive oxygen species (ROS) and/or ROS-induced free radical intermediates, thus breaking the chain reaction and mitigating the subsequent damage caused by ROS (Defeudis; Papadopoulos; Drieu, 2003; Hossain; Asada, 1985; Lü et al., 2010).

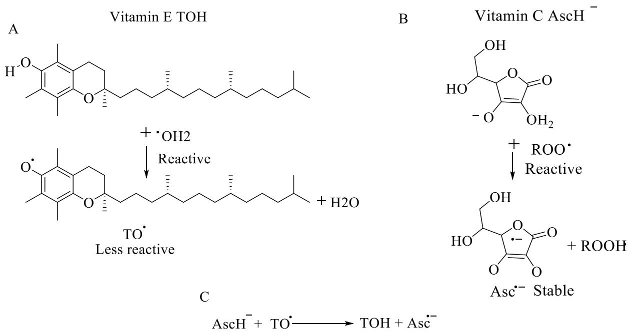


Figure 1 – Antioxidant activity of vitamin E and vitamin C.
Source: Prepared by the author (2024).

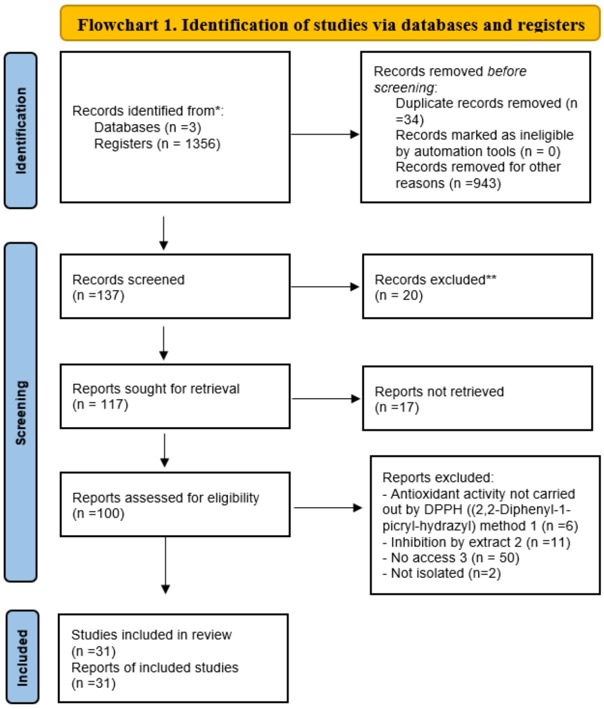
Direct interactions occur between vitamin E (TOH) and the hydroxyl radical (▪OH) as demonstrated in (A), and between vitamin C (AscH−) and the peroxyl radical (ROO▪) as illustrated in (B). Additionally, the process of vitamin E regeneration through vitamin C is represented in (C).

These antioxidant compounds have the ability to directly interact with reactive radicals to render them inert. During this process, they may undergo a transformation into new radicals that are typically less reactive, possess a longer lifespan, and present fewer risks compared to the radicals they neutralized initially. These newly formed radicals can be neutralized by additional antioxidants or alternative mechanisms, effectively terminating their radical nature. For instance, many antioxidants feature aromatic ring structures that facilitate the dispersion of the unpaired electron (Hossain; Asada, 1985). Alpha-tocopherol, in particular, excels at intercepting peroxyl radicals, thereby halting the propagation of lipid oxidation. Upon neutralizing a free radical, an alpha-tocopherol molecule undergoes oxidation, leading to a reduction in its antioxidant capacity. However, other antioxidants, such as vitamin C, possess the capability to restore the antioxidant capacity of alpha-tocopherol (Khadim; Al-Fartusie, 2021).

4 Results And Discussion

4.1 Rosmarinus officinalis (Rosemary)

The research results, as presented in Flowchart 1, highlight the significance of studies on *Rosmarinus officinalis*. The investigation revealed a total of 1356 items, distributed as follows: 142 in PubMed, 796 in Web of Science, and 418 in Scopus.



Flowchart 1. Identification of studies via databases and registers

Source: Prepared by the author (2024).

4.2 Ethnopharmacological use

In addition to other ethnopharmacological uses such as enhancing memory and concentration (Ghasemzadeh Rahbardar; Hosseinzadeh, 2020), relieving muscular and joint pains (Borges et al., 2019; Wei; Liu; Li, 2021), treating digestive issues (Gonçalves et al., 2019), migraines (Yuan et al., 2021), addressing respiratory problems (asthma) (Rosa et al., 2013), improving blood circulation (Yarosh et al., 2023), combating fatigue(Lindheimer; LOY; O'Connor, 2013), and possessing anti-inflammatory properties (Rocha et al., 2015). Rosemary has a multitude of other beneficial applications. These include stimulating hair growth (Rutuja P. Khairnar, 2023), relieving arthritis symptoms (Gonçalves et al., 2018), exhibiting antimicrobial properties (Becer et al., 2023), treating skin issues (Li Pomi et al., 2023), aiding digestion (Karataş et al., 2020), reducing anxiety and depression (Alvarado-García et al., 2023), possessing antispasmodic properties (Wei et al., 2022), inducing relaxation (Aqel, 1991), acting as a diuretic (Haloui et al., 2000), addressing dental problems (Valones et al., 2019), exhibiting antifungal properties (Sharma; Kaur; Chauhan, 2023), stimulating the immune system (YOUSEF et al., 2020), and displaying analgesic and anti-inflammatory activities (Lucarini et al., 2013). Additionally, rosemary has shown anti-arthritic activity (Wei; Liu; Li, 2021), wound healing properties (Abu-Al-Basal, 2010), effectiveness in treating acne (Barbosa et al., 2014), relieving menstrual cramps (Tahoonian-Golkhatmy et al., 2019), treating wounds and burns (Hamza et al., 2020), reducing allergy symptoms (Yousef et al., 2020), stimulating liver function (Rašković et al., 2014), possessing anti-adipogenic properties (Gaya et al., 2013), Treatment of insect bites (LI et al., 2021), acting against worms (Aouadi et al., 2021), Antiviral properties (Al-Megrin et al., 2020), displaying antimutagenic effects (Felicidade et al., 2014), affecting acetylcholinesterase and butyrylcholinesterase (Ozarowski et al., 2013), providing therapeutic effects on insomnia through serotoninergic synapses (Li et al., 2024), offering photoprotective and anti-aging effects (Nobile et al., 2016), impacting postoperative peritoneal adhesion (Roohbakhsh et al., 2020), and addressing kidney stones and high blood sugar levels (Lev, 2006). Moreover, rosemary demonstrates remarkable antioxidant potential (Bouammali et al., 2024).

Traditionally, rosemary has been integral to both mental and physical healing practices, boasting a myriad of uses ranging from enhancing memory and cognitive function to alleviating muscle pains and promoting digestion (Ghasemzadeh Rahbardar; Hosseinzadeh, 2020). These longstanding traditional applications serve as a rich foundation for exploring novel pharmaceuticals and therapies, suggesting that compounds present in rosemary may harbor pharmacological effects that are yet to be fully comprehended or harnessed by modern medicine.

4.3 *Rosmarinus Officinalis* Antioxidant

In the quest to understand the antioxidant potential of essential oils, extensive research has been conducted worldwide. The following Table 1 summarizes important data from various studies, showcasing the isolated compounds from essential oils extracted from plant parts in different countries. Notably, it highlights the IC50 values, a metric for antioxidant efficacy, against the DPPH assay (2,2-diphenyl-1-picrylhydrazyl) – a widely used method to evaluate free radical scavenging activities. The table also compares these values with standard controls, such as gallic acid, Trolox, vitamin C, and BHT (butylated hydroxytoluene), providing a comprehensive overview of the antioxidant capabilities of the oils.

The DPPH (1,1-diphenyl-2-picrylhydrazyl) assay stands as a universally recognized approach for evaluating the capacity of compounds to scavenge free radicals, a pivotal facet of antioxidant functionality (Oliveira, 2015). This assay quantifies the reduction in the characteristic deep purple hue of DPPH (Oliveira, 2015). This assay quantifies the reduction in the characteristic deep purple hue of DPPH following its interaction with an antioxidant. The IC50 values (Inhibitory Concentration, 50%) delineated in the table denote the concentration of essential oil requisite to diminish the initial concentration of DPPH by 50%. Diminished IC50 values signify heightened antioxidant potency (Flieger, 2020).

When assessing the antioxidant potential of compounds, the IC50 measurement is commonly articulated in two formats: as a percentage (Kakde, 2022) and in micrograms per milliliter (μg/mL) (Nordin et al., 2018). The primary distinction between these units lies in their method of quantification. The IC50 in percentage (%) denotes the concentration of the compound necessary to reduce the activity of a substance (such as free radicals in the DPPH assay) by 50%, expressed as a percentage of the initial concentration. This approach facilitates comprehension of the compound's comparative efficacy in relative terms. Conversely, the IC50 expressed in μg/mL furnishes an absolute gauge of the compound's concentration requisite to achieve the same 50% reduction (Martinez-Morales et al., 2020).

This measurement holds particular significance for practical applications and formulations, as it delineates the precise quantity of the compound necessary to elicit a notable effect in a given solution (De Menezes et al., 2021). While both metrics are pivotal, the percentage offers a relative assessment of potency, whereas μg/mL provides an absolute viewpoint essential for practical implementations and direct comparisons among different substances (Sharma; Bhat, 2009).

Rosemary's antioxidative efficacy garners considerable interest across various sectors, spanning from pharmaceutical (Rašković et al., 2014) to cosmetic industries (Sakar et al., 2023) due to its ability to counteract oxidative stress and mitigate damage induced by free radicals (Poprac et al., 2017).Studies consistently illustrate that rosemary's antioxidative potential is not only robust (Li Pomi et al., 2023), but also subject to variation based on several factors, including growth conditions, plant part utilized, and oil extraction method (Lozano-Grande et al., 2018). Such variability underscores the significance of specific environmental and processing parameters in optimizing rosemary's therapeutic efficacy (Boix et al., 2020).

In practical applications, rosemary extracts and oils serve to prolong the shelf life of food products by shielding them from oxidation (Moufakkir et al., 2022).

Table 1 – Antioxidant Activity.

Isolated Compounds and Their Proportion Variations in Essential Oils	Country of Collection	Used Parts	IC50 Inhibition Values of Antioxidant Essential Oil Samples (DPPH)	Control	Author
Camphor (15.1%), verbenone (14.3%), α-pinene (13.6%), 1,8-cineole (11.8%), and borneol (7.9%)	Turquia	Leaves	36,19 ± 3,19% 50,53 ± 1,00% 54,48 ± 1,80% 55,35 ± 0,79% 57,27 ± 2,24%	Gallic acid	(BECER et al., 2023)
1.8-cineol (18.74%), camphor (17.25%), Isoborneol (15.05%), and α-pinene (14.44%)	Turquia	-	15.02 ±0.28 µg/ml 38.43 ±2.10%	-	(Gokbulut; Karaman; Tursun, 2022)
eucalyptol (37.97%), followed by camphor (11.84%). Whereas β-copaene (16.22%), limonene (14.56%), eucalyptol (14.49%) and camphor (13.74%)	Argélia	-	0,43 µg/ml	Trolox	(Amina et al., 2022)
camphor (18.2–28.1%), 1,8-cineole (6.4–18.0%), α-pinene (9.7–13.5%), borneol (4.4–9.5%), and camphene (5.1–8.7%)	Tunísia	Leaves	2,94 a 5,32 µg/mL 1,59 e 5,62 µg/mL.	-	(Arfa et al., 2022)
1,8-cineole (4.81–37.83%), α-pinene (13.07–51.36%), and camphor (11.95–24.30%)	Palestina	Leaves	10,23 ± 0,11 µg/mL 37,15 ± 2,3 µg/mL 38,9 ± 0,45 µg/mL	Trolox	(Al-Maharik et al., 2022)
1,8-Cineol (41,75%), Cânfora (17,66%) e α-Pineno (13,64%)	Egito	Leaves	3,1022 µL/mL	vitamin C	(El-Demerdash; El-Sayed; Abdel-Daim, 2021)
1,8-Cineole (148 mg/mL), camphor (40.0 mg/mL), α-pinene (28.0 mg/mL), α-terpineol (10.6 mg/mL), camphene (8.14 mg/mL), and borneol (8.4 g/mL).	Marrocos	Leaves	6,88 ± 0,00 µg/mL	butylated hydroxytoluene (BHT)	(El Kharraf et al., 2021)
o α-pineno (51,2%; 74,7%) e o 1,8-cineol (20,1%; 10,0%)	Itália	Flowers	13,48 ± 1,58 µg/mL	Trolox	(Garzoli et al., 2021)
1.8-cineol (37.71-65.02 %), camphor (6.09-27.49 %), α-pinene (3.08-9.98 %) and β-pinene (2.83-11.7 %)	Marrocos	Leaves	29,02 ± 1,04 µg/mL	ascorbic acid	(Sabbahi et al., 2019)
1,8-cineole (18.3%), camphene (15.4%) and α-pinene (12.8%).	Argélia	Leaves	24.5±2.1 µg/mL	Ascorbic acid	(Benyoucef et al., 2018)
α-pinene (15.96 ± 0.25), Camphene (6.06 ± 0.17), Limonene (9.63 ± 0.67), 1,8-Cineole (7.92 ± 0.38), Borneol (11.56 ± 0.20), Verbenone (10.88 ± 0.11), Bornyl acetate (15.01 ± 0.39).	Irã	aerial parts	3,40 ± 0,28 mg/mL	ascorbic acid	(Benyoucef et al., 2018)
1,8-Cineole (35.32), Trans-caryophyllene (14.47), Borneol (9.37), Camphor (8.97), α-pinene (7.90) and α-thujone (6.42)	Tunísia	aerial parts	221.43 ± 4.27 µg/mL	butylated hydroxytoluene (BHT)	(Selmi et al., 2017)
camphor (21.51%), β-caryophyllene (10.22%), and eucalyptol (12.59%)	Mexico	Leaves	37,55 ± 0,86 mg	Trolox	(Conde-Hernández et al., 2017)
α-pinene (43.12 %), camphene (10.5 %), 1,8-cineole (10.02 %), camphor (8.07 %), linalool (8.09 %) and limonene (6.12 %).	Irã	aerial parts	11.01±0.41 µg/ ml	-	(Ladan Moghadam, 2015)
α-pinene (22.25%), 1, 8-cineole (18.20%) and camphor (12.35%)	Índia	-	0.042 µl/ml 71.05%	ascorbic acid	(Prakash et al., 2015)
1,8-cineole (43.77%), camphor (12.53%), and α-pinene (11.51%)	Servia	aerial parts	77,6 µl/ml	vitamin E	(Rašković et al., 2014)
α-pinene (31.2%), myrcene (31.1%), 1,8-cineole (18.7%–21.6%), borneol (0.4%–15.4%) and camphor (7.0%–15.4%)	Argentina	Leaves	4,5 µL/mL 18±0,5 µL/mL	-	(Ojeda-Sana et al., 2013)
1.8-Cineole (47.2–27.5%) and Camphor (12.9–27.9%)	Tunísia	Leaves	7 ± 0,5µL/mL	butylated hydroxytoluene (BHT).	(Zaouali; Bouzaine; Boussaid, 2010)
1,8-cineol (38.5%), camphor (17.1%), α-pinene (12.3%), limonene (6.23%), camphene (6.00%) and linalool (5.70%)	Paquistão	Leaves	20.9 µg mL	-	(Hussain et al., 2010)

α-pinene (14.07–42.03%), camphene (2.26–8.19%), β-pinene (0.35–3.76%), α-terpinene (0.55–2.92%), p-cymene (1.22–4.18%), limonene (0.64–2.79%), 1,8-cineole (31.73–40.72%), β-myrcene (2.09–3.2%), linalool (0.22–1.94%), camphor (12.12–19.66%), borneol (0.53–1.67%), and α-terpineol (1.46–7.45%)	Marrocos	aerial parts	2.61–8.58 mg/mL	ascorbic acid	(Sakar et al., 2023)
1,8-cineole (4.81–37.83%), α-pinene (13.07–51.36%), and camphor (11.95–24.30%)	Alemanha	Leaves	10,23 ± 0,11 µg/mL	Trolox	(Al-Maharik et al., 2022)
1,8 cineole (27.6%), α-pinene (26.6%), verbenone (5.3%), camphene (4.5%) and camphor (4.3%),	Marrocos	aerial parts	337,23 ± 3,50 µg/ml	Gallic acid	(Ouknin et al., 2021)
eucalyptol (48.72%), camphor (11.72%), α-pinene (9.86%), β-pinene (8.35%) and camphene (4.34%).	Grécia	-	27%	Trolox	(Risaliti et al., 2019)
1,8-cineole (42.86-46.76%), camphor (16.26-23.42%), α-pinene (6.37-9.19%), camphene (2.27-4.37%), borneol (4.00-4.33%), linalol (2.62-3.56%), α-terpine (2.78-3.41%), decane (2.24-3.12%), limonene (2.23-2.44%) and ρ-cymene (1.69-1.72%).	Iran China	-	47,06±0,78% 42,01±1,17% 41,64±0,99%	Butylated hydroxytoluene (BHT). ascorbic acid	(Wang et al., 2018)
α-pinene (14.076%),1,8-Cineole (23.673%,) Camphor (18.743%), Borneol (15.46%)	Marrocos	aerial parts	523,41 ± 8,25 µg/mL	Ascorbic acid Trolox	(Bouyahya et al., 2017)
1,8-Cineole (43.77%), camphor (12.53%), α-pinene (11.51%), β-pinene (8.16%), camphene (4.55%), and β-caryophyllene (3.93%)	Servia	aerial parts	77,6 µL/ml	α-tocopherol	(Rašković et al., 2014)
borneol, linalool, 1,8 cineole, terpinen-4-ol, carvacrol and thymol	Itália	flowering seeds and leaves	36,78 ± 0,38, 79,69 ± 1,54 111,94 ± 2,56 µL/ml	Trolox	(Beretta et al., 2011)
1,8-cineol (38.5%), camphor (17.1%), α-pinene (12.3%), limonene (6.23%), camphene (6.00%), and linalool (5.70%),	Paquistão	Leaves	20,9 µg mL	Butylated hydroxytoluene (BHT)	(Hussain et al., 2010)
α-pinene (44.2%), camphene (24.5%), and limonene (11.7%), 1,8-cineole (37.6%), camphor (16.5%), and bornyl acetate (21.4%)	Itália	-	55.3 + 6.5 61.1 + 5.7	Trolox	(Pintore et al., 2009)
1,8-cineole (27.23%), α-pinene (19.43%), camphor (14.26%), camphene (11.52%) and β-pinene (6.71%).	China	commercial sources	62.45% ± 3.42%, 42.7% ± 2.5%, 45.61% ± 4.23% 46.21% ± 2.24%	ascorbic acid	(Wang et al., 2008)
,8-Cineole (35.32), Trans-caryophyllene (14.47), Borneol (9.37), Camphor (8.97), α-pinene (7.90) and α-thujone (6.42)	Tunisa	aerial part	221.43 ± 4.27 µg/mL	butylated hydroxytoluene (BHT)	(Selmi et al., 2017)

Source: Prepared by the author (2024).

A study conducted by (Peiretti et al., 2012) demonstrated that combining rosemary extract with nisin treatment effectively halted lipid oxidation, protein degradation, nucleotide breakdown, and microbial growth. Health supplements and cosmetic formulations value these extracts for their ability to safeguard cells against oxidative damage associated with aging and various chronic ailments (Michalak, 2022).

In an evaluation of the protective effects against UVB-induced damage in a skin cell model, (Sánchez-Marzo et al., 2020) compared two formulations. One formulation (F2) included a mixture of citrus and olive extracts, while the other (F1) additionally incorporated a rosemary extract, indicating that F1's superior ability to protect against UVB-induced DNA damage in human keratinocytes is attributed to the presence of rosemary diterpenes and citrus flavanone aglycones. The significant correlation between rosemary's antioxidative prowess and its health advantages has generated considerable interest in the realm of complementary and alternative medicine (Jiang, 2019). Numerous studies have delved into how the antioxidative components of rosemary could prove effective in managing and preventing diseases linked to oxidative stress (Rubió; Motilva; Romero, 2013).

Oxidative stress denotes a biological condition characterized by an imbalance between reactive oxygen species (ROS) production and the body's antioxidant capacity to counteract them. This imbalance results in the oxidation and impairment of crucial cellular constituents such as lipids, proteins, and DNA. While ROS, including free radicals like superoxide and hydrogen peroxide, are natural byproducts of cellular metabolism, their excessive accumulation can instigate pathological processes, contributing to the onset of chronic ailments, aging, and neurodegenerative disorders. The body boasts antioxidant defense mechanisms, encompassing enzymes like superoxide dismutase and catalase, to confront oxidative stress (Sies, 2020; Storz; Imlayt, 1999).

This stress, often linked to aging and various chronic conditions such as cardiovascular and neurodegenerative ailments, can be alleviated by the antioxidant properties of rosemary (Alvi et al., 2019). In Alzheimer's disease, oxidative stress is reported to play a pivotal role in its pathophysiology (Cassidy et al., 2020) oxidative stress plays a crucial role in the pathophysiology of Alzheimer's disease (AD). It contributes to neuronal mitochondrial dysfunction, resulting in cellular damage. Additionally, the oxidation of macromolecules, coupled with the generation of reactive oxygen species (ROS) through the interaction of metal ions with beta-amyloid plaques (Aβ), exacerbates the condition. This process is also associated with the upregulation of phosphorylated tau proteins (p-tau) and Aβ synthesis, which are pathological hallmarks of Alzheimer's disease, further exacerbating neuronal injury and disease progression.

Oliveira, Faria and Amorim, (2021), in their study on the anti-Alzheimer's activity of rosemary, reported promising results, demonstrating a DPPH reduction capacity of 87.21% ± 0.25 in 30 minutes. These findings suggest that rosemary essential oil may be effective in treating Alzheimer's disease by inhibiting oxidative stress. In cardiovascular disease, according to Dubois-Deruy et al., (2020) the rise in reactive oxygen species leads to a decrease in nitric oxide availability, resulting in vasoconstriction and contributing to hypertension development. Furthermore, ROS negatively impact myocardial calcium handling, leading to arrhythmias, and promote cardiac remodeling by triggering hypertrophic signaling and apoptosis. These processes underscore the critical role of oxidative stress in cardiovascular diseases.

In a study by Cuevas-Durán et al., (2017), treatments involving *Crataegus laevigata* (Poir.) DC and *Rosmarinus officinalis* L were found to enhance the total antioxidant capacity and increase the expression of Cu2+/Zn2+ superoxide dismutase (SOD), Mn2+ SOD, and catalase. This led to a reduction in malondialdehyde levels and 8-hydroxy-2′-deoxyguanosine, the extracts also lowered vasoconstrictor peptide levels (angiotensin II and endothelin-1) while elevating vasodilator agents (angiotensin 1-7 and bradykinin) and improving nitric oxide metabolism. Polyphenol treatment restored left intraventricular pressure and cardiac mechanical work. It is concluded that treatment with Ro and Co mitigates morphological and functional ischemia-related changes, both by reducing oxidative stress and by rebalancing vasoconstrictors and vasodilators.

The antioxidant compounds of *Rosmarinus officinalis* have demonstrated promising effects in reducing inflammation, a pivotal factor in numerous chronic conditions (Gonçalves et al., 2022). These findings pave the way for novel therapeutic applications of rosemary in anti-inflammatory treatments.

Nam et al., (2014) investigated the effects of α-pinene (α-PN) in an ovalbumin-sensitized allergic rhinitis (RA) model. Pretreatment with α-PN in ovalbumin-sensitized mice resulted in a significant reduction in clinical symptoms, including decreased nasal rubbing and spleen weight. Additionally, α-PN effectively decreased interleukin (IL)-4 levels and notably reduced TNF-α (Tumor Necrosis Factor), ICAM-1 (Intercellular Adhesion Molecule 1), and MIP-2 (Macrophage Inflammatory Protein-2, also known as CXCL2) in nasal mucosa. It also reduced the number of eosinophils and mast cells in nasal mucosa tissue and markedly decreased IgE levels. Furthermore, α-PN was found to inhibit the activation of Receptor-interacting serine/threonine-protein kinase 2, inhibitor of nuclear factor kappa-B kinase subunit beta, nuclear factor kappa B, and caspase-1 in the activated human mast cell line HMC-1. Additionally, α-pinene exhibits antioxidant activity (Lin; Lee; Chang, 2016; Mekonnen et al., 2016). Continuing research on the antioxidant properties of rosemary and its practical applications reveals even greater potential for this plant (Gad; Sayd, 2015) As more studies are conducted, further benefits and uses of rosemary are anticipated to be uncovered, confirming its role as a valuable natural source of antioxidants in medicine, food, and cosmetics (Aziz et al., 2022).

4.4 Essential oil and antioxidant activity

Essential oils consist of intricate blends of volatile organic compounds that enhance both the fragrance and medicinal characteristics of plants (Wilson, 2003). Table 2 presents a thorough depiction of the various isolated compounds detected in essential oil specimens from the referenced studies.

Table 2 – Antioxidant Activity.

Essential oil	Proportion range (%)
Camphor	4.3 - 28.1
Verbenone	5.3 - 14.3
α-Pinene	7.90 - 51.36
1,8-Cineole	4.81 - 65.02
Borneol	0.4 - 11.56
Isoborneol	15.05
Limonene	6.12 - 14.56
β-Copaene	16.22
Camphene	2.26 - 15.4
β-Pinene	0.35 - 11.7
Trans-caryophyllene	14.47
α-Thujone	6.42
Linalool	2.62 - 8.09
β-Myrcene	2.09 - 31.1
α-Terpineol	1.46 - 10.6
Bornyl acetate	15.01
p-Cymene	1.22 - 4.18
Decane	2.24 - 3.12

Source: Prepared by the author (2024).

The spectrum of proportions for each compound reflects its prevalence across different samples, offering valuable insights into the inherent chemical diversity present in essential oil compositions.

The essential oils listed in Table 2 are all represented in Figure 2. It is possible to observe that in Table 2 1.8-cineol, known for its eucalyptus aroma, dominates at 65.02%, making it the most abundant compound in the plant. α-pinene, known for its distinctive pine fragrance, reaches a notable peak proportion of 51.36%.

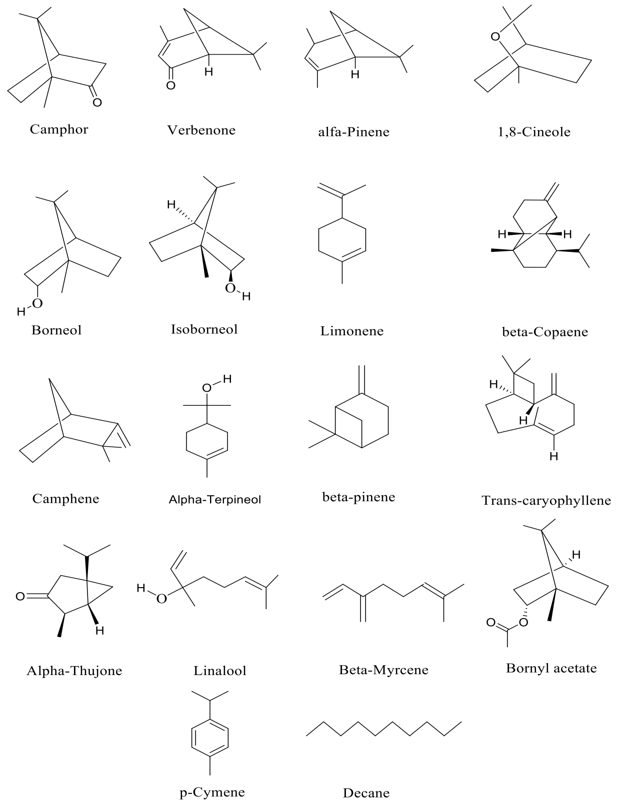


Figure 2 – Compounds present in rosemary.
Source: Prepared by the author (2024).
All the images were drawn using the ChemDraw software (ChemDraw, 1987) according to the PubChem database.

1,8-Cineole (eucalyptol), a natural compound extracted from plants like eucalyptus, rosemary, and bay, boasts a rich history in traditional medicine and showcases a diverse array of biological properties. These include anti-inflammatory, antioxidant, and antimicrobial effects, alongside bronchodilator, analgesic, and pro-apoptotic actions (Hoch et al., 2023).

Hoch et al. (2023) accentuates the health advantages of 1,8-cineole, substantiated by clinical trials involving patients with respiratory ailments such as chronic obstructive pulmonary disease, asthma, bronchitis, and rhinosinusitis, thus underscoring the broad therapeutic spectrum of 1,8-cineole.

Juergens et al. (2018) delve into the dual functionality of the essential oil constituent 1,8-cineole, elucidating its role in inhibiting superoxide anions. This includes the partial dismutation of superoxide anions and independent reduction of H2O2 levels, suggesting a synergistic and nonspecific antioxidant and anti-inflammatory effect of 1,8-cineole. Such versatility positions it as a potential multifaceted therapeutic candidate for future clinical investigations in managing mild to severe Chronic Obstructive Pulmonary Disease (COPD) and as an adjunctive therapy to aid in disease management.

The efficacy of 1,8-cineole as an antioxidant stems from its chemical structure, facilitating electron donation to free radicals, thereby stabilizing them and averting damage. This mechanism proves especially beneficial in mitigating inflammation and safeguarding the body's tissues against oxidative harm (Bektašević et al., 2022)**.**

The efficacy of 1,8-cineole as an antioxidant exemplifies how the molecular structure of a compound can profoundly influence its biological and therapeutic properties (Di et al., 2022; Miguel, 2010). This comprehension opens avenues for the potential utilization of 1,8-cineole in various medical contexts where safeguarding against oxidative damage is imperative (Cai et al., 2021).

α-Pinene, an organic compound abundant in various plants and essential oils, particularly in pine oil, derives its name from its characteristic pine aroma (Russo; Marcu, 2017). It stands out as one of the most prevalent terpenes in nature and has garnered attention not only in aromatherapy, perfume, and cleaning industries but also in the healthcare sector due to its antioxidant properties (Bouzenna et al., 2017).

The antioxidant prowess of α-pinene stems from its molecular structure, enabling it to scavenge free radicals (Miguel, 2010). Free radicals, unstable molecules that can inflict damage to cells and DNA, are implicated in aging and various diseases, including cancer and cardiovascular ailments. By donating electrons to stabilize free radicals, α-pinene helps mitigate cell damage, thus contributing to overall health (Cobley et al., 2015; Fási et al., 2020; Hunyadi, 2019). In addition to its direct antioxidant activity, α-pinene has been investigated for its anti-inflammatory and antimicrobial properties. Research (Mekonnen et al., 2016) has demonstrated antibacterial activity likely attributed to the presence of α-pinene and 1,8-cineole in the oil. Inflammation and oxidative stress are often intertwined, as highlighted by (Mekonnen et al., 2016), where pre-treatment with α-pinene reduced the presence of pro-inflammatory cytokines and enhanced the oxidative stress profile by increasing antioxidant factors and decreasing oxidative elements.

However, it is crucial to acknowledge that numerous studies on α-pinene have been conducted either in vitro or in animal models, warranting further research to comprehensively grasp its effects and potential therapeutic applications in humans. Nevertheless, α-pinene remains a promising compound in the realm of natural medicine and phytotherapy, presenting a potential avenue for mitigating the impacts of oxidative stress. α-Pinene belongs to the terpenoid class of organic compounds, characterized by their molecular structure containing isoprene units (Masyita et al., 2022).

4.5 Geographical distribution and yield of rosemary essential oil

Morocco stands out as the most cited location, with six mentions, suggesting it may be a significant center for studying the antioxidant properties of rosemary. Tunisia also stands out, with five mentions, indicating its importance in this field of research. Countries like Turkey, Algeria, Iran, Serbia, Pakistan, China, and Italy are mentioned twice each. This uniform level of mention suggests these countries moderately contribute to global research on rosemary's antioxidant activity. On the other hand, Palestine, Egypt, Mexico, Argentina, and Greece are referenced once in the dataset. The singular mentions of these countries may reflect a more limited scope of research activity or interest in the context of rosemary's antioxidant applications.

The particular emphasis on Morocco and Tunisia may be indicative of a higher volume of research being conducted or perhaps a higher prevalence of rosemary in these regions, which has triggered a corresponding concentration of scientific investigation. In Morocco, the domain of ethnopharmacology has deep historical roots, entrenched in a cultural tradition of harnessing medicinal plants such as *Rosmarinus officinalis* L. for health and wellness purposes. Across generations, local wisdom has acknowledged the robust antioxidant attributes of rosemary, leading to its incorporation into traditional healing practices. This indigenous knowledge finds validation through scientific inquiry, which underscores the effectiveness of rosemary's bioactive constituents. Consequently, rosemary occupies a prominent position within Morocco's pharmacopeia, serving as a conduit between age-old customs and contemporary scientific exploration, thereby exemplifying the nation's biocultural diversity (Labiad et al., 2020).

Research conducted Kachmar et al. (2021) northeast region of Morocco, focusing on the Southeast; these two regions are distinct not only in their geographical locations but also in their climatic zones, leading to variations in plant biodiversity. Such diversity inevitably influences the selection of plant species for use in traditional medicine, pointing to the frequent use in the Taza region included *Origanum compactum* Benth, *Mentha pulegium* L, *the notable Rosmarinus officinalis* L, *Aloysia citrodora* Paláu, *Calamintha officinalis* Moench, and *Artemisia herba-alba* Asso. In contrast, in the Southeast, traditional medicine practices often cite *Artemisia huguetii* Caball, *Mentha pulegium* L, *Trigonella foenum-graecum* L, *Mentha suaveolens* Ehrh, *Lavandula mairei* Humbert, and *Nigella sativa* L as common medicinal plants.

This significant difference in chemical composition suggests that the predominant soil conditions in Morocco may have contributed to a higher essential oil yield compared to the French and Italian varieties. This result emphasizes the impact of environmental conditions, especially soil composition, on the chemical profile and yield of rosemary essential oil, highlighting the importance of considering geographical and agronomic factors in evaluating the quality and efficacy of essential oil (Oualdi et al., 2021).

The diversity and richness of the Moroccan sector of Aromatic and Medicinal Plants are notable due to its ecological heterogeneity and climatic variations. Among more than 4,200 plant species in Morocco, approximately 800 are of aromatic and/or medicinal interest. This diversity stands out compared to other Mediterranean countries, even against the rich flora of countries like France, Spain, and Turkey (Zrira, 2017a).

This diverse landscape can influence distinct characteristics in rosemary plants grown in Moroccan soil. While plants grown in granitic loam soil exhibit more vigorous growth and intense aroma, those in limestone soil show a higher concentration of oxygenated components, especially 1,8-cineole, reaching up to 31% in some samples. This observation is surprising, as R. officinalis oil from limestone soils typically presents lower levels of 1,8-cineole (Moretti et al., 1998). This high content of 1,8-cineole in Moroccan limestone soil samples may reflect an adaptation to the specific environmental diversity of the country (Moretti et al., 1998), about 280 species are assessed in Morocco, with nearly 100 exported as dried herbs and more than 20 used in the production of essential oils for perfumery, cosmetics, and other aromatic products (Zrira, 2017b).

4.6 Public health applications

Medicinal plants play a vital role in treating diseases and are widely used in various communities. The National Policy on Medicinal Plants and Herbal Medicines, established by Decree No. 5,813 in 2006 (Brasil, 2006), aims to ensure safe access and rational use of these plants, promoting technological and sustainable development in the healthcare sector in Brazil.

Rosmarinus officinalis, commonly known as Rosemary, has a wide range of pharmacological functions attributed by popular use in Brazil, including hypoglycemic, antioxidant, anti-inflammatory, and antidepressant properties. Much of the benefits of this plant are due to its antioxidant properties, which help reduce oxidative stress associated with the development of various diseases (Oliveira; Veiga, 2019).

Rosemary plays a significant role in promoting public health for communities due to its medicinal properties. This aromatic shrub not only enriches culinary dishes but also possesses antioxidant, anti-inflammatory, and antimicrobial properties (Meziane et al., 2024). Its inclusion in the diet can contribute to the prevention of chronic diseases, such as heart disease and diabetes, as well as strengthen the immune system (Sánchez-Quintero et al., 2022).

Rosemary is of utmost importance to public health in Brazil. With its medicinal properties, this aromatic shrub has been used for centuries as an effective tool in promoting health and treating various conditions. Its wide availability and easy cultivation in Brazilian territory make rosemary an accessible and efficient option for promoting the well-being of the population. Integrating rosemary into the Brazilian traditional diet and medicine can represent a valuable strategy for improving public health and reducing the incidence of diseases in the community (De Macedo et al., 2020; Pretto et al., 2021).

5 Conclusion

A comprehensive analysis of *Rosmarinus officinalis* L highlights its highly significant contribution to ethnopharmacology, revealing a profound integration between ancestral knowledge and modern scientific research. Rosemary, with its notable range of antioxidant, anti-inflammatory, and antimicrobial properties, serves as a prominent example of the vast potential of natural resources in promoting health and preventing diseases. This study strongly reaffirms the crucial importance of preserving traditional knowledge, while also emphasizing the need to carefully consider geographic and environmental variations that can influence the composition and effectiveness of medicinal plants.

Thus, *Rosmarinus officinalis* L emerges as an emblematic symbol of the immeasurable wealth of biodiversity and the imperative need to adopt integrated and sustainable approaches in promoting public health on a global scale. Illustrating its extensive ethnopharmacological use, Rosmarinus officinalis stands out not only for its antioxidant and anti-inflammatory properties but also for its comprehensive therapeutic diversity. This study focuses on the deep intersection between tradition and modern science, clearly demonstrating how ancestral knowledge and geographic contexts shape the chemical composition and therapeutic potential of rosemary, thus highlighting its invaluable relevance in promoting global health and biodiversity conservation.

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