**Therapeutic Potential of Rosemary: Bridging Traditional Uses and Modern Applications**

**Abstract**

Medicinal plants play an important role in illness control in both animals and people, and they are most widely utilized by native cultures across the world. *Rosmarinus officianilis* L., popularly known as rosemary, herbaceous perennial plant of the *Lamiaceae* family, receives much attention due to its therapeutic properties. Various secondary metabolites such as diosmin, rosmarinic acid (RA), luteolin, hispidulin 7-O-glucoside, isoscutellarein 7-O-glucoside, glucuronide, flavonoids, polyphenols, terpenes, and genkwanin are found in its leaves, flowers, roots, and stems. Preclinical research indicates that rosemary extract enhances cognitive functions, neuroplasticity, neuroinflammation, suggesting its use in preventing and managing neurodegenerative disorders including Alzheimer’s and Parkinson’s disease. Additionally, rosemary has demonstrated efficacy in regulating the gut-brain axis, aiding gastrointestinal diseases, and minimizing intestinal inflammation. Its antiviral properties, especially concerning influenza A and SARS-CoV-2, highlight its significance in infectious diseases. In dermatology, rosemary helps improve acne due to its antibacterial and anti-inflammatory properties. The herb also has a positive impact on bones by stimulating osteoblastic activity and suppressing bone resorption. Rosemary’s multifunctionality is further highlighted by its insecticidal properties and application in nanotechnology-based drug delivery systems. Thus, Rosemary extracts can be formulated as possible candidates to be used in the diet with promising effectiveness at pre-determined doses, preventing toxicity, provided the aspects outlined above. Although their efficacy as medicinal agents is well established, it is preferable to encourage the creation of novel formulations using rosemary extracts. This review complies the updated rosemary broad therapeutic applications, although further clinical research is required to integrate it effectively into medicine and functional products.

***Keywords***: rosemary, Skin Microbiome and Dermatology, gut microbiome, Anti-osteoporotic, COVID 19

**INTRODUCTION**

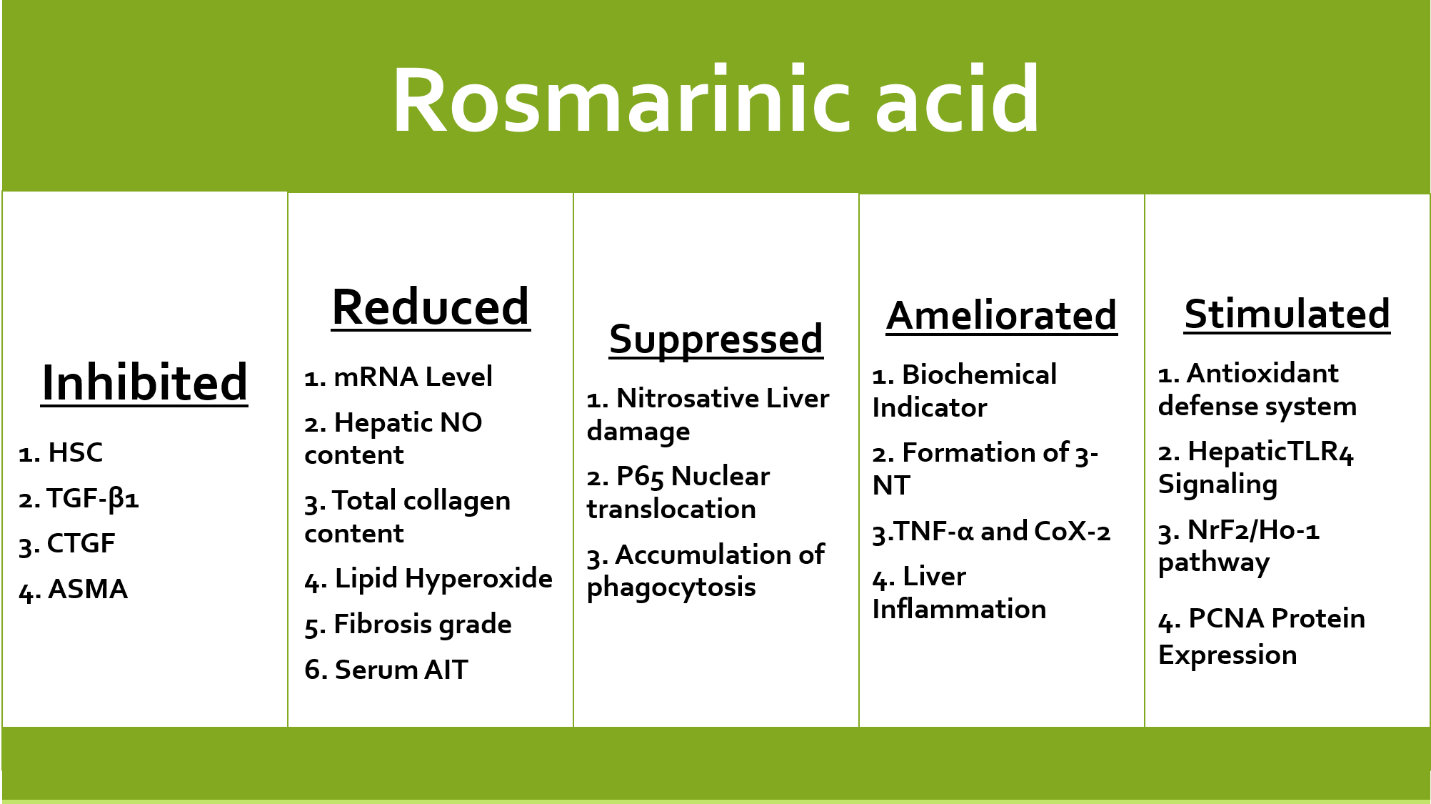
Medicinal plants play an important role in treatment of illnesses in both animals and people, and they are most widely utilized by native cultures across the world. Recently, most medicines have been created from isolated components of medicinal herbs based on their ethnopharmacological uses (Chaachouay N, Zidane L. 2024; Suntar, 2020). Bioprospecting of plants for natural products is increasingly being used in drug production, as they are not only used as medicinal agents, but also as raw materials for drug synthesis. They serve as blueprints for pharmacologically important chemicals (Ibrahim N et al., 2022). To set this resource at the same degree of value, assessing and using plants as a phytopharmaceutical, there is a requirement of lot of fundamental and applied science.

Rosemary belongs to the mint family (*Lamiaceae*), which includes many other herbs such as basil, oregano, thyme, and lavender (Alagawany et al*.,* 2020). It is a good source of calcium, iron and vitamin B6. It is typically prepared as a whole dried herb or a dried powdered extract (Xieet al*.*, 2017). This herb has been hailed since ancient times for its medicinal properties.

Rosemary has traditionally been used to relieve muscular discomfort, promote hair development, enhance memory, act as an immune booster, and support the circulatory and anti-inflammatory systems (Lesnik et al., 2021). Also, according to Estela Fernandes-e-research Silva's docking report in 2020, stated that Rosemary's antiviral activity was attributed to its binding capacity in spike, suggesting that Rosemary can be a protection therapy against the new coronavirus (Patne et al., 2020). The current review compiles the plant's detailed information, including its botanical description, distribution, phytoconstituents and traditional significance.

*Rosmarinus officinalis* L. (syn. *Salvia rosmarinus* Spenn.), popularly known as rosemary, is a evergreen, perennial herb especially in the Mediterranean region, with fragrant, evergreen, needle -like foliage and white, pink, purple, or blue flowers (Blank DE et al., 2020). Various members of *Lamiaceae* family have been experimentally studied for their important traditional applications. For example, *Thymus* spp. is known for its antibacterial activity because of the presence of thymol which also makes it a n effective disinfectant, Among the essential oil, lavender oil is used in the treatment of common fungal infection (dandruff) and hair growth because it contains terpenic compounds and also has antiviral, antifungal and antimicrobial properties (Liu F et al 2017, Fu R et al., 2024).

In herbal medicine, these extracts have been used to treat a variety of ailments, including those with a compromised immune system, cardiovascular issues, genitourinary issues, liver conditions, reproductive functions, and respiratory problems. (Leporini et al., 2020). The plant's essential oils are used in cosmetics and therapeutic lotions to treat a range of conditions, such as arthritis, inflammation, gout, muscular discomfort, neuralgia, and bruising. It is applied topically to the scalp to promote the growth of new hair follicles and stop subsequent balding. (González-Minero et al, 2020; Brindisi et al., 2020). The medicinal benefits of rosmarinic acid derivatives are used in the treatment of bronchial asthma, spasmogenic disorders, peptic ulcers, autoimmune conditions, nephrotoxicity, arteriosclerosis, ischemic heart disease, cataract, cancer, Alzheimer's disease and poor sperm motility (Table 1). They also act as antidepressants and anxiolytic agents (Nieto et al 2018; Hamed et al., 2020).



**Table 1: Mechanism of rosemary metabolites in enzyme regulation**

Numerous phytocompounds with pharmacological properties can be extracted through *R. officinalis* L. essential oils and extracts. The identified phytocompounds are carnosic acid, oleanolic acid, monomeric acid, ursolic acid, caffeic acid, luteolin, chlorogenic acid, eucalyptol, oleanolic acid, rosmarinic acid and eugenol (Pedro Mena et al, 2016) (Table 1) (Boutekedjiret C. et al, 2003). The essential oil of rosemary leaves obtained by steam distillation (yielding up to 2.5%), is water-insoluble, light yellow in appearance, with a distinctive camphor like fragrance. The main constituents of rosemary essential oil are camphor 1,8-cineole, borneol, camphene and limonene, with their varied concentrations depending on the vegetative phase and bioclimatic circumstances (Tawheed Amin et al, 2017).

Regarding the extracts, the primary phytochemicals found in *R. officinalis* are rosmarinic acid, camphor, caffeic acid, ursolic acid, betulinic acid, carnosic acid and carnosol (Wada et al., 2019). The most prevalent polyphenols in *R. officinalis* are diosmin, luteolin, genkwanin, apigenin, phenolic acids and terpenes (Novikov et al., 2016).

**Therapeutic potential of Rosemary compounds**

**Antioxidant activity**

The assessment of the antioxidant activity of rosemary ethanolic extract [REE] suggested that rosmarinic acid had the highest DPPH and hydroxyl radical scavenging activity. The key metabolites carnosol and carnesolic acid have been documented to resolve differential mechanisms of antioxidant capacity (Mimi Guo et al., 2023). The principle phenolic diterpenes essential for the antioxidant effects of rosemary are carnosic acid, carnosol, rosmanol and epirosmanol where carnosic acid and carnosol serve as lipid peroxidation regulators in the liposomal and microsomal systems. These compounds functions as scavengers of peroxyl radicals (CCl3O2), reducing cytochrome c, hydroxyl radicals, as membrane oxidative damage, free radical terminators and chelating agents of reactive oxygen species (ROS), thus reducing the oxygen-derived formation ratio of the reactive species (Samo Lesnik ＆ Urban Bren, 2021). The catechol group plays a key role in scavenging radical electrons generated during oxidation. The skeleton created by the three rings helps the charge to be delocalized. This affinity, especially in aqueous systems, is enhanced by the presence of the -COOH group (Mimi Guo et al., 2023). In addition, stimulation of Nrf2-dependent transcriptional modulation, is also known to be involved in the rosemary antioxidant property. Similarly, antioxidant activities of carnosic acid are attributed to its capacity to enhance or sustain the function of superoxide dismutase and glutathione peroxidase, even under oxidative stress (Solomon H., 2023).

**Neuroplasticity**

Recent research has investigated the neuroprotective effects of rosemary (*Rosmarinus officinalis*), particularly its role in neuroplasticity, the brain’s ability to reorganize and form new neural connections. Studies on the effects of rosemary on neurodegenerative diseases have shown that this herb enhances long-term memory and mitigates dementia by inhibiting acetylcholinesterase activity while stimulating butyrylcholinesterase in the rat brain (Rasoulian B et al., 2019; Sasaki K et al., 2024; Seibel R, et al., 2021). Additionally, research indicates that rosemary compounds, such as carnosic acid, reduce amyloid plaque formation and astrogliosis while promoting synaptic and dendritic markers in Alzheimer’s disease models (Seibel R et al., 2021). A systematic review of multiple preclinical studies found that rosemary administration significantly improved cognitive function in animal models. These effects are likely attributable to the antioxidant properties and anti-inflammatory action, and ability to modulate neurotransmitter systems, all of which contribute to enhanced role in neuroplasticity ((Mimi Guo et al., 2023).

In a study, consuming a rosemary-infused drink was linked to enhanced neural markers of sustained attention. Electroencephalogram (EEG) measurements also showed that rosemary intake improved the brain’s ability to process both relevant and irrelevant stimuli, suggesting an overall enhancement of attentional resources (Leigh M R et al., 2023). This implies that rosemary may support cognitive function by promoting neuroplastic adaptations in attentional networks.

Further, a comprehensive review highlighted the neuroprotective potential of rosemary’s bioactive compounds, particularly rosmarinic acid and carnosic acid. These compounds help combat oxidative stress, reduce inflammation, and regulate neurotransmitter activity, all of which contribute to brain health and plasticity (Satoh T et al., 2022). Given these findings, incorporating rosemary or its extracts into daily routines could be a promising strategy for enhancing cognitive function and supporting long-term brain adaptability.

In diabetic patients, neural tissue damage occurs in central and peripheral nervous system, leading to painful diabetic nerve damage. Numerous neuroprotective and anti-hyperalgesic effects of *R. officinalis* was observed on experimental rats of streptozotocin (STZ)-induced diabetes, including inhibiting of caspase-3 activation, reduce hyperglycemia, hyperalgesia and motor deficiency, and decrease the Bax: Bcl-2 ratio (Rasoulian, B et al., 2019). Further, many investigations have found that RE pre-treatment-induced cerebral ischemia tolerance contributes to a considerable reduction in acute ischemic stroke lesions, even in ischemic penumbra tissue, which is extremely sensitive to hypoxic ischemic damage.

**Gut Microbiota Modulation**

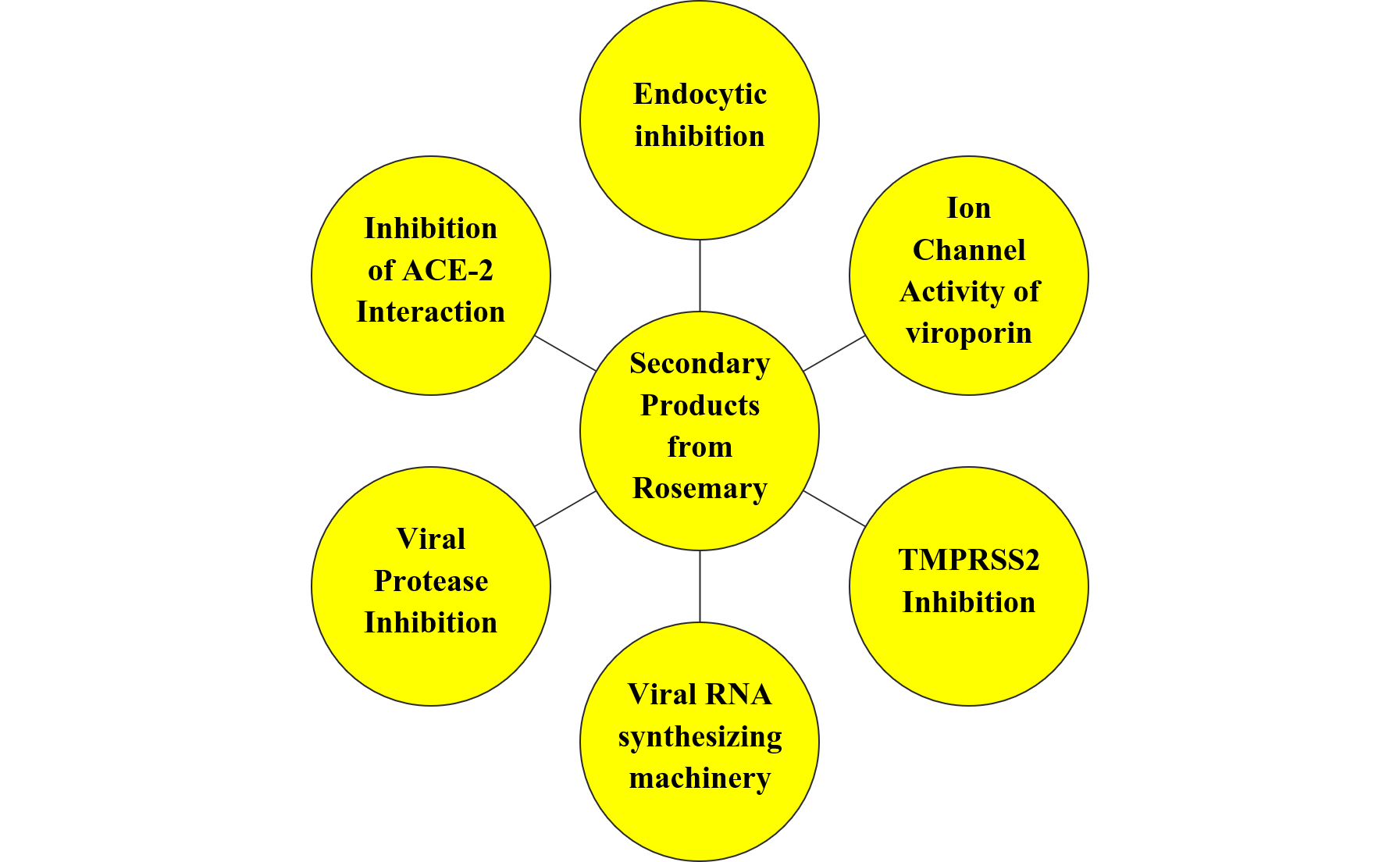
Rosemary extract has been gaining attention for its potential benefits for gut health. Since gut bacteria play a key role in digestion, immunity, and overall well-being, maintaining a balanced microbiome is essential. Rich in natural compounds such as carnosic acid and rosmarinic acid, rosemary extract has antimicrobial and prebiotic-like properties that can positively influence gut bacteria (Zhang L & Lu J, 2024).

These bioactive compounds have been reported to promote the growth of beneficial bacteria like *Lactobacillus* and *Bifidobacterium*, while reducing harmful microbes such as *Lachnoclostridium*, *Escherichia-Shigella*, and *Marvinbryantia* (Naqvi S et al., 2024). In studies with broiler chickens, dietary supplementation with rosemary extract improved their antioxidant levels and immune function, likely due to its ability to balance gut bacteria. By promoting a healthier gut microbiome, rosemary extract may aid digestion, reduce inflammation, and support metabolic health. Its antioxidant and anti-inflammatory effects may also help protect the gut lining, thus lowering the risk of digestive issues (Alimohammadi Z et al., 2024). While more research is needed to fully understand how it works, rosemary extract shows promise as a natural supplement for gut health.

**Anti-viral Activity**

Rosemary extracts when combined with nitrites under acidic environment, yield 6,6-nitro and 6-dinitrorosmarinic acids. Such chemicals were activated when HIV-1 integrase inhibitors blocked viral replication at sub-molecular levels. RA nitration significantly enhanced anti-integrase suppression and antiviral efficacy without rising cellular toxicity levels. Additionally, Herpes simplex viruses 1 and 2 (HSV-1 and HSV-2), which belong to the *Herpesviridae* genus and, through invading the nervous system, induce neurodegenerative problems (Satoh T et al., 2023). Superoxide anion and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free-radical assays, an HSV-1 antiviral assay, were investigated for the antioxidant property of the Rosemary extract, where only viral replication in Vero cells was determined and evaluated using a cytotoxic influence assay (Megrin AL et al.,2020). The inhibition of HSV-1 plaques were caused by rosemary extract upto 65% inhibition of HSV-2 plaques. Rosemary extract could be effective for herpes virus infections as a superficial prophylactic or therapeutic agent (De Oliveira JR et al., 2029). The effectiveness of rosemary cineole (*Rosmarinus officinalis* chemotype 1.8 cineole) in minimizing hepatitis A virus (HAV) infection rates was examined in soft fruit. The effectiveness of EO in minimizing viral titer on berries was identified to be Rosemary cineole. Such observations reinforce our awareness of the antiviral function of these Rosemary EOs and demonstrate their possible role in sanitation for fresh fruit and vegetables (Takumi S et al., 2022).

The coronavirus disease 19 (COVID-19), caused by the SARS-CoV-2 or novel coronavirus, is the source of the current deadly epidemic. There are currently no vaccinations or well-defined therapies for COVID-19, making it critical to research molecules responsible for preventing and/or curing the illness. The Spike molecule is one of the most essential proteins for coronaviruses. This protein is involved for the virus's integration with the host cell, which initiates pathogenesis. Spike blockage might operate as a preventative and/or therapeutic measure by preventing viral fusion with human cells (Figure 1). Rosemary (*Rosmarinus officinalis* L.) was discovered to have the ability to suppress the growth of Sars-CoV-2 by inhibiting interacting and blocking the spike protein via molecular mechanisms (Patne Tet al., 2020, Takumi S et al., 2022). Eliminating of the heteroatoms using the UCSF Chimera were prepared within the receptor and the ligand (Rosemary) with AutoDock Vina. Further, Coronavirus and Rosemary were linked with a free interaction affinity of -6.5 Kcal/mol. The molecules formed six hydrogen bonds and five hydrophobic interactions. Hence it was concluded that Rosemary's antiviral activity in conjunction with its binding ability in Spike could prevent illness as revealed in molecular docking (Takumi S et al., 2022).



**Figure 1: Metabolic pathway representing anti-covid efficacy of rosemary compounds**

**Skin Microbiome and Dermatology**

The skin microbiome plays a vital role in maintaining skin health, by acting as a protective barrier against pathogens, regulating inflammation, and supporting overall skin function. Imbalances in this delicate microbial ecosystem have been linked to various dermatological conditions, including acne, eczema, psoriasis, and premature aging (de Macedo LM et al., 2020). Rosemary extract, known for its rich composition of polyphenols such as rosmarinic acid and carnosic acid, has emerged as a potential natural remedy for modulating the skin microbiome and improving dermatological health. Its antimicrobial properties can help regulate harmful bacterial overgrowth, such as *Cutibacterium acnes*, which contributes to acne development, while preserving beneficial microbes essential for skin balance (Hoskin R et al., 2021).

In recent years, researchers have been increasingly interested in the potential of rosemary to protect the skin from oxidative damage caused by pollution. A study by Nobile et al. investigated the benefits of oral supplementation with four phenol-rich plants, including *Rosmarinus officinalis*, in 100 Caucasian and Asian women living in polluted urban areas of Milan. This randomized, double-blind, placebo-controlled trial found that long-term supplementation improved several skin health markers, including increased elasticity, strengthened barrier function, and reduced wrinkle depth and dark spots (Azizi S et al., 2022).

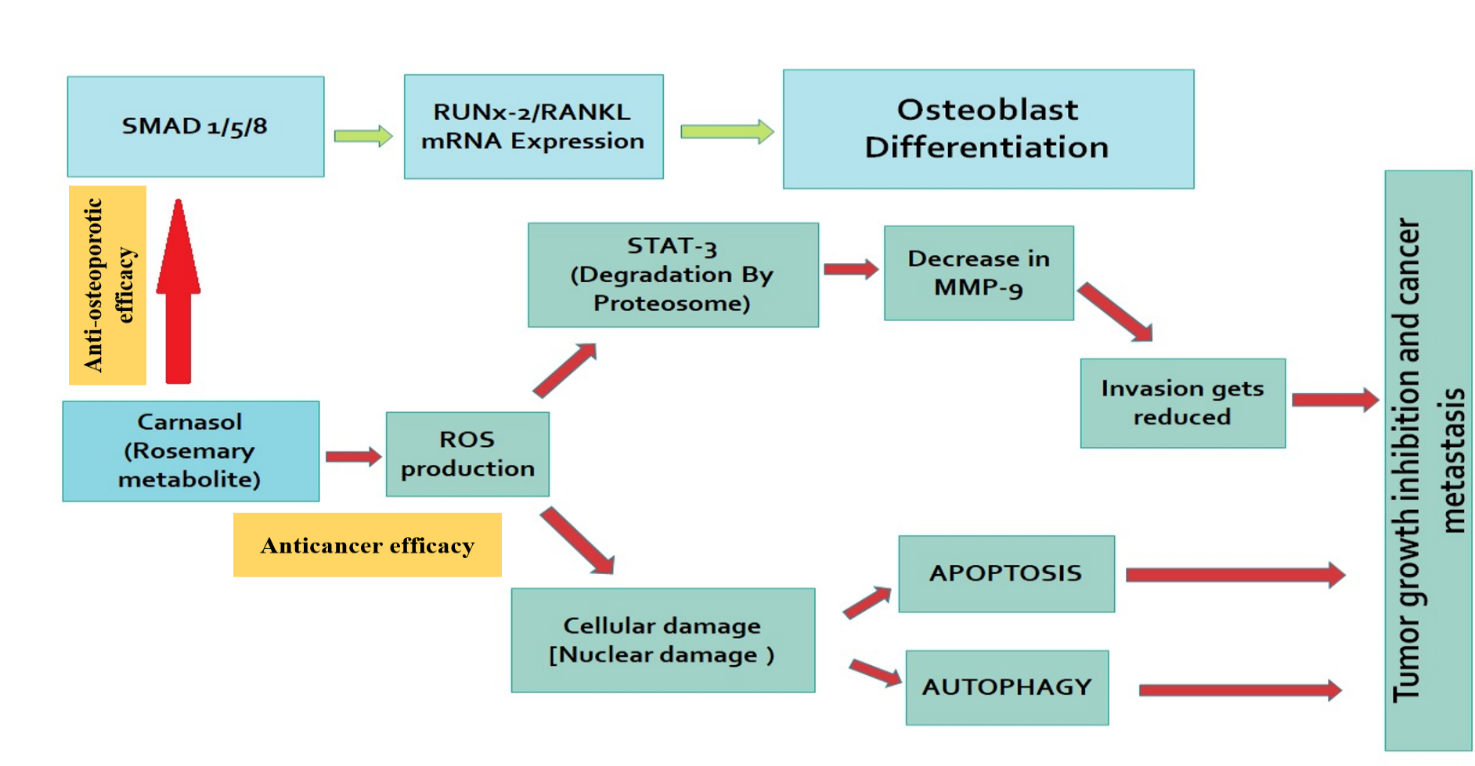
Similarly, Hoskin et al. provided the first evidence of the protective effects of a topical gel containing hydroalcoholic rosemary extract combined with algae proteins against pollution-induced oxidative skin damage. The underlying mechanisms of rosemary’s benefits involve blocking the rise of active metalloproteinase-9 (MMP-9), reducing harmful protein modifications, and preventing filaggrin loss—key factors triggered by exposure to diesel engine exhaust.

Further supporting rosemary’s therapeutic potential, Mengoni et al. explored the anti-inflammatory effects of its key bioactive compounds, carnosol and carnosic acid. There *in vivo* study revealed that these compounds help regulate inflammation by downregulating pro-inflammatory markers like IL-1β and TNF-α, reducing leukocyte migration, and selectively inhibiting COX-2, an enzyme linked to inflammation. These findings highlight rosemary’s promising role in protecting and repairing skin from environmental stressors

Additionally, its potent antioxidant and anti-inflammatory effects may help soothe irritated skin, reduce oxidative stress, and enhance skin barrier function. Research suggests that rosemary extract may also influence sebum production, making it beneficial for both oily and dry skin types. By supporting a balanced microbiome and reinforcing the skin’s natural defense mechanisms, rosemary extract offers promising potential in dermatology, whether as an ingredient in skincare formulations or as part of a holistic approach to skin health. Further, evidence supporting these molecular mechanisms comes from an *in vivo* study by Yeo et al., which explored the anti-inflammatory effects of carnosol in mice with atopic dermatitis (AD) exposed to UVB radiation. Their findings showed that applying carnosol topically helped reduce key signs of skin damage, including thickened skin, redness, swelling, and erosion. Additionally, it significantly lowered the levels of pro-inflammatory markers TNF-α and IL-1β in the bloodstream, along with a notable decrease in UVB-induced serum IgE—an indicator of allergic reactions. These results suggest that carnosol may play a protective role in soothing and repairing inflamed skin.

**Anti-osteoporotic**

Osteoporosis is a major public health issue that affects millions of individuals globally. There is a clear relationship between dietary calcium deficiency and the development of bone loss. Rosemary contains carnosic acid which is a polyphenol and a potent anti-oxidant compound (Elkomy et al., 2015). Research has been designed to conduct the *in vitro* and *in vivo* effects of carnosic acid on bone formation and development that showed carnosic acid reduced H2O2 levels in osteoblastic MC3T3-E1 cells. Moreover, in osteoblastic MC3T3-E1 cells, it also inhibited osteoblast differentiation such as alkaline phosphatase activity and calcium deposition even at 3-10mM concentrations (Elkomy et al., 2015) (Figure 2). In another study, rosemary was found to effectively counteracted calcium deficiency in growing male Sprague–Dawley rats. It mitigates bone loss, raised Ca and vitamin D3 in bloodstream, improved BMD, and also avoided inflammation and oxidative stress (improved TNF-, CRP, and MDA). Therefore, rosemary extract may be recognized as preventive measures of bone resorption and osteoporosis (Fig 2). Additionally, the histological analysis of the treated groups revealed an improvement in bone histology as well as protection from bone loss. (Chan et al., 2015). A report by  [Elbahnasawy](https://pubmed.ncbi.nlm.nih.gov/?term=%22Elbahnasawy%20AS%22%5BAuthor%5D) A S et al found that essential oils and monoterpenes found in thyme and rosemary, commonly used as food additives and in various medical applications, have been shown to effectively inhibit bone resorption. Furthermore, these compounds provide significant benefits for bone formation and possess strong anti-inflammatory properties.

**Figure 2: Metabolic pathway representing anti-osteoporotic efficacy of Carnasol metabolite**

**Targeted Drug Delivery**

Targeted drug delivery aims to enhance the precision and effectiveness of treatments while minimizing unwanted side effects. Recent research highlights rosemary extract as a promising natural component in this field, with its rich bioactive compounds and excellent biocompatibility. Containing polyphenols such as rosmarinic acid and carnosic acid, rosemary extract offers potent antioxidant, anti-inflammatory, and antimicrobial benefits that can improve drug stability and enhance therapeutic potential.

Researchers are investigating its role as a natural carrier in nanoparticle-based drug delivery systems, helping transport medications directly to diseased cells while shielding them from premature breakdown. For instance, a 2024 study by Rania M. Yehia et al. explored the potential of rosemary oil (ROS) in promoting hair growth, addressing its limited ability to penetrate the skin. The study developed innovative ROS-loaded microsponges (MS) for improved topical application, optimizing factors such as solvent volume, polymer blend, and drug concentration. The optimized formula demonstrated impressive results, including a 94% production yield, 99.6% encapsulation efficiency, and 96.4% controlled release of ROS within 24 hours.

Furthermore, lipophilic nature of rosemary extracts allows it to interact with cell membranes, potentially enhancing drug absorption and bioavailability (Cedeno-Pinos C et al., 2022). Studies suggest it could play a valuable role in cancer treatment (Raad C et al., 2024), neuroprotection (Sasaki K et al., 2024), and antimicrobial therapies (Hashem MM et al., 2024) by ensuring the controlled release of active compounds precisely where they are needed. By incorporating rosemary extract into advanced drug delivery systems, researchers aim to develop safer, more effective treatments with fewer systemic side effects.

**Antialgal activity**

Rosemary essential oil has been investigated as a natural alternative to chemical treatments for controlling harmful algal growth. Research assessing its antialgal properties, particularly by measuring chlorophyll A levels, revealed a strong inhibitory effect on the growth of *Chlorella vulgaris* (Ejaz Aziz et al., 2022, Scognamiglio et al., 2013). Similar inhibitory effects have been observed with *Microcystis aeruginosa* and *Chroococcus minor*, two species commonly associated with harmful algal blooms (HABs) worldwide. These blooms are often triggered by excessive nutrients from agricultural runoff, fertilizers, and partially treated wastewater entering water bodies, leading to eutrophication. A study by Najem et al. (2017) found that REO significantly suppressed the growth of *M. aeruginosa* and *C. minor*, with their growth rates decreasing dramatically as both exposure time and essential oil concentrations increased. These findings suggest that REO could be an effective and environmentally friendly approach for managing HABs, offering a sustainable alternative to conventional chemical treatments.

**Antifungal activity**

Rosemary essential oil has been evaluated for its antifungal activity against several pathogenic fungal species such as *Sclerotinia sclerotium, Sclerotinia nivalis, Cylindrocarpon destructans, Alternaria panax, Candida, Botrytis cinerea,* and *Fusarium oxysporum*. The rosemary essential oil is efficient against certain pathogenic strains, while it showed a significant capacity to suppress *Sclerotinia* spp. Growth (Da Silva N, 2023). The antifungal potential of ROE was also investigated against fungal brain infection due to *C albicans*b. Rosmarinic acid can inhibit the RTPase enzyme and was effective against the fungus *C. albicans* (Mahboobeh G R, Hossein H. 2020). The lowest fungicidal content of rosemary oil was 25%, while nystatin's minimum fungicidal concentration was greater than 100%. Also, combined effect of REO and Nystatin exhibit antifungal activity against *Candida* species isolated from HIV/AIDS patients with oral candidiasis (Meccatti VM et al., 2020).

**Antihelminthic activity**

Aquaculturists are increasingly exploring natural alternatives to chemotherapy for managing monogenean parasites, focusing on safe and eco-friendly herbal treatments. Research by Ingelbrecht et al. (2020) has demonstrated the effectiveness of rosemary leaf extracts in combating *Dactylogyrus minutus* infections, highlighting its potential as a therapeutic agent in aquaculture. The study observed that after exposure to varying concentrations of both ethanol and aqueous extracts containing key bioactive compounds such as 1,8-Cineole, α-pinene, β-pinene, camphor, and camphene, the parasites showed a complete loss of activity and self-digestion (autolysis) within a specific timeframe. Among these compounds, 1,8-Cineole exhibited the strongest effect in *in vitro* tests. Supporting this, a study conducted in Tunisia also found that rosemary (*Rosmarinus officinalis*) essential oil, particularly rich in 1,8-Cineole (52.06%), α-Pinene (15.35%), and Camphor (7.69%), demonstrated significant anti-helminthic and anti-coccidial properties against *Eimeria* species and *Haemonchus contortus* (Varadyova et al., 2018). These findings suggest that rosemary extract could be a promising natural alternative for parasite control in aquaculture.

**Sustainable Agriculture Agent-Bioherbicide**

As interest for sustainable agriculture increases, there is growing emphasis on bioherbicides, biopesticides as eco-friendly alternatives to synthetic herbicides. Rosemary extract, rich in bioactive compounds like rosmarinic acid, carnosic acid, and essential oils, has shown promise as a natural weed-control. Its phytotoxic properties can inhibit weed growth by interfering with seed germination, root development, and key enzymatic processes (Christiana M et al., 2023). Unlike conventional chemical herbicides, which contribute to environmental pollution and herbicide resistance, rosemary extract is biodegradable and less toxic, making it a safer option for long-term agricultural use (Roufaida M. E et al., 2024). Additionally, its antioxidant and antimicrobial properties may support soil health and promote beneficial microbial activity. However, large-scale application faces challenges such as formulation stability, cost-effectiveness, and variability in potency due to differences in extraction methods (Maryam A et al., 2019). While initial research is encouraging, further studies are needed to refine extraction techniques, enhance delivery methods, and assess long-term environmental effects. Incorporating rosemary extract into weed management strategies could be a step toward more sustainable farming, but practical hurdles must be addressed before widespread use.

Beyond its herbicidal potential, rosemary oil has also been studied for its insecticidal properties. Research has focused on two key compounds in rosemary oil, 1,8-cineole and camphor, and their effects on the cabbage looper (*Trichoplusia ni*) (Tak JH et al., 2016). When applied topically to larvae, 1,8-cineole was found to be more volatile than camphor, and when the two were combined in their naturally occurring ratio in rosemary oil, they proved to be more effective together. Interestingly, camphor was more toxic when fully absorbed by the larvae, but gas chromatography-mass spectrometry analysis revealed that when mixed with 1,8-cineole, its absorption increased significantly. This enhanced penetration of camphor and cineole in combination resulted in the same level of bioactivity as higher doses of each compound when applied separately (Tak JH, González-Minero FJ et al., 2020) The improved absorption was attributed to reduced surface tension and the ability of 1,8-cineole to increase camphor’s solubility in the insect’s lipid-based cuticle layer (Isman et al., 2015). These findings highlight rosemary oil’s potential as a natural insecticide and open the door for further exploration of its role in integrated pest management.

**Food preservative**

Rosemary (*Rosmarinus officinalis*) has gained significant attention as a natural food preservative due to its potent antioxidant and antimicrobial properties. Rich in bioactive compounds like rosmarinic acid, carnosic acid, and carnosol, rosemary helps prevent lipid oxidation, which is a major cause of spoilage in processed foods, meats, and oils. Studies have shown that adding rosemary extracts to food products can effectively extend shelf life by reducing oxidative rancidity and inhibiting the growth of spoilage microorganisms (Martínez L, et al 2019, Hendel N et al., 2024). Unlike synthetic preservatives, rosemary offers a clean-label alternative that meets consumer demand for natural and chemical-free food preservation (Kaur R et al., 2024). Additionally, its ability to maintain flavor, texture, and nutritional quality makes it an attractive option for the food industry (Ma P et al., 2024). While rosemary is already used in various food applications, ongoing research is exploring advanced extraction methods and nanoencapsulation techniques to enhance its stability and effectiveness in different food matrices. Delivery systems of REO in food preservation applications, such as nano emulsions (NEs), solid particle encapsulation (SPE), and biodegradable food packaging film/coatings (BFPF/BFPC) are used (Gadallah AH et al., 2024; Kaur R et al 2024). As interest in natural preservatives grows, rosemary stands out as a promising solution for safer and more sustainable food preservation.

**Conclusion**

A wide number of bioactive compounds with a significant medicinal potential are found in extract of rosemary that includes triterpenoids, tricyclic diterpenes, phenolic compounds, and essential oils. The further research of rosemary metabolites might aid in its prospective use as a medicinal agent against a variety of contemporary lifestyle problems. However further research is needed to understand the mechanisms underlying therapeutic effects of rosemary metabolites. Preliminary studies suggest that the rosemary metabolites act by different ways such as anti-inflammatory response, antioxidant effects, as well as suppressing cell growth, migration, and selectively induction of apoptosis of cancer cells. Furthermore, the anti-diabetic, anti-inflammatory action shows that it can be helpful in disease prevention. Thus, Rosemary extracts can be formulated as possible candidates to be used in the diet with promising effectiveness at pre-determined doses, preventing toxicity, provided the aspects outlined above. Although their efficacy as medicinal agents is well established, it is preferable to encourage the creation of novel formulations using rosemary extracts.

**Disclaimer (Artificial intelligence)**

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1. Grammarly and Quillbot paraphraser for some sentences

**Authors' contributions**

Arshya Hashim, Faria Fatima, Pooja G Malave designed, performed literature reviews, analyzed data, and authored the manuscript. All authors have read and approved the final manuscript.

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