

Phenolic Compounds in Rosemary (*Rosmarinus officinalis* L.): Scientific Review

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Abstract

Rosemary is a valuable medicinal and aromatic plant of the family Lamiaceae and has been used extensively as food, drug and cosmetic. Its scientific value is closely tied to the high concentration of non-volatile bioactive compounds, such as phenolics, of which Rosmarinus acid, carnosic acid, carnosol and phenolic diterpene related compounds are the most prominent and play an important role in deciding its antioxidant, anti-inflammatory, antimicrobial and other functional properties. Recent literature was synthesized in this review to present data regarding the phenolic profile of rosemary, *Salvia Rosmarinus*, although *Rosmarinus officinalis* was the major synonym in much of the agronomic and phytochemical literature in recent years. Special attention is given to the classification of rosemary phenolics, their biosynthetic pattern, the distribution of rosemary phenolics across various tissues, rosemary genotype effects, light regime and agronomic environment effects, post-harvest handling on phenolics yield and composition, effects of extraction technology on yield and composition of rosemary phenolics, current platforms for characterisation of rosemary phenolics. The review also examines how the phenolics from rosemary are relevant to its functional abilities and the applications of these substances as antioxidants, anti-inflammatory agents, antimicrobial agents, neuroprotective agents, anticancer agents, and preservatives for food, and includes a discussion about the appropriate industrial use of standardized rosemary extracts enriched in carnosic acid and carnosol. Current evidence shows that rosemary should not be viewed merely as a culinary herb or essential-oil crop, but as a strategic plant system for the production of high-value phenolic fractions. Future progress in plant production and value-chain optimization will depend on chemotype-oriented cultivar selection, environmentally informed harvest scheduling, green extraction systems, valorization of processing by-products, and stronger integration between agronomy, analytical chemistry, and application-driven phytochemistry.

Keywords: *rosemary, Rosmarinus officinalis* L., *Salvia Rosmarinus*, *phenolic compounds*, *rosmarinic acid*, *carnosic acid*, *carnosol*, *antioxidants*, *green extraction*, *plant production*.

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Introduction

The multifaceted uses of Rosemary in production, its medicinal properties and reputation, as well as its adaptability to the Mediterranean and semi-arid environments, puts it in a special class of medicinal and aromatic plants. It is traditionally grown as a spice and essential oil crop, but over the last few years,

rosemary has come into the spotlight as a specialized crop where high value phytochemicals are recovered, particularly phenolic compounds which are beneficial for antioxidant, preservative, nutraceutical and pharmaceutical applications (Shankar et al., 2024; Lešnik et al., 2021; Aziz et al., 2022).

At present there is a need for a brief taxonomic clarification of rosemary for the scientific discussion. *Rosmarinus officinalis* L. is the most well-known and widely used name in most of the food, medicinal and agronomic literature, although this name is now used as a synonym of *Salvia Rosmarinus* Spenn. by the authoritative botanical literature. This nomenclatural change does have implications for literature retrieval and scientific reporting as both of these names are still used in current literature (Kew Science, 2026; World Flora Online, 2026).

The phenolic constituents of rosemary are beginning to be of special interest not only for their chemical description, but as a distinguishing factor of cultivars, site and industrial processes in recent years. The focus has now shifted to the balance between *Rosmarinus* acid and other phenolic diterpenes (carnosic acid, carnosol, rosmanol, and others along with related abietane derivatives), as well as their response to agronomic conditions and extraction technology (Baptista et al., 2024; Mohammed et al., 2024).

The aim of this review is therefore to give a rigorous and up-to-date compilation of rosemary phenolics geared towards a scientific audience in the field of plant production and applied phytochemistry. Review gives pertinent aspects on taxonomy and crop relevance, phenolic classification, biosynthesis and distribution, controlling factors for accumulation, extraction and analytical techniques, biofunctional significance and gaps in production and research. Special attention is paid to those studies published after 2020 are selected, and a limited number of foundational and regulatory studies are included where they are still relevant to the application and interpretation of the data.

Botanical Identity, Taxonomy, and Agronomic Relevance

Rosemary is a perennial evergreen shrub native to the Mediterranean basin of the family Lamiaceae, but it makes a valuable ornamental plant and can be fairly grown in warm dry conditions in other temperate, subtropical and semi-arid climates. The plant is characterized by woody stems, narrow aromatic leaves, glandular secretory structures and blue to violet flowers, white and pink flower forms are also in commerce and breeding materials. These morphological features are not only important for species identification but also for the distribution of bioactive metabolites and the rosemary marketability as a fresh herb, dried herb, rosemary essential oil, and rosemary extract (Aziz et al., 2022; Lešnik et al., 2021).

The increasingly greater understanding of rosemary under a crops production perspective should consider this plant system as a plant dual-purpose, associating a first value chain to the volatile fraction and aroma properties with a second value chain to the non-volatiles and their downstream applications like products using rosemary as natural antioxidants and purified fractions. An important aspect of this shift is that essential-oil yield alone is not usually the yardstick used to evaluate rosemary but rather a standardized level of phenolic diterpene content, e.g., carnosic acid and carnosol, which are perceived to generate a more consistent nutritional and medicinal benefit for these products (Shankar et al., 2024; Rafya et al., 2024).

Due to the increasing utilization of rosemary extracts in pharmaceutical development, cosmetics, food preservation and supplements, biomass production and crude herb quality are no longer sufficient for agronomic improvement. However, research on plant production programs is gaining increasing attention to chemotype selection, interactions between the environment and genotype, harvest date and handling after harvest, with a view to optimize plant phenolics and guarantee the material's compositional uniformity for extraction and standardization purposes (Mohammed et al., 2024; Baptista et al., 2024).



Chemical Classification of Phenolic Compounds in Rosemary

The non-volatile part of rosemary phenolic components consists mainly of phenolic acids, phenolic diterpenes, flavonoids and a collection of minor related derivatives. Rosmarinus acid is in general the most prominent and most discussed phenolic acid, often with the presence of caffeic acid and in some cases, chlorogenic acid and other hydroxycinnamates. Rosmarinus acid has a significant contribution to the total reducing capacity and the polar antioxidant ability (Lešnik et al., 2021; Sharma et al., 2020) in many aqueous systems or systems containing a part of water.

In the case of many rosemary extracts, the most significant fraction industrially is the phenolic diterpene. In most cases, the predominant diterpene in fresh or properly treated leaves is carnosic acid; carnosol, rosmanol, epirosmanol, methyl carnosate, and other oxidation and transformation products of terpenes depend on the genotype, state of leaves, conditions of the extraction process, and history of postharvest treatment. These compounds boast a remarkable antioxidant activity in lipid systems, contributing to their widespread commercial applications as natural preservatives in food and beverage industry (Viuda-Martos et al., 2018; Shankar et al., 2024).

Recent HPLC-DAD, LC-ESI-MS/MS, UHPLC-QTOF-MS and analogously techniques also reveal that rosemary is a source of flavonoids (luteolin, apigenin, genkwanin, hispidulin, and quercetin glycosides), but they are present in smaller quantities than the phenolic acids and diterpenes. Their quantitative contribution might be low, but they can have varying effects on the overall bioactivity of the whole extract and on cultivar discrimination and chemometric fingerprinting (Baptista et al., 2024; Mohammed et al., 2024).

Biosynthesis and Tissue Distribution of Rosemary Phenolics

Most of the rosemary phenolics are from the phenylpropanoid network and its branches. The intermediates involved in the formation and the lack of intermediates in the degradation of Rosmarinus acid are, in part, related to caffeic acid, whereas the degradation intermediates of phenolic diterpenes are more directly associated with the special metabolism of aerial tissues that is abietane diterpene. This difference between these can be highlighted by explaining why the extraction selectivity, solvent polarity and tissue choice has a strong effect on the apparent rosemary chemical profile (Lešnik et al., 2021; Shankar et al., 2024).

The agronomic aspect of tissue distribution is also important. Carnosic acid and carnosol are typically found in a major amount in leaf tissue and therefore leaf biomass is particularly useful for food applications targeting these antioxidants. Hydroalcoholic or more polar extracts tend to focus on the polar phenolics, however, such as Rosmarinus acid, as opposed as more apolar extractions. Therefore, plant density, pruning, harvest fraction and processing goals should be determined based on the desired phenolic class of the orchard product as well as biomass production (Aziz et al., 2022; Sharma et al., 2020).

New omics studies contribute more to the understanding of rosemary secondary metabolism and the genetic basis of metabolite accumulation, at a molecular level. While currently the results of transcriptomics research agree with the idea of developmental regulation of phenolic levels in rosemary, with the addition of the fact that its accumulation is related not only to abiotic environmental factors, but also to postharvest transformation processes (Shankar et al., 2024), the biosynthetic regulation of the species is not yet resolved to the same extent as some major model plants.



Factors Affecting the Accumulation of Phenolic Compounds

The composition of the phenolics in rosemary is dependent on a complex combination of genotype, geographical location, season, phenological stage, quality of light, stress levels, and processing after harvest. All of these factors are not to be considered merely individual variables when applied as production-oriented interpretation as they can all affect the concentration of the individual compounds or the relative balance of the polar phenolic acids/lipophilic phenolic diterpenes (Mohammed et al., 2024).

Genetic and Cultivar Variation

Recently, a comparative study of six rosemary varieties, cultivated in the Mediterranean area, revealed that the cultivar-specific phenolic profile is rather similar overall, but statistically significantly different such that it would provide clear cultivar-by-cultivar differences in the antioxidant and potential industrial application in the range of cultivars tested. The amount of carnosic acid derivatives and/or the relative enrichment in Rosmarinus acid showed the highest profile in some cultivars, while various terpene to polyphenol ratios showed up in others. This further demonstrates the rationale of chemotype-based cultivar selection for breeding and commercial cultivation, as opposed to academic research only research (Baptista et al., 2024).

A cultivar developed for fresh-herb flavour or aesthetic purpose might not be most suitable for high value extraction of phenolics. Hence, the compositional screening should be considered as one of the consistent criteria in germplasm selection for plant production programs focusing on harvest of food antioxidants, pharmaceutical precursors or purified phenolic fractions (Aziz et al., 2022).

Geographical Origin, Season, and Phenological Stage

Geographic origin and season are always confirmed in field studies to be the primary factors that control rosemary phenolics. The total phenolic, total flavonoids, tannin and antioxidant contents of the same species can vary significantly among samples from different agro-ecological zones. A study in Kenya also revealed that the extraction efficiency relied heavily on the solvent type, with the extraction of antioxidant active phytochemicals proving to be efficient with 80% ethanol as a solvent (Kabubii et al., 2023).

Seasonal work in Europe and North Africa also suggests that the best time for harvesting varies according to the destination. There is a lack of correlation between maximum vegetal biomass and maximum contents of Rosmarinus acid and phenolic diterpenes. Therefore, the timing of the harvest should be carefully planned with the aim of obtaining the desired phytochemical profile, not only for size or convenience of flowering. (Oalde Pavlović et al., 2025; Kherraz et al., 2026).

Light Regime and Environmental Stress

Light quality is now known to be a way that rosemary phytochemical management can be controlled, particularly in protected cultivation. In this study, the red LED light treatment promoted higher growth, total phenolics, and total flavonoids and Rosmarinus acid concentration compared to the other light treatments, suggesting that spectral management can be utilized for a production approach with a quality focus in addition to its role as a growth-support tool (Park et al., 2025).

Also, the response of rosemary secondary metabolism to environmental stress factors is not linear. Stress (mild or moderate) can cause accumulation of defines metabolites while more severe stress can also lead to a decrease in total metabolite production, although sometimes the concentration per dry weight increases. In drought before that, and humidity, salinity and temperature after, management of rosemary should be seen as optimization problems were maximizing the phenolic output to be extracted per unit area should be the target (Mohammed et al., 2024).



Postharvest Handling and Solvent Effects

The chemical composition of rosemary cannot be predetermined when it is being harvested. The apparent profile of phenolics recovered during the extraction process is affected by drying temperature, exposure to oxygen, storage time, size of particle reduction, and composition of the solvent. Postharvest changes are particularly important for the ratio of carnosic acid to its oxidation products, like carnosol. Hence, the quality of the final extract can be impacted through the few non-standard quality of the biomass when the biomass was initially collected from the field (Lešnik et al., 2021; Mohammed et al., 2024).

After one of the founding principles of chromatography was established, the polarity of the solvents has remained one of the most potent analytic and industrial measures of composition. Hydroalcoholic systems typically extract *Rosmarinus* acid-containing fractions while lipophilic or supercritical systems are able to extract diterpene-containing fractions more effectively. Thus, the reported differences between the studies are not necessarily biological because they may stem from a methodological consequence of the extraction design (Kabubii et al., 2023; Zeroual et al., 2022).

Extraction, Purification, and Analytical Characterization

The recent literature on rosemary phenolics revealed more and more transition from a single solvent extraction to the development of more selective, green and application-oriented systems. Today, the target is not only to obtain a crude extract, but to get chemically defined fractions enriched in molecules of interest (carnasic acid, carnosol, or *Rosmarinus* acid) that preserve antioxidant activity, have processing potential and render the process at large scale safe (Lešnik et al., 2021; Pizani et al., 2022).

Comparative extraction studies show that there is no perfect, universal extraction system – it depends on the type of compound that is targeted. Supercritical fluid extraction techniques demonstrated a high recovery of phenolic diterpenes and high antioxidant activity of obtained rosemary fractions, whereas accelerated solvent extraction and ultrasound-assisted extraction techniques proved to be highly competitive in other conditions and can be optimized using experimental design tools (Ayyildiz et al., 2024; Athanasiadis et al., 2024; Boufetacha et al., 2024).

The valorisation of the rosemary residues after the distillation of essential oil is particularly significant. When treated as waste, a considerable amount of *Rosmarinus* acid, carnosic acid and carnosol is still present in distilled biomass, making it an appealing raw material for circular biorefinery systems. The by-products of such green-extraction process have been transformed into an antioxidant-rich fraction with high industrial potential, as shown in the green-extraction studies (Irakli et al., 2023; Ziani et al., 2025).

Selective extraction methods are getting more advanced. This shift towards specific approaches to the recovery of phenolics, instead of crude extracts, is exemplified in the extraction of *Rosmarinus* acid via ultrasound-assisted extraction, biobased deep eutectic solvent systems, and purification using molecularly imprinted polymer (Pizani et al., 2024; Vieira et al., 2022; Ersoy, 2025).

From an analytical perspective, the use of UHPLC-ESI-QTOF-MS as well as LC-ESI-MS/MS, HPLC-DAD and other hyphenated techniques are now almost standard for rosemary phenolic fingerprinting. These platforms enable not only to differentiate the main compounds, but also the numerous network of associated derivatives which define the living identity of an extract. This means that the resolution has removed the outdated "description of rosemary extract" as chemically one compound that was once the standard description before using the term "rosemary extract", a practice that now will be replaced by a more precise description of "chemotypes" and "process effects" and application specific "fractions" (Sharma et al., 2020; Lešnik et al., 2021; Athanasiadis et al., 2024).



Biological and Functional Significance of Rosemary Phenolics

This extensive applicability of rosemary phenolics is due to the interface of chemistry and function. It is not only the presence of phenolic compounds in rosemary extracts that is of significance, but rather specific molecules and mixtures that regularly demonstrate useful activity in oxidative, inflammatory, microbial and disease related models. Concurrently, the most feasible results have arisen from defined extracts instead of the use of pure compounds, which are abstracted from the Phyto complex.

Antioxidant and Anti-Inflammatory Activity

Antioxidant activity has been the most widely accepted functional activity attributed to rosemary phenolics. Carnosic acid, having a catechol-like redox behaviour and the capacity to interrupt the radical chain reactions, is particularly active in lipid systems, carnosol is effective in more polar systems, mainly in certain metal-related oxidative contexts, and Rosmarinus acid is markedly active in more polar systems. This division of labour is possible, as the effectiveness of whole rosemary extracts varies based on the matrix in which they are used (Viuda-Martos et al., 2018; Shankar et al., 2024).

As the antioxidant applications come and go, the inflammatory discussion is now following suit: oxidative and inflammatory mechanisms are related in lots of applications. Phenolics from rosemary exhibit a number of effects have been reported as reviews and experimental studies to modulate cytokine related and redox sensitive signaling pathways, indicating increased scope for their use beyond food preservation to a broader nutraceutical and biomedical applications. More recent analyses suggest other polyphenols present in rosemary might play a role in conditions of the gut that are associated with inflammation, although much of this evidence is actually still in its preliminary stages (Zhang and Lu, 2024).

Antimicrobial Activity and Functional Uses

The antimicrobial efficacy of rosemary phenolic extracts observed in modern literature is significant, but dependent heavily on the extract composition, dosage, microbial target and role of non-phenolic co-constituents. A combination of phenolics and delivery matrices (such as formulation and co-extraction) is often more effective at achieving the antimicrobial activity in practical applications. In cosmetics and foods, the matrix effects can either accentuate or diminish the apparent efficacy of the product (Viuda-Martos et al., 2018; Zeroual et al., 2022; Rafya et al., 2024).

Amidst other advantages, the use of this antimicrobial property is appealing to the plant/food industry due to its synergy with the protection against antioxidants. A product containing a substance derived from rosemary which can both slow down oxidation and suppress selected spoilage or pathogenic organisms is therefore of greater commercial value than a product containing a substance which slows down oxidation or suppresses spoilage or pathogenic organisms, but not both.

Neuroprotective and Anticancer Potential

Rosemary phenolics, particularly Rosmarinus acid and carnosic acid, have attracted a growing body of research directed toward the study of mechanisms involved in neuroprotection and cancer. Existing reviews report on evidence for the modulation of oxidative stress, mitochondrial dysfunction, inflammatory signalling, pathways involved in protein aggregation, and a variety of proliferation and apoptosis-related processes in model systems. The biomedicine relevance of rosemary phytochemistry has been strengthened by the increasing mechanism literature; although there is only limited clinical translation, this constitutes a noteworthy development.

It has also been identified in recent studies for its potential in the modulation of oxidative stress and in synergy with complex extracts. Science-wise, the notion that some of the whole rosemary extract may work more effectively than single constituent due to intrastructure synergy of the extract is relevant and has implications on the standardization and marketing of rosemary products (Kola et al., 2024). This broader view on rosmarinic acid's and rosemary-derived compounds' functions is also supported by the



results of parallel reviews performed by Kowalczyk et al. (2024) and Bouammali et al. (2024) in the context of diseases related to cancer.

Food, Pharmaceutical, and Cosmetic Applications

Rosemary is the one of the most obvious examples and whose gradual progression from traditional use to a standardized industrial ingredient status has been successful. For foods, the extracts from rosemary that contain a high concentration of carnosic acid plus carnosol are used as natural antioxidants, particularly for lipid-rich foods, which are commonly a concern for oxidative stability during storage, as well as for quality. The further industrial pathway simply provided a stake in standardized extract specifications (Commission Regulation (EU) 2016/56; EFSA, 2018; WHO/JECFA, 2025) and made the consequences of regulatory recognition of extracts as food additives in defined contexts even more impressive.

The use of rosemary goes beyond its direct antioxidant properties in the pharmaceutical and cosmetics industry. Current extraction and purification techniques offer the possibility to prepare compositionally-sorted fractions that can be used in a various range of topical systems, nutraceuticals, delivery platforms and multifunctional formulations. Furthermore, post-production by-products obtained from rosemary essential oil extraction are more user-friendly for fulfilling the circular bioeconomy concept, while supporting the enhancement of the crop profitability through valorization of by-products by cascading process (Rafya et al., 2024; Ziani et al., 2025).

Such application variety will be useful for plant production strategy. If a crop is a value chain food or fiber, then decisions about how to produce it should be made based on the market. The cultivars, cutting schedules, postharvest handling procedures and quality control requirements can differ between a rosemary field used for fresh cosmesis, an essential-oil distillation line, and a phenolic-extract biorefinery.

Production Implications and Research Gaps

The available evidence indicates that in terms of plant production, optimization of chemical value of rosemary is most effectively achieved by a concerted approach to cultivar selection, management of growing environments, optimization of harvest stage, post-harvest protection and extraction design. However, there are many gaps. The scientific literature is still based on a very limited number of samples, greenhouse environments, and very restrictive extraction methods, whereas commercial production demands solid year-round, location and large-scale production (Mohammed et al., 2024).

There is also a persistent demand for better connections of agronomic variables to compound-specific outcomes. Many a report still focuses just on the total phenolic content and yet a lot of industrial users require data on actual concentrations of Rosmarinus acid, carnosic acid, carnosol, and related derivatives. Chemotype breeding and field testing would be highly advantageous for rosemary and enhance its value for strategic crops producing phenolics in a systematic manner (Baptista et al., 2024; Park et al., 2025).

Standardization of valorization of by-products is another priority. Distillation residues and other secondary streams contain phenolic compounds that are undoubtedly an under-utilized feedstock, although their compositions depend on what was done to the feed at the upstream location. Crop management, primary processing, residue stabilization, and extraction engineering, should therefore be considered as combined processes in future works (what we termed single value chains), not as independent ones (Irakli et al., 2023; Pizani et al., 2022; Ziani et al., 2025).



Conclusions

Rosemary is a member of the traditional aromatic herbs, and a considerable amount of evidence indicates it is more than that. A highly chemical plant system which can yield high biological and economic value phenolic fractions. Antioxidant, anti-inflammatory, antimicrobial and other functional attributes of rosemary extracts are mostly attributed to Rosmarinus acid and phenolic diterpenes, with carnosic acid and carnosol being the most significant in these attributes, and their levels and balance are determined by genotype, environment, phenology, postharvest treatment and extraction technology.

For plant production, rosemary quality needs to be more viewed from a phytochemical perspective as the days get longer. The selection of cultivars and the management of light, harvest scheduling, and biomass processing need to be synchronized to the target market(s) and target compounds profile(s). Next steps are likely to involve selection, better protected and open field management, reduction in the extraction-related environmental impacts and comprehensive valorisation of rosemary by-products in the context of a circular biorefinery. In this context rosemary is not just becoming a herb crop, but a key component for phenolic production for food, medicine and cosmetic industries.

Table 1. Major Phenolic Classes in Rosemary and Their General Biological Significance

Class	Representative examples	Predominant functional trait	Applied relevance
Phenolic acids	Rosmarinic acid, caffeic acid	Strong radical scavenging and metal-chelating activity in polar systems	Functional ingredients, aqueous or hydroalcoholic extracts, nutraceutical and pharmaceutical preparations
Phenolic diterpenes	Carnosic acid, carnosol, rosmanol	Potent antioxidant action and comparatively strong performance in lipid systems	Food preservation, oil stabilization, standardized antioxidant extracts
Flavonoids	Luteolin, apigenin, genkwanin, hispidulin	Supportive antioxidant and anti-inflammatory contribution	Broadening the biological value of whole extracts and chemotaxonomic discrimination
Related minor derivatives	Epirosmanol, methyl carnosate, other abietane-related derivatives	Diversification of the chemical fingerprint and modulation of extract behavior	Chemotype discrimination, quality control, targeted fractionation

Table 2. Selected Recent Studies on Rosemary Phenolic Compounds and Their Production or Application Relevance

Study	Main focus	Key finding	Relevance
Baptista et al., 2024	Mediterranean cultivar comparison	Cultivars shared a similar qualitative profile but differed quantitatively in phenolics, terpenes, and antioxidant performance.	Supports chemotype-based cultivar selection.
Kabubii et al., 2023	Season, agro-ecology, and solvent effects	Marked differences were reported in total phenolics, flavonoids, and antioxidant activity across environments and extraction media.	Helps define optimal production zones and extraction conditions.
Oalđe Pavlović et al., 2025	Seasonal and geographic variation	Phytochemical fingerprints and bioactivity changed with season and location, with evidence of functional	Links field environment to downstream functionality.



		synergy involving rosmarinic acid.	
Park et al., 2025	Artificial LED lighting	Red light enhanced biomass, total phenolics, total flavonoids, and rosmarinic acid in protected cultivation.	Demonstrates quality-oriented controlled-environment production.
Ayyildiz et al., 2024	Comparative green extraction	Supercritical extraction performed strongly for recovering phenolic diterpenes and antioxidant-active fractions.	Technology should be selected according to the target compound class.
Athanasiadis et al., 2024	Optimization of four extraction techniques	Experimental design substantially improved extraction efficiency and antioxidant compound recovery.	Highlights the importance of process optimization.
Irakli et al., 2023	Valorization of distilled by-products	Distillation residues remained a useful source of rosmarinic acid, carnosol, and carnosic acid.	Supports circular economy and residue utilization.
Pizani et al., 2024	Sequential selective extraction	Bio-based solvent systems enabled differentiated recovery of rosmarinic-rich and carnosic-rich fractions.	Useful for tailored extracts and market-specific fractions.
Vieira et al., 2022	Biphasic NADES extraction	Selective extraction and stabilization of rosemary bioactives were achieved in a greener solvent system.	Promising industrial route for sustainable extraction.
Boufetacha et al., 2024	Selective supercritical recovery	Selective recovery of rosmarinic acid, carnosol, and carnosic acid was feasible with strong antioxidant performance.	Improves extract standardization and quality control.
Kola et al., 2024	Rosmarinic acid within whole extract	Rosmarinic acid contributed protective effects against copper-induced oxidative stress within the rosemary matrix.	Reinforces the concept of intra-extract synergy.
Zhang and Lu, 2024	Polyphenols and inflammatory bowel disease	Rosemary polyphenols were highlighted as promising modulators of intestinal inflammation in preclinical evidence.	Expands the health relevance of rosemary phenolics.

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Conflict of interests

No conflict of interest.



References

- Andrade, J. M., Faustino, C., Garcia, C., Ladeiras, D., Reis, C. P., & Rijo, P. (2018). *Rosmarinus officinalis* L.: An update review of its phytochemistry and biological activity. *Future Science OA*, 4(4), FSO283. <https://doi.org/10.4155/fsoa-2017-0124>
- Athanasiadis, V., Chatzimitakos, T., Mantiniotou, M., et al. (2024). Optimization of four different rosemary extraction techniques using Plackett–Burman design and comparison of their antioxidant compounds. *International Journal of Molecular Sciences*, 25(14), 7708. <https://doi.org/10.3390/ijms25147708>
- Aziz, E., Batool, R., Akhtar, W., Rehman, S., Shahzad, T., Malik, A., et al. (2022). Rosemary species: A review of phytochemicals, bioactivities and industrial applications. *South African Journal of Botany*, 151(B), 3–18. <https://doi.org/10.1016/j.sajb.2021.09.026>
- Baptista, A., Menicucci, F., Brunetti, C., et al. (2024). Unlocking the hidden potential of rosemary (*Salvia rosmarinus* Spenn.): New insights into phenolics, terpenes, and antioxidants of Mediterranean cultivars. *Plants*, 13(23), 3395. <https://doi.org/10.3390/plants13233395>
- Bouammali, H., Zraibi, L., Ziani, I., et al. (2024). Rosemary as a potential source of natural antioxidants and anticancer agents: A molecular docking study. *Plants*, 13(1), 89. <https://doi.org/10.3390/plants13010089>
- Boufetaicha, M., Ayad, A., Thiebault, N., et al. (2024). Selective extraction of carnosic acid, carnosol, and rosmarinic acid from *Rosmarinus officinalis* L. using supercritical fluid and their antioxidant activity. *The Journal of Supercritical Fluids*, 212, 106344. <https://doi.org/10.1016/j.supflu.2024.106344>
- EFSA Panel on Food Additives and Nutrient Sources Added to Food. (2018). Refined exposure assessment of extracts of rosemary (E 392) from its use as food additive. *EFSA Journal*, 16(11), e05373. <https://doi.org/10.2903/j.efsa.2018.5373>
- Ersoy, Ş. K. (2025). Isolation of rosmarinic acid from rosemary extract utilizing a molecularly imprinted polymer. *Food Analytical Methods*, 18, 670–681. <https://doi.org/10.1007/s12161-024-02729-z>
- European Commission. (2016). *Commission Regulation (EU) 2016/56 of 19 January 2016 amending Annexes II and III to Regulation (EC) No 1333/2008 as regards the use of extracts of rosemary (E 392) in spreadable fats. Official Journal of the European Union*.
- Ghedira, W., Souissi, M., Boudokhane, C., & Dhaouadi, H. (2025). Eco-friendly extraction and antioxidant profiling of *Rosmarinus officinalis* L.: Advances in supercritical fluid extraction, DFT, and ADMET analyses. *Results in Engineering*, 107422. <https://doi.org/10.1016/j.rineng.2025.107422>
- Irakli, M., Skendi, A., Bouloumpasi, E., et al. (2023). Sustainable recovery of phenolic compounds from distilled rosemary by-product using green extraction methods: Optimization, comparison, and antioxidant activity. *Molecules*, 28(18), 6669. <https://doi.org/10.3390/molecules28186669>
- Kabubii, Z. N., Mbaria, J. M., Mathiu, M. P., Wanjohi, J. M., & Nyaboga, E. N. (2023). Evaluation of seasonal variation, effect of extraction solvent on phytochemicals and antioxidant activity on *Rosmarinus officinalis* grown in different agro-ecological zones of Kiambu County, Kenya. *CABI Agriculture and Bioscience*, 4, 1. <https://doi.org/10.1186/s43170-023-00141-x>
- Kew Science. (2026). *Salvia rosmarinus* Spenn. In *Plants of the World Online*. Royal Botanic Gardens, Kew. Retrieved May 7, 2026, from <https://powo.science.kew.org/>
- Kherraz, K., Guelifet, K., Benmohamed, M., et al. (2026). Seasonal variation in wild *Rosmarinus officinalis* L.: Phytochemicals and their multifunctional potential against metabolic disorders. *Molecules*, 31(2), 220. <https://doi.org/10.3390/molecules31020220>



- Kola, A., Vigni, G., Lamponi, S., & Valensin, D. (2024). Protective contribution of rosmarinic acid in rosemary extract against copper-induced oxidative stress. *Antioxidants*, 13(11), 1419. <https://doi.org/10.3390/antiox13111419>
- Kosmopoulou, D., Lafara, M. P., Adamantidi, T., et al. (2024). Neuroprotective benefits of *Rosmarinus officinalis* and its bioactives against Alzheimer's and Parkinson's diseases. *Applied Sciences*, 14(15), 6417. <https://doi.org/10.3390/app14156417>
- Kowalczyk, A., Tuberoso, C. I. G., & Jerković, I. (2024). The role of rosmarinic acid in cancer prevention and therapy: Mechanisms of antioxidant and anticancer activity. *Antioxidants*, 13(11), 1313. <https://doi.org/10.3390/antiox13111313>
- Lešnik, S., Furlan, V., & Bren, U. (2021). Rosemary (*Rosmarinus officinalis* L.): Extraction techniques, analytical methods and health-promoting biological effects. *Phytochemistry Reviews*, 20, 1273–1328. <https://doi.org/10.1007/s11101-021-09745-5>
- Mohammed, H. A., Sulaiman, G. M., Khan, R. A., et al. (2024). Factors affecting the accumulation and variation of volatile and non-volatile constituents in rosemary, *Rosmarinus officinalis* L. *Journal of Applied Research on Medicinal and Aromatic Plants*, 100571. <https://doi.org/10.1016/j.jarmap.2024.100571>
- Oalđe Pavlović, M., Milutinović, M., Alimpić Aradski, A., et al. (2025). Therapeutic potential of *Salvia rosmarinus*: Seasonal and geographical variation in phytochemical composition, bioactivity, and synergistic effects of rosmarinic acid with 5-FU. *Plants*, 15(1), 1. <https://doi.org/10.3390/plants15010001>
- Oresanya, I. O., & Orhan, I. E. (2024). Deciphering neuroprotective effect of *Rosmarinus officinalis* L. (syn. *Salvia rosmarinus* Spenn.) through preclinical and clinical studies. *Current Drug Targets*, 25(5), 330–352. <https://doi.org/10.2174/0113894501255093240117092328>
- Park, J., Seo, J. W., Ham, D. Y., et al. (2025). Antioxidant activity and phenolic compound of rosemary under artificial LED lights. *Agronomy*, 15(3), 636. <https://doi.org/10.3390/agronomy15030636>
- Pizani, R. S., Viganó, J., Contieri, L. S., et al. (2024). New selective and sustainable ultrasound-assisted extraction procedure to recover carnosic and rosmarinic acids from *Rosmarinus officinalis* by sequential use of bio-based solvents. *Food Chemistry*, 437, 137540. <https://doi.org/10.1016/j.foodchem.2023.137540>
- Pizani, R. S., Viganó, J., de Souza Mesquita, L. M., et al. (2022). Beyond aroma: A review on advanced extraction processes from rosemary (*Rosmarinus officinalis*) and sage (*Salvia officinalis*) to produce phenolic acids and diterpenes. *Trends in Food Science & Technology*, 127, 245–262. <https://doi.org/10.1016/j.tifs.2022.07.001>
- Rafya, M., Zehhar, N., Hafidi, A., & Benkhalti, F. (2024). Review of *Rosmarinus officinalis* L. essential oil, hydrosol, and residues analysis: Composition, bioactivities, and valorization. *Industrial Crops and Products*, 221, 119392. <https://doi.org/10.1016/j.indcrop.2024.119392>
- Saklar Ayyildiz, S., Pelvan, E., & Karadeniz, B. (2024). Optimization of accelerated solvent extraction, ultrasound-assisted and supercritical fluid extraction to obtain carnosol, carnosic acid and rosmarinic acid from rosemary. *Sustainable Chemistry and Pharmacy*, 37, 101422. <https://doi.org/10.1016/j.scp.2023.101422>
- Shankar, A., Ali, A., Abdullah, H. M., et al. (2024). Nutritional composition, phytochemical profile, therapeutic potentials, and food applications of rosemary: A comprehensive review. *Journal of Food Composition and Analysis*, 135, 106688. <https://doi.org/10.1016/j.jfca.2024.106688>
- Sharma, Y., Velamuri, R., Fagan, J., & Schaefer, J. (2020). Full-spectrum analysis of bioactive compounds in rosemary (*Rosmarinus officinalis* L.) as influenced by different extraction methods. *Molecules*, 25(20), 4599. <https://doi.org/10.3390/molecules25204599>



- Vieira, C., Rebocho, S., Craveiro, R., Paiva, A., & Duarte, A. R. C. (2022). Selective extraction and stabilization of bioactive compounds from rosemary leaves using a biphasic NADES. *Frontiers in Chemistry*, 10, 954835. <https://doi.org/10.3389/fchem.2022.954835>
- Viuda-Martos, M., Ruiz-Navajas, Y., Fernández-López, J., & Pérez-Álvarez, J. A. (2018). Antioxidant and antimicrobial properties of rosemary (*Rosmarinus officinalis*, L.): A review. *Medicines*, 5(3), 98. <https://doi.org/10.3390/medicines5030098>
- WHO/JECFA. (2025). *Rosemary extract*. Joint FAO/WHO Expert Committee on Food Additives database.
- World Flora Online Consortium. (2026). *Salvia rosmarinus* Spenn. In *World Flora Online*. Retrieved May 7, 2026, from <http://www.worldfloraonline.org/>
- Zeroual, A., Sakar, E. H., Mahjoubi, F., et al. (2022). Effects of extraction technique and solvent on phytochemicals, antioxidant, and antimicrobial activities of cultivated and wild rosemary (*Rosmarinus officinalis* L.) from Taounate region (Northern Morocco). *Biointerface Research in Applied Chemistry*, 12(6), 8441–8452. <https://doi.org/10.33263/BRIAC126.84418452>
- Zhang, L., & Lu, J. (2024). Rosemary (*Rosmarinus officinalis* L.) polyphenols and inflammatory bowel diseases: Major phytochemicals, functional properties, and health effects. *Fitoterapia*, 177, 106074. <https://doi.org/10.1016/j.fitote.2024.106074>
- Ziani, I., Bouakline, H., Merzouki, M., et al. (2025). Purification of bioactive compounds from rosemary by-products for innovative solutions in food industry. *Industrial Crops and Products*, 223, 120125. <https://doi.org/10.1016/j.indcrop.2024.120125>

