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# Phytochemical Diversity, Bioactivity, and Applied Potential of Medicinal and Aromatic Plants: A Review of Extraction, Environmental Variation, and Functional Relevance

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**ABSTRACT**

Medicinal and aromatic plants are widely recognized as rich sources of secondary metabolites, especially phenolic compounds, that are associated with antioxidant, antimicrobial, antihyperglycemic, and broader functional properties. Across the study, phytochemical composition is consistently described as dependent on species identity, extraction conditions, genetics, environment, and eco-climatic context, which means that plant bioactivity cannot be interpreted apart from how and where the material was obtained and processed. The study examined six medicinal plants used in south-eastern Serbia and showed substantial between-species variation in total phenolics, total flavonoids, individual polyphenol profiles, antioxidant activity, α-glucosidase inhibition, and antimicrobial effects. In that study, Lythrum salicaria had the highest total phenolic content, Filipendula vulgaris had the highest total flavonoid content and complete α-glucosidase inhibition, ethanol extracts generally showed stronger antioxidant activity, and Gram-positive bacteria were more susceptible than the tested fungi or Gram-negative targets. The broader review literature in the study indicates that medicinal and aromatic plants also have applications in food, pharmaceuticals, cosmetics, feed, biopesticides, and agriculture, including use as biostimulants and bioprotectants. At the same time, the referred reviews are explicit that ethnobotanical use alone does not establish efficacy and that many medicinal plants still lack strong clinical validation, despite extensive in vitro and applied evidence. Overall, the study support medicinal and aromatic plants as multifunctional bioresource systems whose promise depends on rigorous extraction, analytical standardization, and stronger translational validation.

**Introduction**

Medicinal and aromatic plants have been used worldwide since prehistoric times and remain central to traditional, complementary, and increasingly commercialized health systems (Kisiriko et al., 2021). Their longstanding use reflects the presence of secondary metabolites that can exert physiological effects and, in some cases, serve as therapeutic agents or lead compounds for pharmaceutical development (Aćimović et al., 2026; Tiwari et al., 2023; Kisiriko et al., 2021). The literature reviewed here consistently presents medicinal and aromatic plants as prominent sources of phenolic compounds and other bioactives with relevance to oxidative stress, inflammation, infection, metabolic disease, and broader functional applications (Pinto et al., 2021; Kisiriko et al., 2021).

Renewed scientific interest in these plants has been driven by several converging pressures. Chronic non-communicable diseases, oxidative stress-related disorders, and antimicrobial resistance have intensified the search for safer and multifunctional alternatives or complements to synthetic agents (Aćimović et al., 2026). In parallel, medicinal and aromatic plants have attracted attention beyond medicine, including in foods, nutraceuticals, cosmetics, feed systems, and sustainable agriculture (Fierăscu et al., 2021; Grigore-Gurgu et al., 2025; Kisiriko et al., 2021). This broad utility arises because plant-derived preparations can be used not only as therapeutic or preventive agents for humans, but also as crop biostimulants and bioprotectants that enhance growth or reduce losses from pests and pathogens (Kisiriko et al., 2021).

At the same time, the literature is careful not to overstate the evidence. Traditional use is a useful starting point for plant selection, but it does not by itself establish efficacy, safety, dose-response relationships, or mechanism of action (Aćimović et al., 2026). One review explicitly notes that, despite widespread use, many medicinal plants still lack strong clinical evidence for the pharmacological effects attributed to them

(Kisiriko et al., 2021). This gap between ethnobotanical use, laboratory evidence, and clinical validation is one of the central themes running across the study.

A second major theme is variation. Phytochemical profiles are not fixed traits of a plant name alone. The literature indicates that composition depends on geography, ecological conditions, elevation, genetics, plant part, and extraction parameters (Aćimović et al., 2026; Tiwari et al., 2023; Grigore-Gurgu et al., 2025). Extraction solvent particularly matters because polar systems enrich different classes of compounds than less polar systems, and no universal extraction method is appropriate across all medicinal and aromatic plants (Pinto et al., 2021; Kisiriko et al., 2021). This methodological heterogeneity is not a minor technical detail; it strongly shapes which compounds are detected and which biological activities are observed.

A third theme is the increasing sophistication of phytochemical analysis. The reviewed literature emphasizes the value of modern analytical strategies such as NMR and MS for identifying new molecular structures and characterizing phenolic profiles, alongside chromatographic platforms for quantification and activity-linked profiling (Pinto et al., 2021; Kisiriko et al., 2021). These tools are essential because medicinal and aromatic plants contain complex mixtures rather than single active agents, and their bioactivity may arise from individual compounds, additive effects, or synergy among constituents (Pinto et al., 2021; Kisiriko et al., 2021).

The present review provides an integrated account of medicinal and aromatic plants with emphasis on four linked questions: what phytochemicals they contain, how those compounds are extracted and characterized, what biological activities they show, and what applications emerge from that evidence (Aćimović et al., 2026; Fierăscu et al., 2021; Kisiriko et al., 2021). Particular attention is given to the 2026 Serbian study of six medicinal plants because it contributes original comparative data linking solvent choice, phytochemical composition, and multiple bioactivity assays in a coherent experimental design (Aćimović et al., 2026). The broader review papers then provide the framework needed to interpret those results in relation to phenolic chemistry, extraction science, eco-climatic variation, aromatic herb functionality, and agricultural applications (Pinto et al., 2021; Tiwari et al., 2023; Grigore-Gurgu et al., 2025; Kisiriko et al., 2021).

**Methodology**

This paper is a structured narrative review based exclusively on the papers about Medicinal and aromatic plants. The review corpus includes one original research article focused on Serbian traditional medicinal plants, four broad reviews on medicinal and aromatic plant bioactives, extraction, and applications, and one predictive ecological analysis of phytochemical diversity across eco-climatic zones in Uttarakhand

(Aćimović et al., 2026; Pinto et al., 2021; Fierăscu et al., 2021; Tiwari et al., 2023; Grigore-Gurgu et al., 2025; Kisiriko et al., 2021).

The synthesis followed a comparative thematic strategy. First, statements from the papers were grouped into major analytical domains: phytochemical diversity, extraction and characterization methods, environmental and biological determinants of composition, experimentally measured bioactivities, and downstream applications (Aćimović et al., 2026; Pinto et al., 2021; Tiwari et al., 2023; Grigore-Gurgu et al., 2025; Kisiriko et al., 2021). Second, the findings from the Serbian study were used as a focal experimental case because that study directly measured phytochemical content and three categories of biological activity across six species and two extraction systems (Aćimović et al., 2026). Third, the broader reviews and the Uttarakhand modeling study were used to contextualize those findings and identify where agreement, limitation, or broader applicability exists (Aćimović et al., 2026; Tiwari et al., 2023).

Since the papers differ substantially in study type, the present review does not attempt meta-analysis. Instead, it synthesizes the evidence qualitatively, with emphasis on recurring findings explicitly reported across the papers. Original experimental outcomes were taken primarily from the Serbian article, including measurements of total phenolic content, total flavonoid content, HPLC-DAD polyphenol profiling, antioxidant assays, α-glucosidase inhibition, and antimicrobial testing (Aćimović et al., 2026). Contextual concepts such as the importance of phenolics, extraction variability, analytical strategies, and non-medical applications were drawn from the other five attached papers (Pinto et al., 2021; Grigore-Gurgu et al., 2025; Kisiriko et al., 2021).

A limitation of this review methodology is that it depends on the scope and framing of the selected papers. Several are narrative reviews, which summarize broad evidence but do not provide pooled quantitative effect estimates (Pinto et al., 2021; Fierăscu et al., 2021; Grigore-Gurgu et al., 2025; Kisiriko et al., 2021). Another limitation is that the attached corpus centres strongly on phytochemistry and preclinical or applied bioactivity rather than human clinical outcomes (Kisiriko et al., 2021). Even so, the selected papers are well suited to constructing an integrated review on medicinal and aromatic plants because together they cover chemistry, extraction, ecology, biological function, and practical application.

**Extraction And Phytochemical Diversity**

Extraction method strongly shapes the chemical profile recovered from medicinal and aromatic plants (Grigore-Gurgu et al., 2025; Kisiriko et al., 2021; Tiwari et al., 2023). Polar solvents such as water, methanol, and hydroalcoholic mixtures preferentially recover phenolic compounds, but no universal extraction method fits all plants because phytochemicals differ in polarity, structure, and abundance (Kisiriko et al., 2021; Pinto et al., 2021).

Analytical characterization is therefore essential. The study emphasize HPLC-DAD, NMR, and MS-based strategies for identifying and quantifying plant phenolics and related metabolites (Aćimović et al., 2026; Pinto et al., 2021; Kisiriko et al., 2021). Reviews also stress optimization of solid-liquid, ultrasound-assisted, microwave-assisted, and supercritical fluid extraction to improve accuracy and scalability (Pinto et al., 2021; Fierăscu et al., 2021).

Environmental context also contributes to phytochemical diversity. In Uttarakhand, medicinal plant phytochemical occurrence varied across eco-climatic zones and elevation, with active compounds more probable in alpine, sub-alpine, and cool temperate zones (Tiwari et al., 2023). Aromatic herb reviews similarly report that phytochemical profiles are shaped by genetics, environment, and their interaction (Grigore-Gurgu et al., 2025).

**Comparative Evidence**

| Domain | Main Finding | Supporting Evidence |
|---|---|---|
| Compound richness | MAPs are abundant sources of **phenolic compounds** and other secondary metabolites | (Kisiriko et al., 2021; Tiwari et al., 2023) |
| Extraction effects | **Solvent and extraction method** strongly influence final composition | (Grigore-Gurgu et al., 2025; Kisiriko et al., 2021; Pinto et al., 2021) |
| Environmental effects | **Eco-climatic zone and elevation** predict phytochemical occurrence | (Tiwari et al., 2023) |
| Functional uses | Major uses span **food, pharma, cosmetics, and agriculture** | (Grigore-Gurgu et al., 2025; Kisiriko et al., 2021) |

**Figure 1:** Cross-paper comparison of phytochemical diversity, extraction dependence, environmental variation, and applications.

**Bioactivity Evidence**

Antioxidant activity is the most consistently reported function across the study (Pinto et al., 2021; Grigore-Gurgu et al., 2025; Kisiriko et al., 2021). This pattern is commonly linked to phenolic content and free radical scavenging capacity (Pinto et al., 2021; Tiwari et al., 2023).

The Serbian primary study provides the clearest side-by-side evidence. *Lythrum salicaria* had the highest total phenolic content at 113.56-119.09 mg GAE/g DW, while *Filipendula vulgaris* had the highest total flavonoid content at 65.74-66.31 mg RE/g DW (Aćimović et al., 2026). HPLC analysis identified notable ferulic acid in *L. salicaria* ethanol extract, alongside rutin, luteolin, and myricetin in several species (Aćimović et al., 2026).

Ethanol extracts generally showed stronger antioxidant activity, with *L. salicaria* reaching 378.60 µM TE/g in DPPH and 684.06 µM TE/g in reducing power, while its aqueous extract had the highest ABTS activity at 3621.93 µM TE/g (Aćimović et al., 2026). This supports the broader view that solvent choice changes not only yield but also assay-specific performance (Aćimović et al., 2026; Grigore-Gurgu et al., 2025).

Antihyperglycemic activity was also notable. *F. vulgaris* extracts produced 100% α-glucosidase inhibition (Aćimović et al., 2026). Antimicrobial activity was stronger against Gram-positive bacteria, particularly *Listeria monocytogenes* and *Staphylococcus aureus*, with *F. vulgaris* and *L. salicaria* showing the strongest effects (Aćimović et al., 2026).

**Results**

**Phytochemical Diversity**

Medicinal and aromatic plants are consistently presented across the papers studied as abundant sources of phenolic compounds and other secondary metabolites with biological relevance. The main phytochemical classes identified in the corpus include phenolic compounds, terpenoids, and nitrogen-containing compounds, with many species also discussed in terms of flavonoids, phenolic acids, and related subclasses

The Uttarakhand study reinforces the scale of this diversity. It screened 789 medicinal plant species from 144 taxonomic families and used a systematic approach to assess the presence of chemical groups and active compounds across eco-climatic gradients. That paper also notes that more than 200 specific biologically active compounds were represented in the surveyed medicinal plants and that many species remain insufficiently explored in detail.

The Serbian experimental study provides concrete species-level evidence of compositional heterogeneity. Among the six studied plants, Lythrum salicaria showed the highest total phenolic content and Filipendula vulgaris showed the highest total flavonoid content. HPLC analysis identified particularly notable ferulic acid content in the ethanol extract of L. salicaria, and also detected rutin, luteolin, and myricetin in several of the studied species.

**Extraction and Analytical Methods**

Most of the studies strongly agree that extraction method is a major determinant of phytochemical yield and profile. Polar solvents such as water, methanol, and hydro-alcoholic systems preferentially recover phenolic-rich fractions, but no single extraction strategy can be assumed optimal across all species because phenolics differ in polarity, concentration, and structure.

The broader methodological reviews highlight solid-liquid extraction, ultrasound-assisted extraction, microwave-assisted extraction, and supercritical fluid extraction as important options for improving accuracy and recovery. They also emphasize the value of modern analytical platforms such as NMR and MS for identifying new structures and characterizing phenolic profiles.

The Serbian paper operationalizes this general point by directly comparing aqueous versus 40% ethanol extracts. Its core result is that plant species and extraction solvent both significantly influence the measured bioactivity, which supports the wider conclusion that extraction is not just a technical step but part of the biological interpretation.

**Environmental Patterning**

The ecological paper in the study adds an important dimension that is largely absent from the species-level assay paper: phytochemical occurrence varies across environment and elevation. This study reveals that, chemical groups were more probable in tropical, sub-tropical, and warm temperate zones, whereas active compounds had higher probability toward alpine, sub-alpine, and cool temperate zones.

This study also predicts that the occurrence of species with active compounds declines significantly with elevation, while total active compounds increase across elevation from 1000 m. In parallel, the occurrence of species with chemical groups increases but the total number of chemical groups declines with increasing elevation from 1000 m. These findings suggest that environmental filtering shapes not only whether phytochemicals are present, but how phytochemical richness is distributed across landscape.

**Antioxidant Activity**

Antioxidant activity is the most consistently emphasized biological outcome across the study. Reviews link this activity mainly to phenolic content and free radical scavenging capacity, although they also note that composition and synergy among compounds matter.

In the Serbian study, antioxidant activity was measured using DPPH, ABTS, and reducing power assays. Ethanol extracts generally showed stronger antioxidant performance, and L. salicaria achieved the highest DPPH and reducing power values, while its aqueous extract showed the highest ABTS activity. This pattern supports the interpretation that solvent effects are assay dependent rather than uniform across all antioxidant endpoints.

**Antihyperglycemic Activity**

The Serbian study directly reports the α-glucosidase inhibition data. Its strongest antihyperglycemic result is that F. vulgaris extracts showed 100% α-glucosidase inhibition. This is one of the clearest examples of a strong species-specific functional outcome tied to comparative phytochemical profiling.

**Antimicrobial Activity**

Antimicrobial activity is a second major recurring endpoint across the studied literature. Reviews note antibacterial effects for polyphenol-rich extracts from onion, nutmeg, thyme, and other medicinal or aromatic plants, while also pointing out that potency depends on the concentration and combination of compounds present.

The Serbian study found that Gram-positive bacteria were more sensitive than the tested fungal strains and other targets, with Listeria monocytogenes and Staphylococcus aureus showing particular susceptibility. F. vulgaris and L. salicaria produced the strongest antimicrobial effects among the six species evaluated.

**Discussion**

The review converge on a clear central conclusion: medicinal and aromatic plants are best understood as context-dependent phytochemical systems rather than as fixed therapeutic entities. Their biological properties depend not only on taxonomy, but also on environment, extraction method, and the analytical lens used to detect active compounds. This conclusion is strongly supported by the Serbian study, where the same nominal plant categories yielded materially different antioxidant, antihyperglycemic, and antimicrobial outcomes depending on species and solvent.

A major strength of the study is that it bridges laboratory bioactivity with broader questions of sourcing and application. The study extends the discussion from individual extracts to landscape-level phytochemical diversity, showing that eco-climatic zone and elevation can predict different distributions of chemical groups and active compounds. That matters because it implies that conservation strategy, cultivation choice, and bioprospecting priorities should incorporate ecological gradients rather than relying only on historical use or taxonomy.

The study also shows that medicinal and aromatic plant research now spans more than health-related bioactivity. The aromatic herb review emphasizes applications in food, feed, pharmaceuticals, cosmetics, biopesticides, and textiles. The phenolics review extends that application space further into agriculture, where plant extracts and isolated phenolics have shown biostimulant activities such as enhanced germination, rooting, shooting, and fruiting, along with bioprotectant effects including antimicrobial, insecticidal, nematicidal, and herbicidal actions.

At the same time, the study cares about the limits of the evidence. Traditional medicine is described as a valuable starting point, but not as proof of efficacy, safety, or mechanism. One review explicitly states that there is still a lack of clinical evidence for many of the pharmacological effects attributed to medicinal plants. This means the strongest current evidence in the attached set supports preclinical functionality and applied potential, not established clinical efficacy.

Another important nuance is that phenolics appear to matter both as individual molecules and as components of mixtures. The agricultural phenolics review states that much of extract bioactivity may be due to synergistic interactions, yet also notes that isolated phenolic compounds can be bioactive on their own. That point helps interpret why whole extracts in the Serbian paper could show strong activity even when no single measured compound fully explains the outcome.

Methodological standardization therefore remains a major research need. Multiple papers stress that extraction optimization, sample preparation, and advanced analytical methods are essential for accurate characterization. Without that standardization, comparisons across species, regions, or product types will remain difficult and may overstate or understate true biological differences.

**Conclusion**

Medicinal and aromatic plants contain diverse phytochemicals with reproducibly reported antioxidant and antimicrobial activity, plus more selective evidence for antihyperglycemic and agricultural applications. Across the study, the most robust conclusion is that phytochemical composition and bioactivity are strongly shaped by species, extraction conditions, and environment, so rigorous characterization is essential before translational claims are made.

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