



From Plant Chemistry to Therapeutic Intelligence: Phytochemistry, Extraction and Analytical Standardization of Medicinal and Aromatic Plants

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Abstract

Medicinal and aromatic plants represent an important interface between traditional knowledge, plant chemistry, pharmacology, agriculture and industrial biotechnology. Their applications extend from traditional medicine to pharmaceutical, cosmetic, food, nutraceutical and personal-care industries. Historically, medicinal plants were used as crude drugs, powders, juices, decoctions, poultices and oils, whereas aromatic plants were valued for fragrances, essential oils, preservation and therapeutic applications. Advances in pharmacognosy, phytochemistry, chromatography and spectroscopy transformed botanical materials into sources of chemically characterized metabolites and bioactive molecules. Contemporary research increasingly incorporates metabolomics, advanced extraction, molecular pharmacology, quality control, sustainable cultivation and artificial-intelligence-assisted discovery. This critical review examines medicinal and aromatic plants across historical utilization, plant-part selection, phytochemical diversity, extraction, processing, quality control, biological activity and industrial applications. It proposes therapeutic intelligence as an integrated framework linking botanical identity, genotype, environment, harvesting, processing, extraction, chemical transformation, metabolite exposure, molecular targets and biological responses. Metabolomics, spatial chemical profiling, multi-omics and artificial intelligence may strengthen links between chemical composition, biological function and product standardization. However, chemical variability, reproducibility, toxicity, pharmacokinetics, clinical validation and regulatory standardization remain major barriers. Future research should prioritize predictive, standardized, mechanistically informed and sustainable pathways from plant chemistry to therapeutic products.

Keywords: Medicinal Plants; Phytochemistry; Extraction; Analytical Standardization; Metabolomics; Therapeutic Intelligence

Abbreviations: MPs: Medicinal Plants; APs: Aromatic Plants; ADME: Absorption, Distribution, Metabolism and

Excretion; AI: Artificial Intelligence.

Introduction

Medicinal plants (MPs) and aromatic plants (APs) have accompanied human civilization from the earliest stages of organized healthcare. Plants were initially selected through observation, experimentation and accumulated traditional knowledge, long before the chemical constituents responsible for their effects were known. Aromatic plants were similarly used for medicine, food preparation, preservation, religious practices, cosmetics and perfumery. Their essential oils and volatile constituents later became important subjects of chemical and pharmacological investigation [1-3]. The historical development of MAPs utilization therefore represents a progression from empirical observation to organized materia medica, pharmacognosy, phytochemistry and modern molecular science. The contemporary importance of MAPs arises from their chemical diversity. Alkaloids, terpenoids, phenolics, flavonoids, glycosides, tannins, saponins, coumarins and volatile constituents provide a large chemical space for pharmaceutical and industrial applications [4-6]. Recent advances in metabolomics demonstrate that medicinal plants and botanical preparations possess highly complex chemical profiles in which metabolite distribution can vary considerably among species, cultivars, tissues and physiological conditions [7-9]. In particular, untargeted mass-spectrometry-based metabolomics is increasingly being used to distinguish cultivars, chemotypes and chemically distinct botanical materials, while also providing opportunities for authentication, adulteration detection and quality assessment [9]. The 2026 literature therefore supports a shift from conventional marker-compound analysis toward multidimensional chemical characterization. However, the therapeutic value of a plant cannot be reliably predicted from the presence of a single compound. Chemical composition varies according to species, genotype, geographical location, climate, soil, plant part, developmental stage, harvesting time, drying conditions, storage and extraction technology [7,8]. Contemporary research increasingly demonstrates that these factors can interact rather than act independently. For example, a 2026 systematic review of Mediterranean medicinal and aromatic plants found that stress intensity, duration and genotype influence essential-oil production and composition, suggesting that appropriately controlled mild abiotic stress may represent a potential strategy for modulating secondary-metabolite production while maintaining acceptable plant growth [10,11]. This variability creates an important scientific challenge. The traditional question "Which medicinal plant contains which active compound?" is increasingly insufficient. A more useful question is: How do botanical identity, cultivation, plant chemistry, processing, extraction, molecular transformation and biological activity collectively determine the final therapeutic or industrial value of a medicinal or aromatic

plant? The answer increasingly requires integration of advanced analytical and computational technologies. Spatial metabolomics, for example, enables the localization of metabolites within plant tissues rather than relying exclusively on homogenized samples. Integration with spatial multi-omics, single-cell analysis and artificial-intelligence-assisted image analysis is opening new possibilities for understanding the spatial and temporal regulation of secondary-metabolite biosynthesis [12]. Recent AI research is increasingly addressing medicinal-plant-specific bottlenecks rather than merely transferring conventional drug-discovery algorithms to botanical datasets. These bottlenecks include extract complexity, dereplication, structural elucidation, taxonomic ambiguity, ADMET prediction and multi-component pharmacology. AI-assisted workflows incorporating machine learning, graph-based models, virtual screening and multi-omics network analysis may therefore help prioritize chemically and biologically relevant candidates, although experimental validation remains indispensable [13,14]. APs research is also moving beyond simple essential-oil characterization toward integrated biosynthesis, extraction, formulation and therapeutic translation. Recent research emphasizes that essential oils remain limited by low yields, complex chemical composition, poor aqueous solubility, restricted bioavailability and sensitivity to heat, light and oxidation. Consequently, metabolic regulation, advanced extraction, analytical characterization and formulation technologies are becoming increasingly important for converting volatile plant metabolites into reproducible therapeutic and industrial products [15,16]. This review addresses these developments while following the major educational and scientific domains of MAPs: history and importance, plant-part utilization, extraction and isolation, cultivation and processing, quality control, industrial applications and biological activities. The objective is to move from descriptive phytochemistry toward an integrated framework of therapeutic intelligence should therefore be understood as a decision-support framework rather than an autonomous drug-discovery system; computational prediction cannot substitute for pharmacokinetic, toxicological, manufacturing, regulatory and clinical validation.

Historical Development of Medicinal and Aromatic Plants

The use of medicinal plants predates written pharmacology, originating in early societies that identified plants for healing, nutrition, toxicity and preservation through accumulated experience. In antiquity, Egyptian records documented organized plant-based therapeutics, while Ayurveda and Traditional Chinese Medicine developed extensive botanical materia medica and preparation practices [1,17]. During the Greek and Roman periods,

medicinal plants were systematically described, notably in Dioscorides' *De Materia Medica*. During the medieval period, Arabic and Persian scholars preserved and expanded botanical knowledge and advanced pharmaceutical preparation and distillation technologies [2,3]. The nineteenth century marked the emergence of modern pharmacognosy and natural-product chemistry through the isolation of defined constituents such as morphine and quinine [4,5]. The twentieth century introduced chromatography, spectroscopy, mass spectrometry and NMR, enabling chemical characterization and quality assessment. In the twenty-first century, medicinal and aromatic plant research has progressed toward metabolomics, molecular networking, genomics, computational chemistry and artificial intelligence. Throughout this evolution, traditional use remains hypothesis-generating and requires chemical, pharmacological and toxicological validation [5,17].

Medicinal and Aromatic Plant Parts and their Utilization

Different plant organs accumulate distinct chemical constituents. Roots and rhizomes may concentrate alkaloids, terpenoids and storage metabolites; leaves often contain phenolics, flavonoids and volatile constituents; flowers may accumulate pigments, fragrances and essential oils; fruits and seeds may contain fixed oils, proteins and specialized metabolites; while bark can contain tannins, alkaloids and other defensive chemicals [4-6]. Consequently, the description of a plant simply as "medicinal" is incomplete without specifying the particular plant part used, because roots, rhizomes, leaves, bark, flowers, fruits and seeds may differ substantially in their phytochemical composition, concentration of bioactive constituents and associated biological properties [4-7].

Plant part/material	Representative phytochemical constituents	Conventional utilization/preparation	Suitable extraction or processing approach	Reported biological relevance	Major industrial applications
Roots and rhizomes	Alkaloids, terpenoids, phenolics, saponins, polysaccharides	Powder, decoction, infusion, poultice	Maceration, decoction, solvent extraction, ultrasound-assisted extraction	Anti-inflammatory, antimicrobial, gastrointestinal and neurological activities; immunomodulatory potential [4-6]	Pharmaceuticals, nutraceuticals, herbal formulations
Leaves	Flavonoids, phenolic acids, tannins, terpenoids, essential oils	Juice, infusion, decoction, powder, poultice	Aqueous/ethanolic extraction, ultrasound-assisted extraction, steam distillation for volatiles	Antioxidant, antimicrobial and anti-inflammatory activities; potential metabolic effects [5,6]	Herbal medicines, teas, cosmetics, nutraceuticals
Flowers	Flavonoids, anthocyanins, phenolics, volatile terpenes, pigments	Infusion, decoction, aromatic preparations	Solvent extraction, hydrodistillation, steam distillation	Antioxidant and antimicrobial activities; potential anti-inflammatory and neuroactive effects [7,8]	Perfumes, essential oils, cosmetics, herbal products
Fruits	Phenolics, flavonoids, carotenoids, terpenoids, vitamins and fixed oils	Juice, pulp, powder, decoction	Pressing, solvent extraction, aqueous extraction, supercritical-fluid extraction	Antioxidant and antimicrobial activities; potential metabolic and health-promoting effects [5,6]	Foods, nutraceuticals, beverages and pharmaceuticals
Seeds	Fixed oils, proteins, alkaloids, lignans, flavonoids and terpenoids	Powder, oil, infusion/decoction	Cold pressing, solvent extraction, supercritical-fluid extraction	Antioxidant, antimicrobial and anti-inflammatory activities; potential metabolic effects [4-6]	Nutraceuticals, edible oils, cosmetics, pharmaceuticals
Bark	Tannins, alkaloids, phenolics and terpenoids	Decoction, powder, topical preparations	Aqueous, hydroalcoholic and solvent extraction	Antimicrobial, antioxidant and anti-inflammatory activities [4,5]	Traditional medicines, phytopharmaceuticals

Aerial parts	Polyphenols, flavonoids, terpenoids and volatile constituents	Infusion, decoction, powder and extract	Solvent extraction, hydro-distillation, ultrasound-assisted extraction	Antioxidant, antimicrobial and anti-inflammatory activities [6–8]	Herbal extracts, teas, nutraceuticals and cosmetics
Aromatic leaves/ flowers	Monoterpenes, sesquiterpenes, phenylpropanoids and oxygenated terpenes	Essential oil, infusion, aromatic preparations	Hydrodistillation, steam distillation, microwave-assisted extraction	Antimicrobial, antioxidant and anti-inflammatory activities; potential insect-repellent effects [7,8]	Perfumery, cosmetics, food preservation, aromatherapy and pharmaceuticals
Essential oils	Terpenes, terpenoids, phenylpropanoids and minor volatile constituents	Aromatic oil, topical formulations, inhalation preparations	Hydrodistillation, steam distillation, supercritical-fluid extraction	Antimicrobial, antioxidant, anti-inflammatory and other pharmacological activities [7,8]	Pharmaceuticals, food, fragrance, cosmetics and personal care
Plant exudates/ resins	Terpenoids, resin acids, phenolics and volatile components	Topical preparations, fumigation, traditional medicines	Solvent extraction, steam distillation and resin processing	Antimicrobial, wound-related and anti-inflammatory potential [4–6]	Pharmaceuticals, fragrances, coatings and cosmetics

Table 1: Medicinal and aromatic plant parts, major phytochemical constituents, traditional preparation, extraction approaches and principal applications.

The same species may also serve simultaneously as a medicinal and aromatic resource, depending on the plant organ and the type of preparation obtained. Traditionally, medicinal and aromatic plants have been utilized in diverse preparations, including powders, infusions, decoctions, juices, poultices, lotions, ointments, fixed oils, essential oils, tinctures and crude or partially purified extracts. These preparations are not chemically equivalent because the extraction medium, temperature, duration and processing conditions selectively determine which constituents are recovered, concentrated, degraded or transformed. Aqueous preparations generally favour polar and water-soluble constituents, whereas hydroalcoholic and organic-solvent extractions can recover compounds of different polarity; distillation, in contrast, primarily concentrates volatile constituents and therefore produces a chemical profile distinct from that of non-volatile extracts [15–18]. Thus, the plant part and preparation method together constitute important determinants of the chemical identity, reproducibility, biological activity and eventual therapeutic or industrial value of a MAPs-derived product. These preparations are not chemically equivalent. Water extraction preferentially recovers polar constituents, whereas organic solvents can extract less-polar metabolites. Distillation concentrates volatile components but excludes many non-volatile compounds. Therefore, preparation method effectively determines the chemical identity of the administered product. This observation is particularly important for modern standardization. A plant cannot

be standardized merely by naming its species; the plant part, processing method, extraction solvent and chemical fingerprint must also be defined. Different plant organs differ substantially in their accumulation of specialized metabolites and therefore require different harvesting, processing and extraction strategies [4–10]. The relationship between plant parts, representative phytochemicals, traditional preparations, extraction approaches, biological relevance, industrial applications and quality considerations is summarized in Table 1.

The comparison in Table 1 demonstrates that plant-part selection is a critical determinant of phytochemical composition, extraction efficiency and biological potential. Accordingly, medicinal and aromatic plant research should consider botanical identity, plant organ, harvesting stage and processing conditions as interconnected variables rather than independent experimental parameters.

Phytochemical Diversity and Biological Potential

MAPs contain a chemically diverse array of specialized metabolites that contribute to their characteristic biological and pharmacological properties. Major phytochemical groups include alkaloids, terpenoids, phenolics, flavonoids, glycosides, saponins and volatile essential-oil constituents. These groups differ considerably in their molecular

structures, physicochemical properties, biosynthetic origins and biological targets [5,6]. Table 2 summarizes the principal phytochemical groups found in medicinal and aromatic

plants, representative constituents and their major biological or pharmacological relevance.

Chemical group	Representative constituents	Pharmacological relevance
Alkaloids	Morphine, quinine, atropine	CNS-active, analgesic, antimalarial and other pharmacological effects
Terpenoids	Menthol, thymol, limonene	Aromatic, antimicrobial and anti-inflammatory potential
Phenolics	Phenolic acids, tannins	Antioxidant and antimicrobial potential
Flavonoids	Quercetin, rutin	Antioxidant and signalling-related activities
Glycosides	Various cardiac and phenolic glycosides	Diverse pharmacological effects
Saponins	Triterpenoid/steroidal saponins	Membrane and immunological effects
Essential-oil constituents	1,8-cineole, linalool, eugenol	Fragrance, antimicrobial and pharmacological applications

Table 2: Major phytochemical groups of medicinal and aromatic plants and their representative biological relevance.

As shown in Table 2, no single phytochemical class can explain the overall therapeutic potential of medicinal and aromatic plants. Alkaloids may exhibit potent interactions with specific molecular targets, whereas phenolics and flavonoids frequently participate in antioxidant and cell-signalling processes. Terpenoids and volatile constituents contribute substantially to the characteristic aroma of many MAPs while also exhibiting diverse biological activities. Importantly, the biological response of a plant preparation may arise from additive, synergistic or antagonistic interactions among multiple constituents, rather than from its most abundant compound alone [4-10]. This chemical complexity represents both an opportunity and a challenge. A diverse metabolite profile provides a large chemical space for discovering new therapeutic molecules, but it also makes activity attribution, standardization and reproducibility difficult. Therefore, conventional identification of one or two marker compounds should increasingly be complemented by chromatographic fingerprints, metabolomic profiling and biological-response mapping [7-10]. However, a major limitation of traditional phytochemical research is the tendency to equate chemical abundance with therapeutic importance. The most abundant compound is not necessarily the most biologically important. Minor constituents may interact with major metabolites, alter absorption, modulate metabolic enzymes or contribute to synergistic effects. The therapeutic and industrial potential of medicinal and aromatic plants is determined by a sequence of interconnected processes beginning with botanical material selection and extending

through extraction, phytochemical characterization, biological evaluation and product development. Different plant organs including leaves, flowers, bark, rhizomes, roots, fruits and seeds contain distinct chemical profiles and therefore require appropriate processing and extraction strategies. Conventional techniques such as maceration, solvent extraction and distillation remain important, while modern analytical platforms enable increasingly detailed characterization of complex plant extracts [4-10]. The overall relationship between plant resources, extraction technologies, phytochemical diversity, biological activities and final applications is summarized in Figure 1.

As illustrated in Figure 1, medicinal and aromatic plant research should not be considered as a linear process ending with the identification of a single “active compound.” Rather, it represents a connected chemical-to-biological pathway. Extraction conditions can alter the composition of an extract, while environmental conditions, cultivation practices, harvesting time and post-harvest processing can further influence the abundance and stability of phytochemicals [7-10]. Consequently, chemical characterization should be integrated with biological testing and quality assessment. This integrated perspective provides the foundation for moving from conventional phytochemical investigation toward therapeutic intelligence, in which botanical identity, chemical composition, processing history, molecular activity and potential applications are considered collectively.

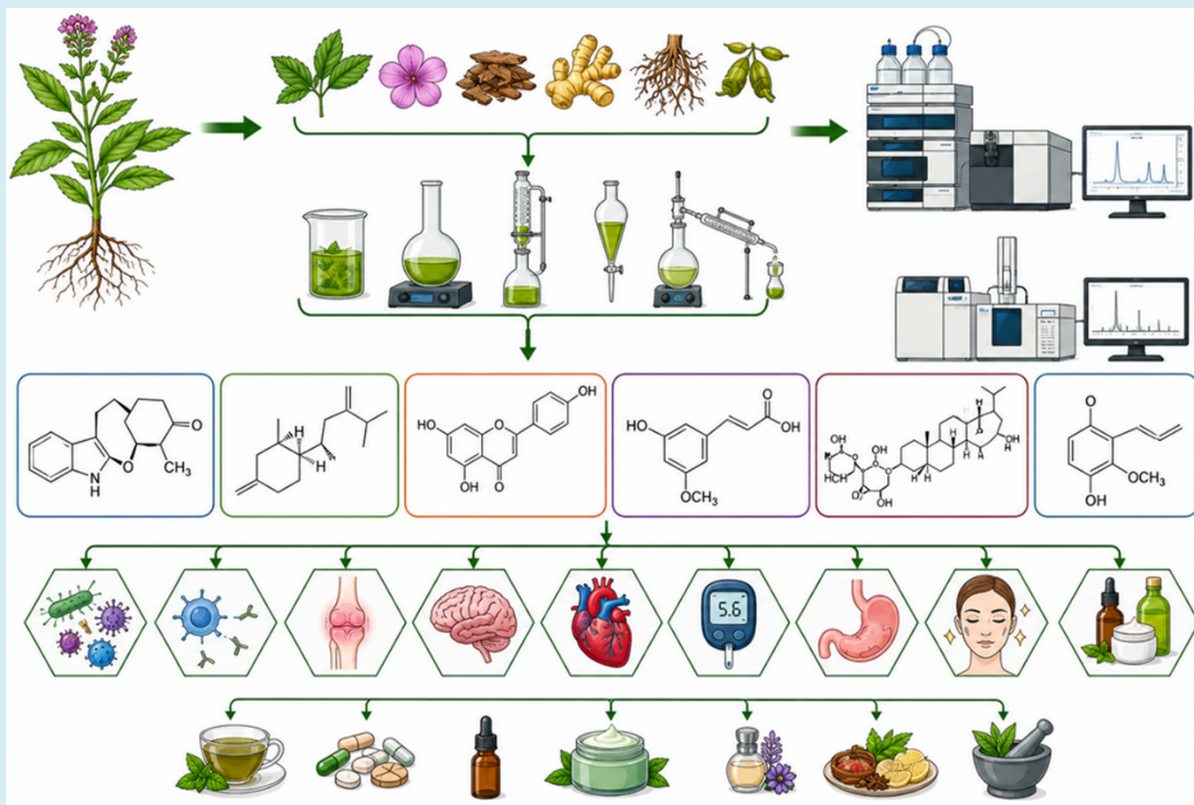


Figure 1: Integrated pathway from medicinal and aromatic plant resources to phytochemical discovery, biological activity and therapeutic applications.

Analytical Chemistry of Medicinal and Aromatic Plants

Analytical chemistry provides the essential bridge between botanical identity, phytochemical composition, quality control and biological interpretation of MAPs. Because botanical materials contain chemically complex and variable mixtures, complementary chromatographic, spectroscopic, mass-spectrometric and molecular approaches are increasingly required for reliable characterization and standardization [7,9-14,19]. HPLC and HPTLC remain important techniques for the separation, identification and quantification of non-volatile phytochemicals, including alkaloids, phenolics, flavonoids, glycosides and other marker constituents. Beyond individual-compound quantification, chromatographic fingerprints can provide broader chemical signatures for comparing batches, geographical origins, chemotypes and processed materials. HPTLC is particularly useful for rapid fingerprinting and routine quality assessment, whereas HPLC provides greater quantitative and separation capability [20,9,19]. GC-MS is particularly valuable for essential oils and other volatile constituents, enabling simultaneous separation and mass-spectral identification of monoterpenes, sesquiterpenes, oxygenated terpenes and phenylpropanoids. It is therefore

widely applied to essential-oil profiling, chemotype differentiation, adulteration assessment and monitoring of compositional changes caused by harvesting, processing, storage and oxidation [10,18,21]. LC-MS/MS extends analytical capability to complex non-volatile metabolomes and supports both targeted quantification and untargeted metabolite profiling. High-resolution MS can detect molecular features that may subsequently be annotated or structurally characterized, thereby facilitating dereplication and the discovery or prioritization of previously unrecognized metabolites [9,13,19]. NMR spectroscopy complements MS by providing information on molecular structure and is particularly useful for relatively abundant metabolites, metabolite profiling and confirmation of structural assignments. Integration of HRMS-based metabolomics with chromatographic separation, molecular networking and multivariate analysis enables complex chemical fingerprints to be associated with biological or botanical differences. Chemometrics and artificial intelligence (AI) can further transform high-dimensional analytical data into authentication, classification and prediction models, including discrimination of species, geographical origins, chemotypes and adulterants [9-14]. However, predictive models require appropriate datasets, chemical annotation and experimental validation. DNA barcoding and

metabarcoding provide an orthogonal approach to botanical authentication, particularly when morphology or chemical markers are insufficient for distinguishing closely related or processed materials. Their greatest value is achieved when combined with chromatographic and spectrometric fingerprints rather than used as replacements for chemical analysis [19]. Thus, hyphenated approaches such as HPLC-MS, HPTLC-MS, GC-MS and LC-MS/MS, integrated with chemometrics, metabolomics and biological assays, provide a multidimensional strategy for connecting botanical identity and chemical composition with biological activity, quality and therapeutic potential.

Extraction Techniques: From Conventional Methods to Green Processing

Extraction is the critical bridge between plant biomass and phytochemical products. Conventional approaches include maceration, percolation, infusion, decoction, Soxhlet extraction, solvent extraction, hydrodistillation and steam distillation. For essential oils, hydrodistillation and steam distillation remain important conventional approaches [15,18]. Hydrodistillation involves contact between plant material and water, whereas steam distillation exposes plant material to steam. The temperature, pressure, duration, particle size, water-to-material ratio and plant moisture content can strongly influence yield and chemical composition. Modern approaches include:

- ultrasound-assisted extraction;

- microwave-assisted extraction;
- solvent-free microwave extraction;
- supercritical-fluid extraction;
- pressurized-liquid extraction;
- enzyme-assisted extraction;
- subcritical-fluid extraction.

These technologies can reduce extraction time and solvent consumption and, in appropriate circumstances, improve recovery of thermolabile or otherwise difficult-to-extract compounds [15,18]. Recent comparative work emphasizes that extraction technology affects not only yield but also economic and green performance. Maximum extraction yield does not necessarily mean maximum therapeutic quality. An extraction process may increase total extractable material while simultaneously degrading thermolabile constituents or altering the relative abundance of biologically important compounds. The optimal extraction process should consequently be defined by a multidimensional objective: yield + chemical integrity + biological activity + safety + energy efficiency + solvent sustainability + economic feasibility. The selection of an extraction method should therefore be treated as a multidimensional optimization problem in which chemical recovery, molecular integrity, biological activity, solvent and energy consumption, environmental burden, scalability and economic feasibility are considered simultaneously (Table 3).

Technique	Main advantage	Main limitation	Best suited for
Maceration	Simple, inexpensive	Long extraction time	Polar/semi-polar compounds
Soxhlet	Exhaustive extraction	High solvent/thermal exposure	Relatively stable compounds
Hydrodistillation	Established EO method	Thermal degradation possible	Volatile oils
Ultrasound-assisted	Faster extraction	Scale-up considerations	Phenolics and flavonoids
Microwave-assisted	Rapid heating	Possible degradation	Polar and thermally manageable compounds
Supercritical CO ₂	Low solvent residue, tunable	High capital cost	Non-polar compounds/essential oils
Pressurized liquid	Rapid and efficient	Equipment cost	Diverse phytochemicals
Enzyme-assisted	Improved cell disruption	Enzyme cost/control	Bound phenolics and complex matrices

Table 3: Comparison of Conventional and Advanced Extraction Technologies for Medicinal and Aromatic Plants.

The comparison in Table 3 demonstrates that no single extraction technology is universally optimal for medicinal and aromatic plants. The appropriate method depends on the chemical nature and stability of the target constituents, desired extract characteristics, energy and solvent

requirements, scale of production and intended application. Importantly, extraction efficiency should not be evaluated solely according to extraction yield. Preservation of chemical integrity, biological activity, safety, environmental impact and scalability should also be considered when selecting an

extraction process [15,18].

Essential Oils and Aromatic Plant Chemistry

Essential oils are complex mixtures dominated by volatile terpenoids and related compounds. Their composition is strongly affected by genetics, geographical origin, developmental stage, environmental conditions and extraction method [18,21]. Major components may include monoterpenes, sesquiterpenes, oxygenated terpenes and phenylpropanoids. Compounds such as menthol, thymol, carvacrol, eugenol, linalool, limonene and 1,8-cineole contribute to the characteristic chemical and sensory properties of many aromatic plants. Essential oils have attracted interest because of reported antimicrobial, antioxidant, anti-inflammatory, analgesic, insecticidal and other biological activities. Their applications extend to pharmaceuticals, food preservation, cosmetics, perfumery and nutraceutical products [18,21]. Nevertheless, essential oils have important limitations: low yield, volatility, oxidation sensitivity, poor aqueous solubility, variable composition and sometimes limited bioavailability. A recent 2026 review specifically highlights these challenges and emphasizes the growing importance of biosynthetic understanding, extraction optimization, analytical characterization and formulation strategies such as encapsulation. Thus, the future of aromatic plant research should not focus solely on “extracting more oil”, but on producing chemically reproducible, stable and biologically validated volatile formulations.

Chemical Transformation During Processing and Biological Exposure

The chemical composition of MAP materials is not static; phytochemicals may undergo substantial transformation during harvesting, drying, storage, extraction, formulation, digestion and metabolism. Consequently, compounds detected in the fresh or dried botanical material may not necessarily represent the chemical species ultimately responsible for biological effects. Processing conditions such as temperature, moisture, oxygen exposure, light and extraction solvent can promote oxidation, hydrolysis, degradation, isomerization or volatilization of susceptible constituents, thereby modifying the chemical profile and biological properties of the resulting preparation [7,15,16,18]. Drying and storage are particularly important for volatile and oxidation-sensitive constituents. Essential oils can undergo compositional changes because of volatilization and oxidative degradation, while prolonged or inappropriate storage may alter the relative abundance of individual terpenoids and other constituents [10,18]. Similarly, extraction should be regarded not simply as a recovery process but as a chemical-selection step. Solvent polarity, temperature, extraction duration and processing

technology determine which metabolites are recovered and whether thermolabile compounds are preserved or transformed. Thus, an extraction procedure producing the highest overall yield may not necessarily produce the chemically or biologically optimal extract. Chemical transformation can continue after administration. During gastrointestinal digestion and human metabolism, plant-derived constituents may undergo hydrolysis, oxidation, reduction, conjugation and other biotransformation reactions, generating metabolites with physicochemical and pharmacological properties different from those of the parent compounds [5,16]. Some transformation products may retain or enhance biological activity, whereas others may be inactive or contribute to toxicity. Therefore, evaluation based exclusively on compounds identified in the original botanical extract may provide an incomplete representation of actual exposure. Modern analytical approaches provide opportunities to characterize these dynamic chemical changes. Chromatographic and mass-spectrometric techniques, including HPLC, GC-MS and LC-MS/MS, can monitor degradation and transformation products, while NMR and metabolomic approaches can provide complementary information on broader chemical changes [7,9,12]. Integration of chemical profiling with pharmacokinetic, toxicological and biological data is therefore essential for linking botanical composition with actual metabolite exposure and therapeutic response. A comprehensive MAP evaluation should consequently consider the continuum: plant material → processing → extraction → transformation → absorption → metabolism → active exposure → biological response. This perspective reinforces the concept of therapeutic intelligence by recognizing that the chemically relevant entity may change throughout the pathway from botanical material to therapeutic application.

Analytical Quality Control and Standardization

Analytical quality control is fundamental to ensuring the identity, purity, consistency and reproducibility of MAP materials and their derived preparations. Botanical authentication should constitute the first step, with acceptance based on 100% concordance with the authenticated taxonomic identity and specified plant part, followed by organoleptic and microscopic examination. Routine physicochemical specifications should include moisture content preferably ≤10% unless a monograph specifies otherwise, together with ash, extractive-value and microbial limits established according to the relevant pharmacopeial monograph [20,21]. Foreign matter should comply with the applicable monograph, while heavy metals, pesticide residues, aflatoxins and other contaminants should remain within current pharmacopeial or regulatory limits [20,22]. Modern analytical strategies should combine

chromatographic, spectroscopic and molecular techniques. HPLC/HPTLC methods should demonstrate specificity, acceptable precision and accuracy, with quantitative marker content maintained within the validated specification range. GC-MS should provide reproducible essential-oil fingerprints, with major volatile constituents falling within predefined chemotype-specific ranges. LC-MS/MS and NMR can support broader metabolite profiling, while DNA-based authentication should confirm the declared botanical identity [7,9,12]. Chromatographic fingerprints should demonstrate high similarity with an authenticated reference profile, with the similarity threshold predefined and validated for the particular material. Accordingly, MAP standardization should integrate botanical authentication + physicochemical testing + chromatographic fingerprint + metabolomic profile + quantitative markers + contaminant analysis + relevant biological assay [9,12,20,22]. Batch acceptance should require compliance with all critical identity, purity, marker-content and contaminant specifications, rather than relying on a single marker compound. This multidimensional approach is particularly important because processing, storage, extraction and metabolism may generate transformation products affecting stability, efficacy and safety [9,22-24].

From Chemical Profile to Biological Activity

The biological activity of medicinal and aromatic plants is determined not simply by the presence of individual phytochemicals, but by the qualitative and quantitative composition of the complete chemical profile. Plant extracts may contain hundreds to thousands of metabolites, including major and minor constituents whose additive, synergistic or antagonistic interactions can collectively influence biological responses [7,10,25]. Consequently, chemical characterization should be integrated with bioactivity assessment rather than performed as an independent analytical step. Modern chromatographic and spectrometric platforms, including HPLC, GC-MS, LC-MS/MS and NMR, enable comprehensive profiling of complex botanical matrices, while metabolomics and multivariate chemometrics can associate chemical fingerprints with biological phenotypes [7,9,25,26]. Such approaches facilitate the identification of candidate bioactive metabolites, discrimination of chemotypes and authentication of chemically distinct botanical materials. High-resolution mass spectrometry-based metabolomics can further connect phytochemical composition with molecular targets and pharmacological responses, helping overcome the limitations of conventional marker-compound analysis [26,27]. Importantly, the compound detected in the original plant material may not necessarily represent the biologically active entity after extraction, processing, digestion or metabolism. Transformation products may possess altered pharmacological or toxicological properties and therefore

require analytical identification alongside parent compounds [28]. Thus, a meaningful chemistry-to-biology workflow should progress from botanical authentication → chemical fingerprinting → metabolite identification → bioactivity screening → mechanism elucidation → pharmacokinetic evaluation → safety assessment. This integrated approach can convert descriptive phytochemical data into mechanistically interpretable evidence and support the development of standardized, reproducible and therapeutically relevant botanical products.

Pharmacokinetic, Toxicological and Translational Considerations

The therapeutic potential of medicinal and aromatic plant preparations cannot be established solely from phytochemical composition or *in vitro* activity. Pharmacokinetic evaluation is essential for defining absorption, distribution, metabolism and excretion (ADME) and determining whether phytoconstituents reach biologically relevant concentrations *in vivo*. Bioavailability may be limited by poor solubility, restricted intestinal absorption, extensive first-pass metabolism, rapid elimination or chemical instability. Importantly, phytoconstituents may undergo biotransformation into metabolites with activities distinct from their parent compounds; therefore, both parent and transformed molecules should be considered during therapeutic evaluation [25,26,29]. Herb-drug interactions constitute another important translational concern. Plant-derived constituents can modulate drug-metabolizing enzymes and membrane transporters, potentially altering drug exposure, efficacy and toxicity [27,28,30]. Such interactions may occur during intestinal absorption, hepatic metabolism or elimination. Accordingly, mechanistic *in vitro* screening should be followed by appropriately designed pharmacokinetic investigations before clinically relevant conclusions are drawn [28-30]. Toxicological assessment is equally critical because “natural” does not necessarily imply safety. Adverse effects may arise from intrinsically toxic constituents, excessive exposure, contamination, adulteration, misidentification, inappropriate preparation or interactions with conventional medicines [29,30]. Chemical variability between batches further complicates dose-response interpretation and safety evaluation. Thus, translational development should follow an integrated sequence: chemical characterization → bioavailability and ADME → mechanism of action → toxicological evaluation → interaction assessment → preclinical validation → clinical investigation → standardized therapeutic product. This framework can help bridge the gap between promising laboratory findings and reproducible, safe and clinically meaningful botanical medicines [25,29,31].

Industrial Applications and Value Addition

MAPs are important sources of chemically characterized ingredients for pharmaceutical, food, cosmetic, nutraceutical and agricultural applications. Plant-derived natural products provide structural templates and bioactive molecules for pharmaceutical development, while standardized extracts and phytochemicals support phytopharmaceutical and nutraceutical products [4,5]. Essential oils and phenolic-rich extracts are investigated as natural flavouring, antioxidant and antimicrobial agents for food preservation and functional formulations [18,41]. Cosmetic and personal-care industries utilize essential oils, volatile terpenoids and plant extracts in perfumes, creams, soaps and shampoos because of their characteristic aromas and biological properties [18,41]. Selected metabolites with insecticidal, repellent or antifungal activities may also support botanical crop-protection strategies. Industrial value addition is increasingly shifting from crude materials toward chemically standardized extracts, purified fractions and defined formulations. Processing residues can further be valorized as sources of polyphenols, pigments, fibres and other functional materials, supporting a circular bioeconomy. Thus, the MAP value chain can progress from raw material → processed material → extract → enriched fraction → standardized ingredient → formulation → high-value product. Sustainable cultivation, responsible harvesting, conservation, chemical productivity, extraction efficiency and product quality should be integrated to support scalable and environmentally responsible MAP-based products [21,22].

From Phytochemistry to Therapeutic Intelligence

Medicinal and aromatic plant research is increasingly moving from descriptive phytochemical cataloguing toward an integrated, predictive framework that connects botanical identity, chemical composition, processing, biological activity and therapeutic relevance. Conventional workflows often follow a linear sequence of plant selection, extraction, compound identification and bioactivity testing; however, chemical variability arising from genotype, environment, plant part, harvesting and processing can substantially alter the resulting metabolite profile [7,8,9]. Advanced analytical platforms, including chromatography, mass spectrometry, NMR and metabolomics, now enable multidimensional chemical fingerprinting, metabolite annotation and detection of chemically distinct botanical materials [9,12]. Integration of these datasets with chemometrics, network pharmacology and artificial intelligence can facilitate metabolite prioritization, dereplication, target prediction and ADMET assessment [13,14,19]. Accordingly, therapeutic intelligence may be conceptualized as a systems-level framework linking botanical identity → cultivation → biosynthesis → extraction

→ chemical transformation → analytical fingerprint → molecular target → biological response → therapeutic product. This approach recognizes that therapeutic effects may arise from multiple constituents and their interactions rather than from a single marker compound. Importantly, computational predictions remain hypothesis-generating and require experimental, pharmacokinetic, toxicological and clinical validation [13,14]. Thus, therapeutic intelligence represents a transition from isolated phytochemical discovery toward reproducible, mechanistically informed and analytically standardized botanical therapeutics.

Major Research Gaps and Translational Barriers

Despite substantial advances in medicinal and aromatic plant (MAP) research, important gaps continue to limit translation from traditional botanical knowledge to reproducible therapeutic products. Chemical variability arising from genotype, chemotype, geographical origin, environmental conditions, cultivation, harvesting and post-harvest processing can generate substantial batch-to-batch differences and remains a major obstacle to reproducibility and therapeutic consistency [7,8,11,32-36]. Recent mass-spectrometry metabolomics approaches demonstrate that even closely related cultivars can exhibit distinct chemical signatures, supporting a transition from simple species identification toward cultivar-to-chemotype characterization [32]. Bioactive constituent attribution remains another major challenge because biological effects may originate from multiple constituents, minor metabolites or synergistic interactions rather than a single marker compound [4-7,19,32]. Furthermore, processing, digestion and human metabolism may generate transformation products that differ chemically and pharmacologically from compounds identified in the original plant material, yet these products remain insufficiently characterized in many botanical investigations [5,7,16,19]. Bioavailability and pharmacokinetics represent additional translational barriers: promising in-vitro activity does not necessarily produce therapeutic effects when absorption, distribution, metabolism, tissue exposure or systemic availability are inadequate [15,16,37-40]. Recent reviews of essential oils similarly identify insufficient in-vivo pharmacokinetic and toxicity information as important limitations to therapeutic development [40]. Safety assessment also remains disproportionately less developed than efficacy research, requiring systematic evaluation of dose-response relationships, exposure duration, administration route, drug interactions, organ toxicity and metabolite safety [5,10,40-42]. Standardization is particularly challenging for chemically complex botanical preparations because single-marker specifications cannot adequately capture chemotype, adulteration, degradation or multi-component

biological activity. Contemporary approaches increasingly combine botanical authentication, chromatographic and spectrometric fingerprints, metabolomics, chemometrics and bioassay-guided evaluation to improve reproducibility and quality assurance [9,12, 20,22,23]. A recent 2026 review further emphasizes raw-material inconsistency, complex phytochemical composition, contamination and differences among regulatory systems as continuing barriers to standardized herbal medicines [23]. Artificial intelligence (AI) offers opportunities for metabolite prioritization, dereplication, target prediction, ADMET assessment, network pharmacology and metabolic-network reconstruction; however, current evidence remains dominated by proof-of-concept and preclinical studies, with limited quantitative evidence that AI has yet improved clinical productivity or therapeutic success [9-14,33]. Importantly, AI-ready medicinal-plant datasets require appropriate metadata, balanced datasets, standardized chemical annotation and rigorous external validation [13,33]. Finally, regulatory translation remains constrained by differences in botanical definitions, raw-material specifications, manufacturing standards, quality-control requirements and post-market surveillance across jurisdictions [22,24,33]. Addressing these interconnected barriers therefore requires a shift from isolated phytochemical discovery toward a validated, multidimensional and predictive framework of therapeutic intelligence, integrating botanical identity, cultivation, chemical composition, molecular transformation, biological mechanism, pharmacokinetics, toxicology, computational prediction, manufacturing quality and clinical evidence [9, 23,24,25,33].

Future Perspectives

The future of medicinal and aromatic plant research will increasingly depend on integration. Metabolomics can characterize complex chemical profiles, while molecular networking can help associate unknown compounds with known chemical families. Genomics and transcriptomics can reveal biosynthetic pathways, and machine learning can potentially predict relationships between chemical profiles and biological activity. Artificial intelligence should not replace experimental validation. Instead, it should help answer questions such as:

- Which plant chemotype is most promising?
- Which extraction condition preserves target compounds?
- Which phytochemicals are likely to be bioactive?
- Which compounds may be toxic?
- Which combinations may show synergy?
- Which cultivation conditions maximize chemical quality?
- Which samples represent authentic botanical material?

The future therefore lies in closed-loop MAP research, in which cultivation data inform chemistry, chemistry

informs extraction, extraction informs biological testing, and biological results feed back into cultivation and processing optimization. The revised European GACP framework already reflects the increasing sophistication of herbal starting-material production and the need for quality systems spanning cultivation and processing.

Conclusion

Medicinal and aromatic plants have evolved from traditional remedies into important sources of bioactive molecules, essential oils, pharmaceutical ingredients, functional foods and industrial products. However, their value cannot be adequately defined by identifying individual compounds or reporting isolated biological activities. MAP chemistry is dynamic and strongly influenced by genetics, environment, cultivation, harvesting, processing, storage and extraction. These factors collectively determine chemical composition, biological activity, quality and safety. The central message is that the therapeutic value of a medicinal or aromatic plant depends not only on what compounds it contains, but on how those compounds are produced, preserved, transformed, extracted, delivered and biologically expressed. The transition from plant chemistry to therapeutic intelligence therefore offers a more integrated framework linking traditional knowledge with phytochemistry, advanced extraction, metabolomics, pharmacology, computational analysis and quality control. Such integration can improve reproducibility, safety, sustainability and translational potential, helping transform chemically variable botanical resources into scientifically validated therapeutic and industrial products. Despite rapid advances, several fundamental questions remain unresolved: which metabolites or metabolite combinations are truly responsible for clinical effects; how processing-generated transformation products influence efficacy and safety; how botanical variability can be converted into predictable chemical specifications; and how AI predictions can be experimentally and clinically validated. Addressing these questions will determine whether MAP research progresses from descriptive phytochemistry toward genuinely predictive therapeutic science.

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Conflict of Interest

None

References

- Petrovska BB (2012) Historical review of medicinal plants' usage. *Pharmacogn Rev* 6(11): 1-5.
- Koul O, Walia S, Kumar S (2020) The history of herbs, medicinal and aromatic plants, and their extracts: Past, current situation and future perspectives. In: *Aromatic Plants and Herbs in Animal Nutrition and Health*. Elsevier, pp: 1-18.
- Heinrich M, Barnes J, Gibbons S, Williamson EM (2012) *Fundamentals of Pharmacognosy and Phytotherapy*. 2nd (Edn.), Churchill Livingstone Elsevier.
- Atanasov AG, Waltenberger B, Pferschy-Wenzig EM, Linder T, Wawrosch C, et al. (2015) Discovery and resupply of pharmacologically active plant-derived natural products: A review. *Biotechnol Adv* 33(1): 1582-1614.
- Atanasov AG, Zotchev SB, Dirsch VM, Supuran CT (2021) Natural products in drug discovery: Advances and opportunities. *Nat Rev Drug Discov* 20: 200-216.
- Cragg GM, Newman DJ (2013) Natural products: A continuing source of novel drug leads. *Biochim Biophys Acta* 1830(1): 3670-3695.
- Wolfender JL, Litaudon M, Touboul D, Queiroz EF (2019) Innovative omics-based approaches for prioritisation and targeted isolation of natural products - new strategies for drug discovery. *Nat Prod Rep* 36(1): 855-868.
- Latif R, Nawaz T (2026) Medicinal plants and human health: A comprehensive review of bioactive compounds, therapeutic effects, and applications. *Phytochem Rev* 25(1): 2299-2342.
- Chen J, Cai J, Duong HTQ, Bunsupa S, Han R, et al. (2026) AI-driven integration and optimization of medicinal plant multi-omics metabolic networks. *Front Plant Sci* 17(1): 1756809.
- Dhifi W, Bellili S, Jazi S, Bahloul N, Mnif W (2016) Essential oils' chemical characterization and investigation of some biological activities: A critical review *Medicines* 3(1): 25.
- Farajpour M (2026) Artificial intelligence applications in medicinal and aromatic plants: A review of cultivation, phytochemical profiling, drug discovery, and processing energy. *Energy Nexus* 23: 100800.
- Gong Y, Yang D, Hou Z (2026) Spatial metabolomics in medicinal plant research: Current advances, technical challenges, and future perspectives. *Anal Methods* 18(27): 5608-5620.
- Gangwal A, Ansari A, Siddique MU, Sawale J, Padmane S, et al. (2026) Integrating artificial intelligence into drug discovery from medicinal plants: Current applications and infrastructural challenges. *Chem Biol Drug Des* 108(2): e70372.
- Lavecchia A (2026) Artificial intelligence-driven natural product drug discovery: From computational genome mining to clinical translation. *Med Res Rev* 7.
- El Asbahani A, Miladi K, Badri W, Sala M, Ait Addi EH, et al. (2015) Essential oils: From extraction to encapsulation. *Int J Pharm* 483(1): 220-243.
- Dai X, Lin W, Wu K, Cheng G, Wan N (2026) The evolutionary journey of essential oils: From synthesis to biomedical applications. *Chinese Chemical Letters*.
- Eddouks M, Chattopadhyay D, De Feo V, Cho WCS (2014) Medicinal plants in the prevention and treatment of chronic diseases. *Evid Based Complement Alternat Med* 2014: 180981.
- Azmir J, Zaidul ISM, Rahman MM, Sharif KM, Mohamed A, et al. (2013) Techniques for extraction of bioactive compounds from plant materials: A review. *J Food Eng* 117(1): 426-436.
- Chettupalli AK, Pathak P, Sharma P, Jadi RK, Thota SK (2026) Integrated counter current separation and omics approaches for discovery of bioactive compounds from medicinal plants. *Front Pharmacol* 17(1): 1901153.
- (1998) *Quality Control Methods for Medicinal Plant Materials*. World Health Organization, Geneva.
- (2003) *WHO Guidelines on Good Agricultural and Collection Practices (GACP) for Medicinal Plants*. World Health Organization, Geneva.
- European Medicines Agency (2025) *Guideline on Good Agricultural and Collection Practice (GACP) for Starting Materials of Herbal Origin*.
- Jindal D (2026) Current approaches to herbal drugs standardization: From ancient practices to modern scientific techniques. *Nexus* 2026: 101756.
- Pawar AT, Chandrasekar SB, Venkatesh MP (2026) Navigating the regulatory landscape of herbal medicines: A global comparison of India, China, Europe, the United States and Japan. *J Ayurveda Integr Med* 17(3): 101343.

25. Wolfender JL (2024) Advanced high-resolution chromatographic strategies for efficient isolation of natural products from complex biological matrices: From metabolite profiling to pure chemical entities. *Phytochem Rev*.
26. Okada T, Afendi FM, Altaf-Ul-Amin M, Takahashi H, Nakamura K, et al. (2010) Metabolomics of medicinal plants: The importance of multivariate analysis of analytical chemistry data. *Curr Comput Aided Drug Des* 6(3): 179-196.
27. Wang Z, Guo S, Cai Y, Yang Q, Wang Y, et al. (2024) Decoding active compounds and molecular targets of herbal medicine by high-throughput metabolomics technology: A systematic review. *Bioorg Chem* 144: 107090.
28. Chemical metabolism of medicinal compounds from natural botanicals (2012). *Phytother Res*. The literature supports the importance of identifying metabolites and transformation pathways because parent compounds and/or their metabolites can contribute to pharmacological effects.
29. Kim JH, Shin HK, Lee HW, Kim YK, Lee CH, et al. (2015) Pharmacokinetic interactions of herbs with cytochrome P450 and P-glycoprotein. *Evidence-Based Complementary and Alternative Medicine* 2015: 736431.
30. Suroowan S, Lu L, Bacha DS, Baborun T, Neergheen-Bhujun VS (2021) Herb-drug interactions and toxicity: Underscoring potential mechanisms and forecasting clinically relevant interactions induced by common phytoconstituents via data mining and computational approaches. *Food and Chemical Toxicology* 156(1): 112432.
31. Posadzki P, Watson LK, Ernst E (2013) Contamination and adulteration of herbal medicinal products (HMPs): An overview of systematic reviews. *European Journal of Clinical Pharmacology* 69(1): 295-307.
32. Kellogg JJ, Jordan RT, Ranaweera MM, Custer K, Anez SG, et al. (2026) Cultivar to chemotype: Characterizing complex botanicals with mass spectrometry metabolomics. *Nat Prod Rep* 43(1): 1181-1200.
33. Lee SS, Yoo YC (2026) Data-quality-guided AI strategies for natural product drug discovery. *Trends Pharmacol Sci* 47(7): 726-742.
34. Khan MN, Shah SMZ, Rahman S, Musharraf SG (2026) Understanding the metabolome of four stress-relieving and cognitive-enhancing medicinal plants: A comprehensive HR-LC-ESI-MS/MS analysis. *Metabolomics* 22(2): 41.
35. Formica V, Romano D, Verdeguer M, Zingale S, Leoni F, et al. (2025) Mild abiotic stresses improve essential oils yield and composition of Mediterranean medicinal and aromatic plants with minimal impact on plant growth: A systematic literature review. *Italian Journal of Agronomy* 21(1): 100079.
36. Basak BB, Thondaiman V, Saha A, Manivel P (2018) Good agricultural and collection practices of medicinal plants for supply of quality raw herbal drug. *Indian Farming* 68(10).
37. Review on essential oil extraction from aromatic and medicinal plants: Techniques, performance and economic analysis (2022) *Sustainable Chemistry and Pharmacy* 30(1): 100829.
38. Milicic M, Furlan V, Knez Marevci M, Bren U (2026) *Thymus vulgaris* and *Thymus serpyllum*: Extraction, distillation, and encapsulation strategies, phytochemical composition and bioactivity. *Phytochem Rev* 1-53.
39. Afassi F, Charki A, El Youssfi C, Loukili EH, Labhar A, et al. (2026) Chemical composition and biological activities of essential oils from medicinal plants: A comprehensive review and bibliometric analysis. *Results in Engineering* 32(1): 112439.
40. Monith RG, Wilson D, Jenitha V, Kokelavani NB, Nandana V, et al. (2025) Human cell toxicity and in vivo bioavailability of therapeutic essential oils-A review. *Fitoterapia* 186(1): 106801.
41. Ferrentino G, Morozova K, Horn C, Scampicchio M (2020) Extraction of essential oils from medicinal plants and their utilization as food antioxidants. *Curr Pharm Des* 26(5): 519-541.
42. Orhan IE, Senol DFS (2026) The enduring legacy of medicinal and aromatic plants from ancient civilizations to modern era - a brief overview. *EMU J Pharm Sci* 9(1): 57-76.

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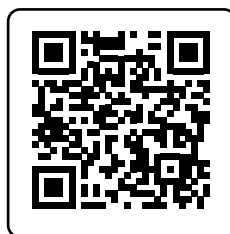
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