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THERAPEUTIC POTENTIAL AND MARKET VALUE OF COMMON JUNIPER'S (*JUNIPERUS COMMUNIS L.) BERRIES AND* ESSENTIAL OIL

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Abstract

Juniperus communis L., typically known as common juniper, is a widely distributed conifer native to Europe, North America, and parts of Asia, with multiple subspecies adapted to diverse climatic and ecological regions. Populations exhibit considerable chemotypic and morphological diversity. The species holds significant economic value, primarily through the harvest and trade of berries and essential oil. Juniper berries are utilized as a spice in culinary applications, as a herbal supplement in traditional medicine, and as the defining flavoring botanical in gin and other alcoholic beverages. Wild-harvested berries and their essential oils contribute to local and global markets, with prices influenced by origin, quality, certification status, and chemotype specificity. *J. communis* essential oil is characterized by a complex mixture of monoterpenes, sesquiterpenes, and oxygenated derivatives, with ***α*-pinene** consistently identified as the dominant constituent across most regions. Other compounds, including *β*-myrcene, sabinene, limonene, and *β*-pinene, vary substantially depending on geographic origin, plant part, and harvesting conditions. This variability has implications for both biological activity and commercial applications, influencing anti-inflammatory, chondroprotective, diuretic, and anticancer properties. In North Macedonia, the extensive distribution and pronounced economic relevance of *Juniperus communis* further underscore its regional importance. The species supports rural livelihoods through widespread berry collection, supplying distilleries and producers of essential oil and gin, while its ecological role helps structure mountain shrublands and open habitats across many mountain ranges. This review integrates data on the global distribution, regional chemical diversity, economic significance, and multifunctional applications of *Juniperus communis*, highlighting its importance as both a bioactive medicinal resource and a commercially valuable plant product.

Keywords: Juniperus communis, pseudo-fructus, volatile oil composition, chemotaxonomy, spice, medicinal plant, economical importance.

1. Introduction

The evergreen coniferous shrub or small tree *Juniperus communis* (Cupressaceae) is remarkable for its very wide natural distribution, occupying large swathes of the temperate and boreal Northern Hemisphere. Common juniper has circumpolar distribution covering North America, Europe and Asia, of the conifers having the widest distribution range (Mao et al., 2010). In Europe its range spans from northern Scandinavia, central Europe, parts from Spain, Italy, and it is widely distributed in Balkan countries (Bojkovska et al., 2022; Enescu et al., 2016).

Ecologically, *J. communis* occupies a wide variety of habitats from sea-level lowlands to arctic tundra and alpine zones, on a range of substrates (acidic to calcareous) and under harsh conditions (cold, drought, poor soils) (Thomas et al., 2007). In North Macedonia, *Juniperus communis* is widely distributed and of considerable ecological and economic importance. It contributes to the structure and diversity of mountain shrublands and open habitats across numerous montane landscapes, while also supporting rural livelihoods through berry collection that supplies distilleries and producers of essential oil and gin.

Beyond its ecological interest, *J. communis*, particularly its berries and essential oils have multiple economic, medicinal, culinary and industrial uses. The "berries" (actually fleshy seed-cones, or galbuli) are used as a spice (especially in European cuisine), as botanical flavouring in gin and other spirits, and as herbal medicinal material (e.g., traditional diuretic, antiseptic uses). In parallel, the global and European market for juniper berries and derived products (spice, flavourings, botanicals for beverages, essential oils) appears to be growing. For example, one market survey estimated the juniper berry market size at ca. USD 198.07 million in 2024, projected to ~USD 352 million by 2033. The essential oil derived from the berries has been studied for its chemical composition (monoterpenes, sesquiterpenes) and bioactivity (antioxidant, antimicrobial, anti-inflammatory) (Bojkovska et al., 2022; Sela et al., 2011, 2013, 2015, 2015).

Because of the wide distribution, high value-added uses, and chemical variability (chemotypes) of the species, *J. communis* is of interest in multiple fields: ecology, phytochemistry, industrial botany, food & beverage science, and herbal medicine. Furthermore, the chemotaxonomic variation (essential-oil composition, genetic fingerprinting) can relate to geographic origin (terroir) of raw material, which is relevant for botanical sourcing and quality control. Thus, a comprehensive review that covers its distribution (global and European), its market importance, the uses of berries (spice, herbal, beverage), and essential-oil composition across regions is timely.

2. Methodology

A conventional way to plan a manuscript is to construct an outline. An outline has two interacting This review synthesizes information from peer-reviewed journal articles, monographs, market-analysis reports, and authoritative databases. Literature searches were conducted using platforms such as Web of Science, PubMed, and Google Scholar, applying keywords including *"Juniperus communis distribution," "juniper berry market," "juniper essential oil composition," "gin juniper botanical," "Juniperus communis chemotype,"* and *"juniper berry medicinal properties."* Market information was gathered from publicly accessible industry reports and specialized databases offering summaries of pricing, trade flows, and sector-specific developments. Data on essential-oil composition from studies conducted across Europe, North America, and Asia were extracted and tabulated to illustrate regional variability. Chemotaxonomic analyses employing GC/FID, GC–MS, PCA, or cluster analysis were critically examined. Where possible, comparative datasets were emphasized to connect ecological and biogeographical patterns with commercial and industrial relevance.

Inclusion criteria were applied to ensure scientific rigor and comparability. Eligible sources included peer-reviewed studies reporting quantitative essential-oil composition using validated analytical techniques; publications providing clear geographical or ecological origin of samples; and research presenting chemotaxonomic assessments such as PCA or cluster analysis. Market analyses or technical publications reporting economic value, production volumes, or specific industrial uses of juniper were also included, as were studies addressing sensory characteristics or botanical sourcing in gin production.

Exclusion criteria removed studies lacking quantitative compositional data, investigations that did not specify the plant part analyzed, and research combining multiple *Juniperus* species without clearly distinguishing *J. communis*. Market reports with unclear methodologies or insufficiently detailed juniper-specific information were also excluded, as were non-scientific sources that could not be verified for reliability.

3. Distribution and Ecology of Common Juniper

Juniperus communis displays a circumpolar distribution across the Northern Hemisphere, making it one of the most widely distributed woody plants. It occurs throughout North America, Europe and Asia, from northern Scandinavia and the Arctic tundra, down to mountainous zones near 30° N (in North America) and in isolated relict populations (e.g., Atlas Mountains of Africa) (Enescu et al., 2016). In Europe specifically, it is found from Scandinavia, through central Europe, the British Isles, the Alps, Pyrenees, and in scattered habitats in southern Mediterranean mountain zones.

The species is ecological-versatile: it inhabits low-elevation pasture, calcareous grassland, rocky outcrops, heathland, but also alpine and tundra zones. The species is fundamentally light-demanding, requiring unshaded and open conditions with short ground vegetation for successful regeneration (Thomas et al., 2007). Light intensity preferences are quantified at level 8 on ecological scales, confirming the species' intolerance to shade (Jocienė et al., 2023). *Juniperus communis* demonstrates both drought and frost tolerance, enabling colonization of harsh environments. In Mediterranean regions, summer drought represents a primary mortality factor for seedlings, while the species shows adaptability to low temperatures (Thomas et al., 2007).

In the Balkans, it often grows on heathlands in communities with bilberry (*Vaccinium myrtillus* and *V. uliginosum*) and *Bruckenthalia spiculifolia* (Stefkov et al., 2025). In open habitats including upland acid grasslands, dry heathlands, and lowland calcareous grasslands, *J. communis* functions as a community dominant (Broome et al., 2017). In North Macedonia (Macedonia in further text), *Juniperus communis* is widely distributed and forms an important component of many mountainous landscapes, such as Osogovo, Kozhuf, Shar Planina, Karadžica especialy the national parks (NP) NP Sar Mountain, NP Pelister, NP Mavrovo, NP Galicica etc.. It thrives in open, high-altitude habitats, rocky slopes, and mixed shrub communities, where it often co-occurs with bilberry and other ericaceous species (Stefkov et al., 2014, 2025).

4. Common Juniper Essential Oil Composition

The essential oil of *Juniperus communis* is characterized with complex composition of monoterpenes and sesquiterpenes. Most of the literature research suggest that the essential oil is predominantly represented by monoterpene hydrocarbons, with **α-pinene** consistently reported as the principal constituent and often comprising **30–70%** of the total oil (Kurose et al., 2007). Considerable variability in phytochemical composition has been documented across different populations, reflecting the influence of genetic factors, environmental conditions, altitude, ripeness of the berries, and the specific plant part distilled.

The Balkan studies revealed considerable chemotype diversity within relatively close geographic proximity. Serbian populations exhibited two distinct chemotypes: an α-pinene chemotype (32.68-51.10%) from multiple localities and a sabinene-dominant chemotype (39.4%) from *J. communis* var. *communis* from different location (Gusinjac et al., 2024a; Rajcevic et al., 2016). Additionaly, Gusinjac et al. showed α-pinene as the dominant compound (32.68-51.10%), β-phellandrene (6.43-24.77%), and β-pinene (9.84-14.09%), with samples clustering into two distinct groups based on component variance. Kosovo populations demonstrated the α-pinene chemotype across multiple studies. The eastern Kosovo population showed α-pinene at 36.2% and β-myrcene at 21.1%, with monoterpene hydrocarbons comprising 69.4% of the total oil composition (Haziri et al., 2013). A broader survey of five wild populations in Kosovo identified α-pinene, β-myrcene, sabinene, and D-limonene as principal components, with essential oil yields ranging from 0.4 to 3.8% depending on population origin (Hajdari et al., 2015). Analyzed juniper berry samples from Macedonia showed variable but α-pinene (15.59-43.19%) and β-myrcene (2.89%-26.50%) dominant chemotypes. Other major compounds were β-pinene (1.65%-5.35%), sabinene (2.80-11.77%), and limonene (2.90-4.46%) (Sela et al., 2011). Juniper berries samples from Bulgaria showed a dominant scent of α-pinene (25.3%) and β-myrcene (12.6%), followed by sabinene (5.99%), limonene (2.99%) and β-pinene (2.98%) (Zheljazkov et al., 2018). Also, samples from Greece showed similar dominant compounds with α-pinene (37-55%) and β-myrcene (11-16%) and sabinene (6-13%) (Chatzopoulou & Katsiotis, 2006).

The Northern European profiles were represented by mainly α-pinene as dominant compound. Berry oils from Estonia contained α-pinene at 53.6-62.3%, β-myrcene at 6.5-6.9%, and germacrene D at 4.5-6.1% (Orav et al., 2010). Lithuanian populations belonged to the α-pinene chemotype (39.7-64.9%), with β-myrcene (4.8-19.6%) and α-cadinol (2.7-7.1%) as additional major components. (Table 1.)

Table 1. Essential oil composition of *Juniperus communis* berries from different regions

Region	Composition (major components as reported)	Source
Serbia	Two chemotypes: α-pinene (32.68–51.10%); sabinene (39.4%), β-phellandrene (6.43-24.77%), β-pinene (9.84-14.09%).	Gusinjac et al., 2024; Rajcevic et al., 2016
Kosovo (Eastern Kosovo)	α-pinene (36,2%), β-myrcene (21,1%); sabinene, D-limonene	Haziri et al., 2013; Hajdari et al., 2015
Macedonia	α-pinene (15.59–43.19%), β-myrcene (2.89-26.50%), β-pinene (1.65–5.35%), sabinene (2.80-11.77%), limonene (2.90-4.46%).	Sela et al., 2011
Bulgaria	α-pinene (25,30%), β-myrcene (12.60%), sabinene (5.99%), limonene (2.99%), β-pinene (2.98%).	Zheljazkov et al., 2018
Greece	α-pinene (37-55%), β-myrcene (11–16%), sabinene (6–13%).	Chatzopoulou & Katsiotis, 2006
Estonia	α-pinene (53.60–62.30%), β-myrcene (6.5–6.90%), germacrene D (4,50–6,10%).	Orav et al., 2010
Lithuania	α-pinene (27.70–64.90%), myrcene (4.8–19.60%), α-cadinol (2.70–7.10%).	Butkienė et al., 2006

5. Biological Activities and Medicinal Application of *Juniper* Essential Oil

5.1. Anti-inflammatory activity: Several studies have demonstrated that *J. communis* essential oil exhibits strong anti-inflammatory properties. Han and Parker (2017) showed that juniper berry essential oil significantly reduced IL-6 and MMP-1 expression in LPS-stimulated human dermal fibroblasts, indicating effective suppression of skin-related inflammatory pathways. These findings support the oil's traditional use in dermatological and connective tissue disorders (Han & Parker, 2017).

As previously reviewed, α-pinene is the dominant compound in the essential oil which represents big part of its composition and playing vital role in the biological activities of the EO. Isolated α-pinene demonstrates potent anti-inflammatory effects, acting through well-defined molecular pathways. Kim et al. (2015) found that α-pinene suppresses MAPK signaling and inhibits activation of the NF-κB pathway in mouse peritoneal macrophages. This suppression led to reduced nitric oxide production and lower levels of pro-inflammatory cytokines, confirming α-pinene as a major contributor to the essential oil's anti-inflammatory profile (Kim et al., 2015).

Further, Rufino et al. (2014) showed that the (+)- α-pinene enantiomer exhibits both anti-inflammatory and chondroprotective effects. The compound inhibited nitric oxide release and reduced expression of cartilage-degrading enzymes in stimulated chondrocytes, offering mechanistic insight into its potential application in joint inflammatory conditions (Rufino et al., 2014).

The chondroprotective properties of α-pinene suggest an important therapeutic role for juniper-derived compounds in diseases involving cartilage degradation. By stabilizing chondrocyte activity and reducing catabolic enzyme expression, α-pinene protects against inflammatory damage within joint tissue, aligning with traditional medicinal uses (Rufino et al., 2014). The summary of the biological activities is presented in Table 2.

5.2. Anticancer activity: Recent research has expanded the therapeutic scope of *J. communis* to include **anticancer activity.** Marković et al. (2024) demonstrated that juniper essential oil induces concentration-dependent reductions in cell viability in both HeLa and HCT 116 cancer cell lines. Mechanistic analyses revealed activation of the intrinsic apoptotic pathway, evidenced by increased levels of cleaved caspase-3, a higher Bax/Bcl-2 ratio, cytochrome C release into the cytosol, and mitochondrial membrane depolarization indicated by JC-10 monomer formation. The oil also inhibited key cell-survival pathways in HCT 116 cells and induced S-phase arrest in HeLa cells, indicating multi-target antitumor activity (Marković et al., 2024).

A recent review further corroborated these findings, identifying antitumor effects as one of the essential oil's principal therapeutic actions. The review highlighted the potential of juniper berry oil as a **chemopreventive supplement**, particularly in colon cancer, and reported in vivo evidence of apoptosis induction in mouse models, providing physiological validation of the cellular mechanisms observed in vitro(Albrecht & Madisch, 2022).

Table 2. Biological Activities and Medicinal Potential of Juniperus communis Essential Oil

Biological Activity	**Tested Material**	**Mechanism of Action**	**Observed Effect / Outcome**	**Source**
Anti-inflammatory	α-Pinene	Suppression of MAPK signaling and NF-κB activation; reduced nitric oxide and pro-inflammatory cytokine production	Reduced inflammatory mediator levels in mouse peritoneal macrophages	Kim et al., 2015
Anti-inflammatory	*Juniperus communis* essential oil	Downregulation of IL-6 and MMP-1 in LPS-stimulated human dermal fibroblasts	Attenuation of skin inflammation markers	Han & Parker, 2017
Chondroprotective	(+)- α-Pinene	Inhibition of nitric oxide release and cartilage-degrading enzymes; protection of chondrocytes	Preservation of cartilage integrity and chondrocyte viability	Rufino et al., 2014

Diuretic	Juniper berry preparations	Increased renal excretion; dose- and time-dependent response	Elevated urine output in rats	Stanić et al., 1998
Anticancer / cytotoxic	*Juniperus communis* essential oil	Activation of intrinsic apoptotic pathway: cleaved caspase-3, Bax/Bcl-2 ratio, cytochrome C release, mitochondrial depolarization; S-phase arrest; inhibition of survival pathways	Concentration-dependent reduction in viability of HeLa and HCT 116 cells	Marković et al., 2024

6. Economic aspects of *Juniper* Berries and Essential Oil

The commercial value chain for *Juniperus communis* (common juniper) spans wild-harvested dried berries sold to culinary and spirits markets, and distilled essential oil sold into aromatherapy, cosmetics, fragrance and niche therapeutic markets. Market-level figures suggest the juniper berry oil segment is a modest but stable niche within the broader essential-oils industry: one market analysis estimates the global juniper berry oil market at approximately USD 213 million in 2024, with a projected compound annual growth rate (CAGR) of about 5.8% to 2034, reflecting steady demand from specialty food & beverage and personal-care sectors (Gandhi, 2025).

The single largest demand-side driver for juniper berries is the beverage sector—most importantly gin production-because juniper is the legally defining botanical flavor of gin. Craft and premium spirits growth has therefore supported stable year-on-year demand for food-grade berries. Secondary demand comes from small-batch perfumers, natural cosmetics and aromatherapy producers who value the oil's piney, resinous profile and its marketing story (wild/foraged origin, regional terroir). These uses typically accept higher unit prices for certified organic or traceable lots, which allows suppliers to capture premiums. Market reports and supplier summaries emphasize these dual demand streams as the primary economic anchors for juniper product flows (Gandhi, 2025; Perfumer's Apprentice, 2025).

Retail and wholesale price data indicate substantial variation by country, seasonality and quality (food-grade cleaned berries vs. crude wild lots). Retail price trackers for European markets show typical **retail** ranges of roughly **USD 10–30 per kg** for consumer packs in Western Europe, with variation by country and year; national price indices for France and Germany report similar bands and indicate some year-to-year volatility tied to harvest yields and trade flows. Lower wholesale floors-reported in some regional trade snapshots-can be substantially below retail, particularly for bulk, ungraded wild lots destined for processing rather than direct culinary use (Selina Wamucii, 2025b, 2025a).

Essential oil prices are substantially higher on a weight basis because yields from berries are low (oil typically represents a small fraction of berry mass). Commercial bulk listings illustrate this: a common U.S. bulk supplier lists a 3.24-kg gallon of juniper berry oil at **USD 875 (≈ USD 270/kg),** while smaller retail bottles translate to much higher per-kilogram equivalents when sold in consumer sizes. Premium or organic-certified juniper oils sold by specialty suppliers show per-bottle price premiums and frequent discounting on larger bulk orders; reported retail item prices from aromatherapy/perfume suppliers for small volumes are consistent with a high per-kilogram valuation when scaled. These price levels reflect both the low oil yield per kg of berries and the cost of wild harvesting, cleaning and distillation (Jedwards International, Inc., 2025; Perfumer's Apprentice, 2025).

A defining feature of the juniper supply base is its reliance on **wild-harvested** material across much of Europe and parts of Asia and North Africa. Wild sourcing reduces cultivation costs but increases variability and risk: interannual yield fluctuation, access restrictions in protected habitats, and sustainability concerns can tighten supply and push prices upward in low-yield years. Furthermore, the chemical variability (chemotypes) observed across regions influences commercial value - α-pinene-rich profiles typical of northern populations may be preferred by one buyer group, while other buyers seek different aromatic balances - which allows producers with traceable, consistent chemotypes to command premiums. Distillation costs (energy, labor, low yield per kg) remain a large component of oil cost, explaining the steep jump from berry price per kg to oil price per kg (Gusinjac et al., 2024b; Haziri et al., 2013).

For stakeholders who merely collect and sell dried berries, margins tend to be modest and sensitive to transport and grading costs; processors who clean, dry and package for culinary markets or distillers who produce essential oil capture higher value per raw-kg. Distillers and branded aroma-product makers can achieve significantly higher margin capture if they control certification, branding (e.g., protected origin, organic, fair-wild) and direct sales to niche buyers. Market reports highlight that value-added strategies (organic certification, vertical integration into distillation, or direct relationships with craft gin producers) are effective ways to improve producer returns in what otherwise is a commodity-like raw material market (Gandhi, 2025).

Buyers should request certificates of analysis (COAs) and batch GC–MS profiles to match chemotype expectations and to comply with International Fragrance Association (IFRA)/cosmetic regulations if the oil will be used in personal care products. Producers and wild-harvest cooperatives considering scale-up should evaluate: (1) the feasibility and cost of post-harvest cleaning to reach food-grade standards; (2) options for cooperative distillation to capture oil value; and (3) certification possibilities (organic, fair-wild) to secure premiums. Seasonal planning and diversified customer channels (gin, cosmetics, perfumery) reduce exposure to one market segment's price swings (Gandhi, 2025; Jedwards International, Inc., 2025).

In Macedonia, *J. communis* holds substantial socioeconomic importance. The species is one of the most commonly collected wild plants in the country, with numerous rural households engaging in seasonal berry harvesting. These berries represent a valuable source of income, as collectors sell them to distilleries and processing companies that use them either for essential-oil production or as a key botanical in gin manufacturing. This sustained demand—both from the essential-oil market and the growing craft-gin sector—drives continuous interest in juniper resources and contributes meaningfully to local livelihoods. Consequently, the broad distribution, ecological prominence, and strong economic relevance of *J. communis* make it a species of considerable importance for both natural and rural socioeconomic systems in Macedonia.

7. Conclusion

Juniperus communis has emerged as a botanically and economically important species whose value is reinforced by its chemical diversity, broad therapeutic potential, and stable commercial demand. Across Europe, considerable variation in essential oil composition has been documented, with α-pinene consistently identified as the predominant constituent, although notable regional chemotypes - such as sabinene- or β-myrcene-rich profiles - are present in Serbia, Macedonia, Bulgaria, Greece, and parts of Kosovo and the Baltic region. These compositional differences, shaped by environmental and genetic factors, influence both bioactivity and market positioning, particularly as essential oil pricing and trade are increasingly driven by purity, chemotype specificity, and quality certification. The global market for juniper berries and essential oil remains steady, with demand coming from the food, beverage, cosmetic, and aromatherapy industries, while price fluctuations reflect natural resource availability and harvest limitations. Pharmacological evidence strongly supports the biological relevance of *J. communis* essential oil and its dominant monoterpene, α-pinene. Studies demonstrate that α-pinene exerts potent anti-inflammatory effects through MAPK and NF-κB inhibition and shows chondroprotective activity via suppression of nitric oxide production and cartilage-degrading enzymes. The essential oil itself reduces inflammatory mediator expression in dermal fibroblasts, while juniper berry preparations display significant diuretic effects, validating traditional uses. Recently, its anticancer potential has gained attention, with juniper essential oil inducing intrinsic apoptosis in HeLa and HCT 116 cells, disrupting mitochondrial integrity, altering Bax/Bcl-2 ratios, and inhibiting survival pathways, findings further supported by review data suggesting chemopreventive potential in colon cancer models. Collectively, the chemical richness, therapeutic versatility, and economic importance of *Juniperus communis* underscore the need for continued research on sustainable harvesting, standardization of chemotypes, and deeper exploration of its pharmacological mechanisms to optimize both scientific and commercial applications. Furthermore, the extensive distribution and strong economic relevance of *common juniper* in Macedonia highlight its importance as both a natural and livelihood-supporting resource. Ensuring sustainable management of its widely collected berries is essential for maintaining the ecological balance of mountain habitats while supporting the rural economies that rely on juniper harvesting and processing.

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