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# SECONDARY METABOLITES OF COMMON JUNIPER (*JUNIPERUS COMMUNIS* L.) SUITABLE FOR USE IN AGRICULTURE AND FOOD PRODUCTION. REVIEW

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***Abstract***

*Juniperus communis (common juniper) is a shrub or small coniferous tree with certain botanical characteristics, including its evergreen nature and berries, which mature over a period of 2-3 years and may occur on the plant at different stages of ripeness simultaneously. This enables an extended availability of both needles and berries. This review summarises findings published over the last 20 years in scientific journals and monographs. The needles and berries of common juniper differ significantly in their secondary-metabolite profiles and in their applications in sustainable agriculture and healthy food products. The needles are characterised by elevated monoterpene content, and these compounds exhibit toxicity and repellent activity against certain pests in both field and warehouse conditions. Allelopathic suppression of weed seed germination by needle extracts of J. communis is regarded as a promising strategy for the development of natural bioherbicides. Berries accumulate substantial amounts of phenolic compounds and pigments, including proanthocyanidins, which exhibit antioxidant and antimicrobial activity. These properties are used to stabilize food matrices, impart a distinctive flavour, and extend the shelf life of products.*

***Key words****: Juniperus communis, needle, berry, secondary metabolite, application, horticulture.*

## INTRODUCTION

*Juniperus communis* L. (common juniper) is a perennial, evergreen, slow-growing woody species of the family Cupressaceae, occurring as a shrub or small tree. Common juniper has a circumpolar distribution, occupying the temperate and subarctic regions of the Northern Hemisphere (Thomas et al., 2007; Enescu et al., 2016; Salamon et al., 2023; Stefkov et al., 2025). In Europe, it occurs from the Atlantic coast of Portugal and Ireland across Central and Eastern Europe, including Scandinavia, the Balkans, the Alps, and the Carpathians, to the Urals and Western Siberia. In Asia, populations are found in Anatolia, the Caucasus, the boreal and steppe zones of Western and Eastern Siberia, the mountains of Central Asia, and the Russian Far East. In North America, it is present in Canada, northern USA states, and in the subalpine and alpine zones of the Cordilleras (Enescu et al., 2016). Isolated populations have also been reported in high-altitude regions of Nepal and northern Pakistan, as well as in the Atlas Mountains of North Africa (Lakušić & Lakušić, 2011; Serebryanaya & Shinkarenko, 2015), but these do not constitute the main circumpolar range. Across these continents, *J. communis* inhabits a broad spectrum of ecosystems, ranging from lowland mixed coniferous-broadleaved forests and boreal forest-steppe to tundra communities, subalpine meadows, and rocky slopes, reflecting its high ecological plasticity and capacity to adapt to diverse edaphic and climatic conditions (Lakušić & Lakušić, 2011).

The exceptionally wide geographic distribution of *J. communis* is closely associated with pronounced intraspecific variability and a high degree of ecological adaptability, which together contribute to the formation of diverse physiological and biochemical response strategies under contrasting environmental conditions (Kerckhoffs et al., 2020; Hantemirova & Bessonova, 2023; Zlámaný, 2024). As an evergreen woody species with long-lived

assimilating organs and an extended reproductive cycle, *J. communis* maintains continuous metabolic activity throughout the year, while simultaneously supporting generative structures at different stages of development (Thomas et al., 2007). This biological organization ensures prolonged and spatially differentiated synthesis and accumulation of secondary metabolites in both vegetative and generative organs, creating a stable and renewable source of phytochemically diverse plant material (Raal et al., 2022).

## SECONDARY METABOLITES PROFILE

The study of the chemical composition of Juniperus species began in the mid-20th century, initially focusing on identifying the major compounds of essential oils. Subsequently, essential oils and extracts obtained from berries, needles, shoots, and bark were analysed.

Comprehensive studies have been published examining both the qualitative and quantitative characteristics of the chemical composition of various *J. communis* organs (Filipowicz et al., 2003; Seca & Silva, 2006; Bakkali et al., 2008; Seca et al., 2015; Tavares & Seca, 2018), as well as the proposed biosynthetic pathways for its secondary metabolites (Orhan, 2019).

Like many woody taxa of economic and ecological relevance, *J. communis* is characterized by an intensive,organ-specific secondary metabolism, producing a wide range of low-molecular-weight compounds involved in chemical defence, stress tolerance, and ecological interactions (Bakkali et al., 2008; Belov et al., 2023). The needles predominantly synthesize volatile terpenoids, particularly monoterpenes, which play a key role in protection against herbivores, pathogens, and competing vegetation (Höferl et al., 2014; Raal et al., 2022), whereas the berry-like cones accumulate phenolic compounds, including proanthocyanidins and related antioxidants, associated with antimicrobial activity and the protection of reproductive tissues (Filipowicz et al., 2003; Belov et al., 2023).

Such a pronounced functional differentiation of secondary metabolites between organs is well documented for woody species, but appears especially distinct in *J. communis*, reflecting its complex life history and ecological breadth.

Since the publication of these reviews, new data on the chemical composition of *J. communis* needles and berries, obtained using modern analytical methods, have accumulated (Butkienė et al., 2015; Judžentienė, 2019; Tobolková et al., 2024). This makes it relevant to review the papers from the past 10-12 years, taking into account geographic and environmental variability in the qualitative and quantitative composition of secondary metabolites. The main classes of secondary metabolites found in needles and berries and their biological activity are presented in the Table.

***Terpene***. The majority of chemical investigations of different parts of common juniper have focused on the identification of monoterpene and sesquiterpene constituents, such as *sabinene*, *α-pinene, β-myrcene, caryophyllene*, *γ-terpinene, limonene, and germacrene D*. However, their relative proportions in essential oil or different extracts vary significantly between plant parts, harvesting time of the plant samples, extraction procedures, and species populations (Judžentienė, 2019; Fejér et al., 2020; Rajčević et al., 2020; Gonçalves et al., 2022; Raal et al., 2022; Belov et al., 2023).

More than 135 constituents were identified in the essential oil of needles of common juniper from the north-western Balkans, north-western and northern Europe populations, with pronounced predominance of monoterpene compounds (Judžentienė, 2019; Rajčević et al., 2020; Dumitrescu et al., 2022; Raal et al., 2022). A similar monoterpene dominance in the essential oils of needles, forming the structure of the volatile fraction, was also described for Slovak populations from Central Europe (Dimitrov et al., 2024). However, the relative proportions of some monoterpene constituents, such as *sabinene* and *α-pinene* varied significantly in the essential oil of needles between populations. In particular, the average values for *sabinene* content detected by Rajčević et al. (2020) varied within limits of 19.8-26.4%, while the proportion of *α-pinene* was 15.2-18.5%. Different ratios between these monoterpenes were determined in the needle oil of Lithuanian and Estonian populations: *α-pinene* varied in wide diapason from 21.7 to 76.8%, but mostly, the detected values ranged between 35 and 40%. The same samples of oil contained approximately 0.5-14.2% of *sabinene*

(Judžentienė, 2019; Raal et al., 2022). The proportion of sesquiterpenes, represented primarily by *germacrene D* and *β-caryophyllene*, reaches approximately 3.0% of the total essential oil profile of needles (Table 1), indicating their significant contribution to the chemical architecture of vegetative organs. In shoots of *J. communis*, the proportion of sesquiterpenes can increase to 20%. However, such values are characteristic of vegetative tissues and are not intended for direct quantitative comparison with generative organs (Judžentienė, 2019).

Table 1. Secondary metabolites detected in needle and berries of *J. communis* using HPLC-DED and GC-MS methods, and their potential biological activity and nutritional value

| Secondary metabolite | Content range | References | Biological activity, nutritional value |
|---|---|---|---|
| Monoterpenes (α-pinene, sabinene, β-pinene, limonene | 5-38% in essential oil | Bajac at al. (2025); Bais et al. (2014); Basha et al. (2024); Butkienė et al., 2015; Çolak et al. (2026); Dimitrov et al. (2024); Dumitrescu et al. (2022); Jojić et al. (2024); Judžentienė (2019); Höferl et al. (2014); Kalaba et al. (2020); Raal et al. (2022); Raina et al. (2019); Rajčević et al. (2020); Salamon et al. (2023); Semerdjieva et al. (2021); Tsitsirigka et al. (2025) | Antimicrobial and repellent activity Aroma component |
| Sesquiterpenes (β-caryophyllene, germacrene D, pinocarvone) | 0.4-3.0% | Bajac et al. (2025); Basha et al. (2024); Belov et al. (2023); Butkienė et al., 2015; Çolak et al. (2026); Dumitrescu et al. (2022); Jojić et al. (2024); Höferl et al. (2014); Kalaba et al. (2020); Raal et al. (2022); Raina et al. (2019); Rajčević et al. (2020); Semerdjieva et al. (2021); Tsitsirigka et al. (2025) | Anti-inflammatory activity Aroma stabilization |
| Total phenolic compounds | 9-68 mg GAE*/g of dry residue | Fejér et al. (2020); Mediavilla et al. (2023); Rawat et al. (2025); Tobolková et al. (2024) | Antioxidant activity |
| Flavonoids (quercetin, rutin, catechin, kaempferol) | 0.2-10 mg/g of dry residue | Bais et al. (2014); Belov et al. (2023); Çolak et al. (2026); Kalaba et al. (2020); Markó et al. (2021); Raina et al. (2019); Tahir et al. (2016) | Antioxidant activity |
| Biflavonoids (amentoflavone, ginkgetin) | 0.02-0.09% of dry residue | Bajac et al. (2025); Butkienė et al., 2015; Dimitrov et al. (2024); Jojić et al. (2024); Rajčević et al. (2020) | Antimicrobial and anti-inflammatory activity |
| Lignans (podophyllotoxin-like compounds) | 0.01-0.05% | Bajac et al. (2025); Bais et al. (2014); Butkienė et al., 2015; Çolak et al. (2026); Jojić et al. (2024); Kalaba et al. (2020); Raina et al. (2019); Rajčević et al. (2020); Tahir et al. (2016) | Antimicrobial and cytotoxic activity |
| Aldehydes (benzaldehyde, p-anisaldehyde, vanillin) | 0,10-0.36% in essential oil | Bajac et al. (2025); Bais et al. (2014); Belov et al. (2023); Dimitrov et al. (2024); Dumitrescu et al. (2022); Jojić et al. (2024); Judžentienė (2019); Kalaba et al. (2020); Popescu et al. (2023); Raina et al. (2019); Tahir et al. (2016) | Aroma component |
| Ketones (camphor, terpinen-4-one, pinocarvone) | 0.10-0.70% | Bais et al. (2014); Çolak et al. (2026); Dimitrov et al. (2024); Dumitrescu et al. (2022); Fejér et al. (2020); Jojić et al. (2024); Judžentienė (2019); Kalaba et al. (2020); Rajčević et al. (2020) | Antimicrobial activity Aroma component |
| Total organic acids | 0.18-0.50% | Dimitrov et al. (2024); Popescu et al. (2023) | Antiseptic activity Food taste improving |
| Organic acids (citric, malic, tartaric, acetic) | 0.10-0.36% | Bajac et al. (2025); Belov et al. (2023); Çolak et al. (2026); Fejér et al. (2020); Jojić et al. (2024); Judžentienė (2019); Raina et al. (2019); Tahir et al. (2016) | Food taste improving |
| Alcohols (α-terpineol) | 0.15-0.45% | Butkienė et al., 2015; Dimitrov et al. (2024); Judžentienė (2019) | Aroma component |

*Note. GAE - gallic acid equivalent.

Markó et al. (2021) studied sexual dimorphism in *J. communis*, which includes an analysis of essential oil from vegetative organs and demonstrates that the qualitative terpene

composition of needles in male and female plants generally retains the same dominant component structure. The monoterpenes *α-pinene* and *sabinene* remain the main constituents of the essential oil, regardless of plant sex, while differences primarily concern essential oil yield and the relative proportions of individual minor components. These data indicate that sexual differentiation has a limited impact on the qualitative terpenoid profile of needles and does not disrupt the overall monoterpene dominance characteristic of the species (Markó et al., 2021).

The data reviewed demonstrate that the terpenoid profile of *J. communis* needles in different European regions is characterized by a consistent predominance of monoterpenes, with high inter- and intra-population variability in the relative proportions of individual components. The monoterpenes *α-pinene* and *sabinene* form the structural basis of the essential oil fraction, while the contribution of sesquiterpenes remains stable but quantitatively secondary, reflecting the adaptive plasticity of terpene metabolism in needles across a wide range of environmental conditions.

The major constituents of berry essential oil remain the monoterpenes: *α-pinene, β-pinene*, and *sabinene*, with moderate participation of *limonene* and sesquiterpenes (*β-caryophyllene, germacrene D*). However, variability in relative proportions is determined by both local environmental conditions and the stage of berry ripening (Gonçalves et al., 2022; Surso, 2022; Belov et al., 2023; Dimitrov et al., 2024). Thus, ethanol extracts from juniper berries of the second year of ripening contained two times less *α-pinene, β-myrcene, germacrene D,* and *β-caryophyllene*, and the fractions of *sabinene* and *limonene* found in berries of the first year of ripening were not detected in samples of the second year of ripening. The acetone extracts of the same samples of berries did not have significant differences in detected contents (Belov et al., 2023). However, some authors argue that during berry ripening, a tendency toward an increase in the proportions of *α-pinene* and *β-caryophyllene* is observed, reflecting the dynamics of terpene synthesis during phenological development (Fejér et al., 2020; Markó et al., 2021).

***Phenolic constituents.*** The total content of phenolic compounds in extracts from needles and berries varies widely from 9 to 68 mg GAE (gallic equivalent) per gram of dry residue of the extract (Table 1). The phenolic profile of the juniperus needles is characterized by a consistent predominance of quercetin and kaempferol glycosides with a moderate contribution of phenolcarboxylic acids. Quantitative values of quercetin-3-O-glucoside varied from 0.37 to 1.15%, rutin from 0.21 to 0.54%, and the total phenolic fraction was 0.8-2.3% of dry weight (Judžentienė, 2019; Rajčević et al., 2020; Gonçalves et al., 2022; Tobolková et al., 2024).

The phenolic profile of *J. communis* berries is presented in comparable ranges in a number of European and Eastern European studies (Fejér et al., 2020; Gonçalves et al., 2022; Belov et al., 2023). The total phenolic content in the berries reaches approximately 6.5-18 mg/g dry weight, with the flavonoid and proanthocyanidin fractions, depending on the ripening stage and growing conditions. Among the identified components, quercetin-3-O-rutinoside and isorhamnetin-3-O-glucoside dominated, with their shares fluctuating between 0.25-0.48% and 0.18-0.31%, respectively. Interannual and location variability was manifested in fluctuations in quercetin and rutin concentrations, highlighting the sensitivity of the berry phenolic profile to climatic and ecological conditions, as well as to the stage of fruit ripeness (Fejér et al., 2020; Belov et al., 2023; Popescu et al., 2023). The highest phenolic compound values are consistently recorded in mature berries, which is interpreted as a result of the accumulation of secondary metabolites in the reproductive organs. In addition to terpenes and phenolic compounds, the secondary metabolism of *J. communis* includes a wide range of organic acids, sugars, amino acids, and lipophilic compounds, which can manifest the biological activity and food technological properties.

***Other organic constituents***. The content of organic compounds of *J. communis* needles, including aldehydes, ketones, organic acids, and alcohols, was analysed (Judžentienė, 2019; Dimitrov et al., 2024).

The aldehydes (p-anisaldehyde, benzaldehyde) were present in the range of 0.10-0.32%, ketones (camphor and terpinen-4-one) - 0.2-0.6%, organic acids - 0.25-0.5%. Among the organic

acids, the authors note citric acid – 0.18-0.25%, malic acid – 0.12-0.21%, malotartaric acid – 0.10-0.18%, which is consistent with the data of Belov et al. (2023). In contrast to needles, berries showed higher interlocal and interannual variability, particularly in the ketone fraction, reflecting the phenological dynamics of fruit metabolism. The organic acids (acetic, malic, citric) in *J. communis* berries were detected in the range of 0.18–0.36%, aldehydes (benzaldehyde, vanillin) - 0.10-0.28%, ketones (terpinen-4-one, pinocarvone) - 0.1-0.32% of dry weight (Fejér et al., 2020; Belov et al., 2023; Popescu et al., 2023).

In addition, the other secondary metabolites are present in the needles and berries of *J. communis* including biflavonoids and lignans, the concentrations of which are generally lower and exhibit organ-specific localization. The several biflavonoids (amentoflavone, ginkgetin) and lignans (podophyllotoxin-like compounds) were identified in needles from European populations at concentrations of 0.02-0.08% and 0.01-0.09% of dry weight, respectively. In berries, the presence of these compounds is minimal (<0.01%), emphasizing the organ-specific localization of secondary metabolites (Dimitrov et al., 2024; Jojić et al., 2024).

Thus, the chemical profile of *J. communis* is designed by a combination of environmental, phenological, and genetic factors. Geographic location and associated climatic conditions (temperature, insolation, humidity, and altitude) have a key influence on the relative proportions of terpenes and phenolic compounds in both needles and berries (Fejér et al., 2020; Rajčević et al., 2020; Tobolková et al., 2024; Rawat et al., 2025).

Analysed data confirm that the chemical profile of *J. "Communis"* needles and berries is a highly variable but structurally organized system of secondary metabolites, in which monoterpenes, sesquiterpenes, phenolic compounds, and organic acids are integrated based on organ specificity, phenology, and geographic context. The influence of sex, age, and reproductive state of plants is an additional factor, introducing moderate quantitative changes but not altering the overall structure of the chemical profile.

## APPLICATIONS OF *Juniperus communis* SECONDARY METABOLITES IN AGRICULTURE AND THE FOOD INDUSTRY

Owing to the rich and chemically diverse spectrum of secondary metabolites, including terpenoids, phenolic compounds, flavonoids, and lignans, extracts and essential oils of common juniper (*J. communis*) exhibit considerable potential for application across a wide range of fields, including medicine, pharmaceuticals, nutraceuticals, veterinary science, cosmetics, and plant protection. Of particular practical relevance is their use in agriculture and the food industry as sources of natural antioxidants, antimicrobial and preservative agents, as well as biologically active components capable of enhancing product stability and quality.

Numerous studies demonstrate that *J. communis* extracts and essential oils exhibit pronounced antioxidant activity in standard *in vitro* model assays, with the contribution of individual classes of compounds varying depending on the type of preparation and the extraction method employed (Bais et al., 2014; Höferl et al., 2014; Belov et al., 2023). For juniper berry essential oil, Höferl et al. (2014) reported high scavenging activity of free 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radicals, with more pronounced effects in reactions based on hydrogen atom transfer mechanisms, which the authors attributed to the high content of monoterpenes, particularly α-pinene.

At the same time, several studies have shown that ethanolic berry extracts exhibit high antioxidant activity in fluorescence recovery after photobleaching (FRAP) assays and hydroxyl radical scavenging tests, highlighting the significant role of the polyphenolic fraction in shaping overall antioxidant capacity (Fejér et al., 2020). The values of the inhibitory concentration, which scavenges 50% of free radicals ($IC_{50}$), determined by ABTS and DPPH assays may vary substantially depending on the plant origin, conditions of growth, extraction procedures, chemical composition of the oil or extracts (Höferl et al., 2014; Basha et al., 2024, Hrytsyna et al., 2024).

Therefore, direct quantitative comparisons between studies are constrained by methodological differences.

However, most conclusions from the analysis of different *J. communis* populations showed that the antioxidant activity of ethanol extracts is closely related to their phenolic compound content (Fejér et al., 2020; Belov et al., 2023).

In addition to studies assessing exclusively the direct free radical scavenging activity of juniper berry essential oil *in vitro*, activation of cellular antioxidant responses has been demonstrated in the *Saccharomyces cerevisiae* model, including increased activity of the primary enzymatic antioxidant defence systems, superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) (Höferl et al., 2014).

Due to the chemical composition of juniper essential oil and extracts, as well as their biological activities, they can serve as sources of antioxidants and functional compounds in food model systems (Ibraimova et al., 2025; Tsitsirigka et al., 2025)

Incorporation of *J. communis* berries into bread formulations resulted in an almost two-fold increase in the antioxidant activity of the final product, as determined by DPPH analysis (Ibraimova et al., 2025). This observation may indicate a transfer of functional properties during food processing, an effect not reported by authors who investigated isolated extracts alone.

Essential oils and organic extracts of *J. communis also* exhibit antibacterial activity against a range of Gram-positive bacteria, including *Staphylococcus aureus*, *Bacillus subtilis,* and *Listeria monocytogenes*, with Gram-positive strains generally showing higher susceptibility than Gram-negative bacteria (Bais et al., 2014; Tavares & Seca, 2018; Semerdjieva et al., 2021; Dumitrescu et al., 2022). In the case of Gram-negative bacteria such as *Escherichia coli*, *Salmonella enterica,* and *Pseudomonas aeruginosa*, the degree of growth inhibition varies depending on concentration, the chemical composition of the oil or extract, and the methodological approach applied in antimicrobial testing (Bais et al., 2014; Semerdjieva et al., 2021; Çolak et al., 2026). The authors noted higher efficacy against pathogen bacteria, suggesting the potential applicability of juniper oils in multifarious applications, including food-related and environmental systems.

These observations are further supported by the study of Čmiková et al. (2024), which demonstrated that essential oil obtained from dried *J. communis* berries reduced the bacterial load of *S. enterica* in a vacuum-packaged carrot model, indicating that antimicrobial activity can be retained within a real food matrix. Kalaba et al. (2020) also reported inhibitory effects of juniper essential oil against *S. aureus* and *L. monocytogenes*, confirming its activity against pathogens of relevance to meat and dairy products.

More recent investigations by Peruč et al. (2021, 2022, 2024) established the ability of juniper essential oil to inhibit biofilm formation and disrupt mature biofilms of non-tuberculous mycobacteria (*Mycobacterium avium*, *M. intracellulare,* and *M. gordonae*). In addition, the authors identified synergistic effects between *J. communis* essential oil and selected antibiotics, pointing to the potential relevance of juniper oil for preventing microbial contamination in water supply systems.

Several studies have also confirmed the antifungal activity of *J. communis* essential oils against phytopathogenic fungi, including *Fusarium* spp., *Rhizoctonia solani*, *Botrytis cinerea,* and *Colletotrichum* spp., whereas aqueous extracts generally exhibit weak or negligible activity (Bais et al., 2014; Semerdjieva et al., 2021).

Bajac et al. (2025) demonstrated that microencapsulated forms of juniper essential oil retain antimicrobial activity and enable prolonged release of active terpenes, including α-pinene and sabinene.

Despite substantial variability in the investigated materials (berries, processing by-products, microencapsulated formulations) and methodological approaches, the majority of studies converge on the conclusion that *J. communis* exhibits a broad spectrum of antimicrobial activity (Carroll et al., 2011; Tavares & Seca, 2018; Semerdjieva et al., 2021). Essential oils generally display stronger inhibitory effects than extracts, while the efficacy of extracts is strongly dependent on the solvent used and the resulting chemical composition (Bais et al., 2014; Semerdjieva et al., 2021). Taken together, these findings

indicate the potential of *J. communis* essential oils and extracts as sources of natural antimicrobial agents, with effectiveness demonstrated in laboratory assays and model applied systems (Čmiková et al., 2024; Bajac et al., 2025; Çolak et al., 2026).

Comparative analysis of the published data indicates that the insecticidal and acaricidal activity of *J. communis* is predominantly associated with its essential oils, whereas extracts and powders tend to exhibit more limited or indirect effects (Carroll et al., 2011; Shafaie et al., 2019; Semerdjieva et al., 2021; Hrytsyna et al., 2024).

In the study by Shafaie et al. (2019), berry powders and extracts of *J. communis* exerted ovicidal and reproduction-inhibiting effects on stored-grain pests; however, under comparable experimental conditions, essential oils demonstrated higher efficacy.

The insecticidal activity of *J. communis* essential oil depends primarily on the presence and relative proportions of terpene classes, notably monoterpenes (α-pinene, sabinene) and, to a lesser extent, sesquiterpenes, which contribute to toxic and repellent effects against insects and mites Garay et al., 2020). The authors accentuated that the efficacy of *J. communis* essential oil against pests, including mosquitoes, aphids, and certain other phytophagous insects, correlated with the concentration of these terpene components. The higher levels of α-pinene and sabinene were associated with increased mortality and reduced feeding activity in arthropods, whereas oils with lower proportions of these compounds exhibited weaker activity. In particular, the monoterpenoids α-pinene and sabinene were shown to interfere with insect nervous system physiology and to suppress vital processes more effectively than many synthetic analogues, especially within integrated pest management systems (Garay et al., 2020).

The nematocidal activity of *J. communis*-based extracts has been attributed by some authors to the presence of totarol, a tricyclic phenolic diterpene with a totarane skeleton (Tavares & Seca, 2018). Using the model nematodes *Caenorhabditis elegans* and *C. briggsae*, Belov et al. (2023) demonstrated that 70% ethanolic and acetone extracts obtained from first-year ripening juniper berries, owing primarily to their content of monoterpenes (α-pinene, β-myrcene and limonene), sesquiterpenes (germacrene D), phenolic compounds, as well as other constituents such as myo-inositol (a cyclic polyol), may be regarded as potential sources of natural biopesticides, including agents for nematode control.

One of the most consistently reported findings across different studies is the pronounced repellent and deterrent activity of *J. communis* essential oil against arthropods, including ticks (*Ixodes scapularis and Amblyomma americanum*) and stored-product insect pests (*Sitophilus granarius and Callosobruchus maculatus*). These effects are commonly attributed to the combined action of mono- and sesquiterpenes, particularly the high content of α-pinene, sabinene, and myrcene (Carroll et al., 2011; Shafaie et al., 2019; de Aguiar et al., 2024).

Semerdjieva et al. (2021) demonstrated that *J. communis* essential oil effectively reduces the viability and feeding activity of aphids (*Rhopalosiphum padi and Sitobion avenae*), exhibiting antifeedant and insecticidal effects comparable to those of plant-derived biopesticides.

These findings are further extended by de Aguiar et al. (2024), who reported pronounced larvicidal activity of a commercial *J. communis* essential oil against *Aedes aegypti* ($LC_{50} \approx 92.45$ ppm), along with a deterrent effect on oviposition, supporting the high sensitivity of mosquitoes to the monoterpene components of the oil.

The acaricidal potential of *J. communis* has been additionally confirmed by Erdoğan (2026), who demonstrated the toxicity of the essential oil against *Varroa destructor* ($LC_{50} \approx 3.75$ μL/L), while simultaneously observing a lack of adverse effects on honey bees, a factor of critical importance for practical applications in apiculture.

Earlier work by Carroll et al. (2011) established that the repellent activity of *J. communis* essential oil against *A. aegypti* and ticks is retained at low doses, indicating the high biological activity of volatile terpenes. Subsequently, Bajac et al. (2025) showed that microencapsulated formulations of the essential oil provide prolonged insecticidal and repellent effects through controlled release of active

components, thereby enhancing the stability and applied value of such systems.

Despite differences in target organisms (mosquitoes, ticks, aphids, agricultural insect pests, and store-bought pests) and observed biological effects (insecticide, repellent, antifeedant, ovicidal, and acaricidal), the majority of authors converge on the view that the biopesticidal activity of *J. communis* is multifactorial in nature and is determined by a complex of mono- and sesquiterpenes, particularly α-pinene, sabinene, and myrcene (Carroll et al., 2011; Semerdjieva et al., 2021; de Aguiar et al.; 2024). Overall, the literature analysis indicates that *J. communis* essential oils represent a promising source of plant-derived biopesticides and acaricides for integrated plant protection systems, agricultural product storage, and veterinary applications, whereas extracts and powders appear more suitable as auxiliary or complementary agents (Shafaie et al., 2019; Bajac et al., 2025; Erdoğan, 2026).

Owing to their rich chemical composition, particularly the terpenoids and polyphenols present in the essential oil and extracts of *J. communis*, which influence both aroma and flavour as well as functional properties, including antioxidant protection and the stabilisation of biologically active compounds, these juniper-derived materials are widely used in the manufacture of a variety of food products and beverages. Traditionally, essential oil derived from common juniper berries has been employed in the production of strong alcoholic beverages, including gin and various herbal liqueurs (Höferl et al., 2014; Gari et al., 2020; Albrecht & Madisch, 2022; Basha et al., 2024; Čmiková et al., 2024; Stefkov et al., 2025).

Hrytsyna et al. (2024) report that in Slovakia, juniper cones (berries) are used in the production of the national alcoholic beverage “Borovička”. The terpene and oxygenated compound profile of *J. communis* imparts a characteristic “coniferous-citrus” flavour to such beverages.

Despite their traditional use in alcoholic beverages, juniper essential oil may also be applied in other food flavouring systems, such as marinades, sauces, different meat products, beverages and functional foods, where a coniferous-spicy note is desired (Gari et al., 2020; Stefkov et al., 2025).

Gbaguidi et al. (2020) further suggest that essential oils from aromatic plants, including *J. communis*, may be regarded as natural biopreservatives for both liquid and semi-liquid food systems, as well as for meat products. Their unique properties support potential application in sauces and seasonings, where the oil may simultaneously suppress the growth of spoilage microorganisms and slow lipid oxidation, thereby maintaining microbiological stability and the aromatic profile of the product without the use of synthetic preservatives.

In an experimental study, Tomović et al. (2020) incorporated *J. communis* berry essential oil into the formulation of dry fermented sausages as a partial or complete alternative to sodium nitrite. The authors demonstrated that inclusion of the essential oil resulted in a statistically significant reduction in lipid oxidation during ripening and storage, as evidenced by lower thiobarbituric acid reactive substances (TBARS) values compared with control samples without the oil. Simultaneously, the essential oil contributed to the suppression of undesirable microflora, ensuring microbiological stability comparable to that of traditional nitrite-containing formulations. Sensory evaluation indicated that, at optimally selected concentrations, juniper oil did not impair, and in some cases improved, the aromatic profile of the sausages through characteristic coniferous-spicy notes (Tomović et al., 2020). On the basis of combined technological, microbiological, and sensory data, the authors concluded that *J. communis* essential oil may be used as a functional ingredient in the development of “cleaner” and healthier meat products with reduced levels of synthetic additives.

The nanoemulsions of *J. communis* essential oil at concentrations up to 0.75% effectively inhibited the growth of *Listeria monocytogenes* and *E. coli* while simultaneously slowing the increase in lipid oxidation indices (TBARS), making such systems promising for chilled fish fillets and semi-processed products (Çolak et al., 2026).

Bampidis et al. (2023) evaluated the use of *J. communis* berry essential oil and tincture as feed additives for all animal species. The report indicates that, when included in feed at recommended dosages, these products are safe and do not induce toxic effects in animals. Their

pronounced antioxidant potential contributes to the stabilisation of lipid components in feed and prevents rancidity. In addition, biologically active compounds present in the oil exert moderate antimicrobial effects, contributing to a reduction in microbial load in feed mixtures. Collectively, these effects identify *J. communis* essential oil as a promising natural ingredient for improving feed quality and enhancing food safety in animal production. Extracts of *J. communis* included in the diet of fish, Nile tilapia (*Oreochromis niloticus*) have been shown to improve growth performance and feed conversion ratio (Radwan et al., 2024). They exert positive effects on gut health by enhancing the morphological integrity and functional capacity of the intestinal mucosa. Active components of the extract strengthen antioxidant and immune responses, reducing oxidative stress and increasing resistance to infections. Furthermore, inclusion of the extract stimulates the expression of genes associated with immunity and antioxidant defence, supporting its potential as a functional additive in aquaculture feeding strategies.

Essential oils obtained from *J. communis* needles are characterised by a harsher terpene profile, with elevated levels of α-pinene and other monoterpenes, which limits their direct application in food systems due to sensory aggressiveness. The primary applications of needle-derived oils are therefore associated with antimicrobial and disinfectant potential, including possible use in the sanitation of surfaces, water, and air, as well as in veterinary and household products (Albrecht & Madisch, 2022).

## CONCLUSIONS

A synthesis of the published data shows that the biological and practical value of *J. communis* is primarily determined by its essential oils and extracts, which are rich in mono- and sesquiterpenes, polyphenols, and other secondary metabolites, with composition and activity strongly dependent on the source material and processing methods. Essential oils exhibit the most pronounced antioxidant, antimicrobial, insecticidal, and acaricidal effects, whereas extracts and powders generally show more selective and less intense activity, but can be effective in functional food and feed systems. The practical applicability of *J. communis* products has been confirmed in real matrices – meat products, bakery goods, fish-based foods, and aquaculture feeds, where they enhance antioxidant stability, microbiological safety, and, at appropriate dosages, sensory quality. Additionally, by-products of juniper can be effectively integrated into cascade utilisation chains, including the production of biochar with adsorption and agronomic functions. Overall, these findings confirm the high potential of *J. communis* as a multifunctional natural resource for the food, agricultural, veterinary, and related industries, provided that the form, dosage, and application context are scientifically optimized.

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