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Review Article

MEDICINAL POTENTIAL OF MINT (*MENTHA* SPP.): AN EVIDENCE-BASED REVIEW OF PHYTOCHEMISTRY, PHARMACOLOGICAL ACTIVITIES, AND THERAPEUTIC APPLICATIONS

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ABSTRACT

Mint (*Mentha* spp.) is widely recognized for its culinary applications and has also been extensively investigated for its medicinal properties. The genus contains diverse bioactive phytochemicals, including terpenoids, flavonoids, phenolic acids, and volatile constituents such as menthol, menthone, and pulegone, which may contribute to its biological and pharmacological activities. Preclinical and clinical studies have investigated the potential of *Mentha* species and their phytochemicals in the management of gastrointestinal disorders, including colic, functional dyspepsia, and irritable bowel syndrome. Mint-derived preparations have also been investigated for their potential effects on oral and respiratory health. In addition, essential oils from *Mentha* species have shown antibacterial, antifungal, and antiviral activities in experimental studies. Emerging evidence further suggests potential roles for *Mentha* phytochemicals in metabolic regulation, cognitive function, and cancer-related pathways. However, considerable variation in phytochemical composition among species and chemotypes, as well as differences associated with cultivation conditions, plant material, extraction procedures, formulations, and dosage, presents challenges in translating experimental findings into consistent clinical applications. This comprehensive review summarizes the phytochemistry, pharmacological properties, and available clinical evidence concerning the medicinal potential of *Mentha* species. It also highlights current research gaps and emphasizes the need for standardized preparations, well-designed translational studies, and adequately powered randomized controlled trials to establish the safety, efficacy, and clinical relevance of *Mentha*-derived preparations.

Keywords: *Mentha,* Phytochemistry, Essential oils, Pharmacological activities, Therapeutic potential.

INTRODUCTION

Medicinal plants have long been an integral part of traditional healthcare systems worldwide, providing remedies for a wide range of ailments and contributing to the maintenance of health. The genus *Mentha* comprises more than 25 recognized species and belongs to the family Lamiaceae. Mint is widely valued for its culinary applications and has also attracted considerable attention because of its traditional and medicinal uses (Tafrihi *et al*., 2021; Mahboubi, 2021). Among the economically and medicinally important species are *Mentha piperita* (peppermint), *M. spicata* (spearmint), *M. arvensis* (cornmint), and *M. longifolia* (horsemint). For centuries, various *Mentha* species have been used in traditional medical systems and folk practices for the management of

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digestive, respiratory, and inflammatory conditions (Farzaei *et al*., 2017; Mahendran *et al*., 2017). The medicinal properties of *Mentha* species are associated with a diverse array of bioactive phytochemicals, including flavonoids, phenolic acids, terpenoids, and volatile constituents. Flavonoids reported from *Mentha* include luteolin, apigenin, and hesperidin, whereas important phenolic acids include rosmarinic acid, caffeic acid, and ferulic acid. The essential oils of different *Mentha* species commonly contain compounds such as menthol, menthone, carvone, pulegone, limonene, linalool, and related monoterpenes and sesquiterpenes (Table 1). The relative abundance of these constituents varies considerably among species and chemotypes. Among the major constituents of peppermint, menthol has been extensively investigated because of its characteristic cooling sensation and effects on smooth muscle and nociceptive pathways. Its biological effects are associated, in part, with interactions with transient receptor potential (TRP) channels and calcium-dependent mechanisms. The combined presence of these bioactive constituents contributes to the diverse pharmacological properties reported for *Mentha* species.

Table 1. List of various Mint-derived phytochemicals.

Phytochemical Class	Major Compounds	Properties / Biological Role	References
Essential Oils (Monoterpenes & Sesquiterpenes)	Menthol, Menthone, Pulegone, Carvone, Limonene, 1,8-Cineole, β-Caryophyllene	Cooling sensation, smooth muscle relaxant, antimicrobial, analgesic, carminative	Mimica-Dukić *et al.* (2003); Singh & Pandey (2018)
Flavonoids	Luteolin, Apigenin, Diosmin, Hesperidin, Rutin, Quercetin	Antioxidant, anti-inflammatory, cardioprotective, anticancer	Mahendran *et al.* (2021)
Phenolic Acids	Rosmarinic acid, Caffeic acid, Ferulic acid, p-Coumaric acid	Antioxidant, anti-inflammatory, neuroprotective, hepatoprotective	Farzaei *et al.* (2017); Fazel Nabavi *et al*. (2015)
Tannins	Condensed tannins, Hydrolyzable tannins	Antimicrobial, antioxidant, gastroprotective	Mamadalieva *et al.* (2020)
Glycosides	Menthoside, Hesperidoside	Antioxidant, metabolic regulation	Mimica-Dukić *et al.* (2003); Mamadalieva *et al.* (2020)
Sterols & Triterpenes	β-Sitosterol, Oleanolic acid, Ursolic acid	Anti-inflammatory, anticancer, hepatoprotective	Liu (1995); Farzaei *et al.* (2017);
Vitamins & Minerals	Vitamin A, Vitamin C, Calcium, Iron, Potassium, Magnesium	Nutritional support, immune regulation	Anwar *et al.* (2019)
Other Compounds	Polysaccharides, Coumarins (Umbelliferone, Scopoletin)	Immunomodulatory, antioxidant, antimicrobial	Yousefian *et al.* (2019)

An increasing body of experimental and clinical evidence has investigated several of the traditional uses of *Mentha*. Preclinical studies have reported antioxidant, anti-inflammatory, antibacterial, antifungal, antiviral, gastroprotective, hepatoprotective, neuroprotective, and metabolic effects in different *Mentha* species and their preparations (Anwar *et al*., 2019; *Wani et al*., 2022; Chakraborty *et al*., 2022). However, the strength of evidence varies among individual activities, species, extracts, and experimental models. Among the medicinal applications of mint, gastrointestinal disorders have received considerable clinical attention. Peppermint oil has been investigated extensively in patients with irritable bowel syndrome (IBS), with systematic reviews and meta-analyses reporting improvements in overall IBS symptoms and abdominal pain (Ingrosso *et al*., 2022). *Mentha*-derived preparations have also been investigated for functional dyspepsia, respiratory symptoms, oral health, common-cold symptoms, and effects on cognitive performance. However, these applications differ substantially in the quality and extent of available clinical evidence, and therefore should not be considered uniformly established therapeutic indications. The traditional use of peppermint and other *Mentha* species extends across several geographical regions, including India, Europe, and Africa. Peppermint has traditionally been used for digestive complaints such as nausea, diarrhea, abdominal discomfort, and other gastrointestinal disturbances. Traditional applications have also included conditions such as bronchitis, fever, hypertension, diabetes, and urinary tract disorders. Experimental investigations have further indicated potential chemopreventive and anticancer activities of *Mentha* preparations. For example, Samman *et al.* (1998) investigated the effects of peppermint-related preparations in experimental models of benzo[a]pyrene-induced lung tumor development in mice and chemically induced oral carcinogenesis in the hamster cheek pouch. Such findings provide experimental evidence for potential anticarcinogenic activity but should not be interpreted as evidence of established anticancer efficacy in humans.

The essential oils of *Mentha* species are generally colourless to pale yellow or greenish-yellow liquids, although their appearance can vary according to species, chemotype, plant material, and extraction conditions. Their chemical composition is dominated primarily by volatile terpenoids and related compounds. Frequently reported constituents include menthol, menthone, isomenthone, linalool, carvone, menthyl acetate, linalyl acetate, pulegone, piperitone, and piperitenone derivatives. The proportions of these constituents vary markedly among *Mentha* species and chemotypes (Mimica-Dukić & Božin, 2008; Salehi *et al*., 2018). It is important to distinguish the volatile constituents of *Mentha* essential oils from the non-volatile phenolic compounds present in leaves and other plant tissues. Phenolic constituents reported from *Mentha* include rosmarinic acid and other caffeic acid derivatives, as well as ferulic acid, cinnamic acid derivatives, oleanolic acid, and caftaric acid (Benedec *et al*., 2013; Taamalli *et al*., 2015). *Mentha* species also contain flavonoids and other phenolic compounds, including luteolin, apigenin, acacetin, salvigenin, diosmin, and related derivatives. Flavanols such as catechin may also occur in some species, while coumarin derivatives have been reported from *Mentha* plants (Salehi *et al*., 2018). The phytochemical profile of *Mentha* is therefore highly complex and can vary according to species, genotype or chemotype, geographical origin, environmental conditions, cultivation practices, developmental stage, harvesting conditions, and extraction method. Such variability can influence the biological activity and reproducibility of *Mentha*-derived preparations. Consequently, differences in plant material, extraction procedures, chemical composition, formulation, and dosage represent important challenges when translating experimental findings into standardized therapeutic applications. A comprehensive and critical assessment of the available evidence is therefore necessary. The present review focuses on the phytochemistry, pharmacological activities, and clinical evidence associated with *Mentha* species, while also highlighting the limitations of current research and the need for standardized preparations and well-designed clinical trials to establish their therapeutic potential.

Antibacterial and Antifungal Properties of Mint

Bacterial infections remain a major cause of human disease, while the increasing emergence of antimicrobial resistance has created significant challenges in the treatment of infectious diseases. In many remote and underserved communities, access to conventional medicines may be restricted by cost, availability, and geographical barriers. Consequently, medicinal plants continue to be investigated as potential sources of antimicrobial compounds and complementary therapeutic agents (Kim *et al*., 2020). Several experimental studies have demonstrated that *Mentha* species and their essential oils possess antibacterial activity against a broad range of Gram-positive and Gram-negative bacteria (Table 2). The antibacterial activity of *Mentha* essential oils is associated with their complex composition of volatile constituents, particularly monoterpenes and oxygenated monoterpenes. Compounds such as menthol, menthone, carvone, pulegone, and related terpenoids may contribute to antimicrobial activity. The biological activity of individual compounds depends on their chemical structure, lipophilicity, concentration, and interactions with microbial cell membranes. In phenolic compounds such as carvacrol and thymol, the free hydroxyl group can contribute to antimicrobial activity by facilitating interactions with microbial membranes and altering membrane integrity and cellular homeostasis. However, the antimicrobial activity of essential oils generally results from the combined effects of several constituents rather than from a single functional group or compound (Gulluce *et al*., 2007; Ultee *et al*., 2002; Ben Arfa *et al*., 2006). Phenolic compounds may also affect bacterial physiological processes and gene expression. Experimental studies with *Escherichia coli* have demonstrated that phenolic compounds such as gallic acid can alter cellular metabolism and transcriptional responses, affecting pathways associated with energy metabolism, transport, and other cellular functions (Liu *et al*., 2022). These findings suggest that the antimicrobial effects of plant-derived phenolic compounds may involve multiple cellular targets.

Table 2. Antimicrobial effects of phytochemicals derived from Mint.

Target Microorganism	Compound	Observed Effect	Proposed Mechanism	References
Bacillus subtilis, *Klebsiella pneumoniae*, *Escherichia coli*	*Mentha* spp. extracts	Broad-spectrum antibacterial activity against Gram-positive and Gram-negative bacteria	Membrane disruption and growth inhibition	Mamadalieva *et al.* (2020); Mahboubi & Haghi (2008)
Various bacteria	Phenolic compounds in mint oil	Significant antimicrobial activity	Hydroxyl groups of phenolics interfere with microbial cell functions	Ultee *et al*. (2002); Lambert *et al*. (2001)
Multiple bacterial strains	*Mentha longifolia* essential oil	Strong antibacterial activity	Essential oil-mediated membrane damage	Li *et al.* (2023)
Multiple bacterial and	*Mentha*	Antibacterial and	Disruption of microbial cell	Gulluce *et al.*

fungal strains *Candida albicans*	*longifolia* oil Menthol (*Mentha piperita* oil)	antifungal effects Antifungal activity	integrity Inhibits the H^+-ATPase pump and disrupts ergosterol biosynthesis, causing leakage of intracellular contents	(2007) Samber *et al.* (2015)

Nikšić *et al.* (2012) reported that the essential oil of *Mentha longifolia* exhibited antibacterial activity against both Gram-positive and Gram-negative bacteria. Similarly, Gulluce *et al*. (2007) recorded significant antimicrobial activity of *M. longifolia* essential oil against a wide range of microorganisms. They identified several volatile constituents in the oil, with cis-piperitone epoxide, pulegone, and piperitenone oxide among the major components. These findings support the potential of *Mentha* essential oils as sources of naturally occurring antimicrobial compounds.

The antimicrobial activity of *Mentha* is not restricted to bacteria and also extends to pathogenic fungi. Samber *et al.* (2015) investigated *M. piperita* essential oil and its major constituents against *Candida* species and reported that menthol affected plasma-membrane H^+-ATPase activity and membrane-associated functions. Menthol treatment was associated with changes in intracellular pH, reduced cellular ergosterol content, and disruption of membrane integrity, resulting in loss of cellular homeostasis. These findings indicate that *Mentha*-derived essential oils and their constituents may exert antimicrobial effects through multiple mechanisms involving membrane disruption and interference with essential cellular processes. Fungal infections represent an important health concern, particularly in populations vulnerable to opportunistic and pathogenic fungi. The increasing occurrence of resistance to conventional antifungal agents has stimulated interest in the identification of new antifungal compounds from natural sources. Several studies have reported the inhibitory effects of *Mentha* species against filamentous fungi. For example, the essential oil of *M. spicata* has been reported to inhibit the mycelial growth of *Fusarium oxysporum*, while essential oils from different *Mentha* species have shown activity against several pathogenic and food-associated fungi (Jianu *et al*., 2021; Yousefian *et al*., 2023). The antifungal activity of *Mentha* essential oils has been associated with their volatile constituents, particularly oxygenated monoterpenes such as menthol and menthone, together with other compounds including carvone and piperitenone derivatives. The antifungal potential of peppermint essential oil has also been proven experimentally. Moghtader (2013) investigated the essential oil of *M. piperita* against *Aspergillus niger* and reported strong inhibitory activity. His study also reported that peppermint essential oil showed greater inhibition of *A. niger* than the gentamicin control. The oil contained 23 identified compounds, with menthol, menthone, and menthyl acetate as the major constituents, suggesting that these compounds may contribute to its antifungal activity. However, the activity of the complete essential oil should not be attributed exclusively to a single constituent because interactions among multiple volatile compounds may contribute to the overall effect.

The antifungal effects of peppermint essential oil have also been investigated using the yeast *Saccharomyces cerevisiae* as a model organism. Exposure to *M. piperita* essential oil was associated with increased intracellular reactive oxygen species, mitochondrial fragmentation, chromatin condensation, and an increased frequency of respiratory-deficient mutants, indicating damage to the mitochondrial genome and impairment of mitochondrial function. These observations suggest that oxidative stress and mitochondrial dysfunction contribute to the cytotoxic effects of peppermint essential oil in yeast (Ferreira *et al*., 2014). Furthermore, Samber *et al.* (2015) recorded anti-*Candida* activity of *M. piperita* essential oil and its major constituents. Their study investigated plasma-membrane H^+-ATPase activity and cellular ergosterol content and concluded that treatment affected proton extrusion and membrane-associated functions. These findings provide evidence that peppermint essential oil can interfere with essential cellular processes in pathogenic yeasts and contribute to loss of cellular integrity. Therefore, the available experimental evidence indicates that *Mentha* essential oils possess considerable antifungal potential against a variety of filamentous fungi and yeasts. Nevertheless, most available evidence remains based on *in vitro* experiments, and further studies involving standardized preparations, defined active constituents, toxicity assessment, and well-designed clinical investigations are required before their therapeutic antifungal applications can be established.

Antiviral Properties

Herrmann and Kucera (1967) reported that *Melissa officinalis* (lemon balm), a member of the mint family (Lamiaceae), contains both tannin and nontannin polyphenolic antiviral fractions. The tannin fraction exhibited antiviral activity against Newcastle disease virus (NDV), whereas the nontannin polyphenolic fraction showed activity against herpes simplex and vaccinia viruses. They also reported that *M. piperita* and other members of the mint family contain tannin fractions with antiviral properties. Peppermint extracts were subsequently shown to possess antiviral activity against several viruses, including NDV and herpes simplex virus. The peppermint extract contained a tannin fraction with affinity for NDV and a nontannin fraction with antiviral activity against herpes simplex virus, although its antiviral activity was lower than that observed for *M. officinalis*. These findings suggested biochemical similarities among members of the mint family, particularly with respect to their tannin

fractions. More recently, Mazzanti *et al.* (2008) reported that a hydroalcoholic leaf extract of *M. officinalis* inhibited HSV-2 replication *in vitro*. The extract contained cinnamic-acid-like compounds, with rosmarinic acid being the predominant identified phenolic constituent.

Anticancer Properties

Cancer comprises a diverse group of diseases characterized by the uncontrolled proliferation and dissemination of abnormal cells. Globally, an estimated 18.1 million new cancer cases and 9.6 million cancer deaths occurred in 2018 (Bray *et al*., 2018). A substantial proportion of cancers is associated with modifiable risk factors, including tobacco use, alcohol consumption, unhealthy diet, physical inactivity, and excess body weight, highlighting the importance of lifestyle-related factors in cancer prevention (Islami *et al*., 2018). Current cancer treatments include surgery, chemotherapy, radiotherapy, targeted therapy, immunotherapy, and other treatment modalities. Although chemotherapy is an important component of cancer management, its use can be associated with several adverse effects, including nausea, vomiting, fatigue, and hair loss. Certain chemotherapeutic agents may also produce long-term or late effects, including infertility and damage to organs such as the heart and lungs.

A recent approach is to investigate the anticancer potential of plant-derived bioactive compounds and to develop nanotechnology-based delivery systems for their therapeutic application (Chaudhary *et al*., 2023). Essential oils and extracts of several *Mentha* species have also shown cytotoxic effects against Vero, HeLa, and Hep-2 cell lines (Rahimifard *et al*., 2010). Similarly, Hussain *et al.* (2010) reported that the essential oils of *M. arvensis, M. piperita, M. longifolia,* and *M. spicata* showed cytotoxic activity against the human breast cancer cell line MCF-7 and the prostate cancer cell line LNCaP. Sharma *et al.* (2014) further reported in vitro anticancer activity of extracts from *Mentha* species against MCF-7 and other human cancer cell lines. In addition, Ohara and Matsuhisa (2002), in a screening of 120 medicinal plants for inhibition of okadaic acid-induced tumor promotion, identified *Mentha* species among the plants exhibiting strong inhibitory activity.

Green-synthesized silver nanoparticles using *Mentha pulegium* extract have also displayed anticancer activity. Kelkawi *et al.* (2017) reported considerable cytotoxicity of *M. pulegium*-mediated silver nanoparticles against MCF-7 and HeLa cancer cells. Further studies have indicated that *M. pulegium*-derived silver nanoparticles can induce caspase-9-dependent cell death in MCF-7 and MDA-MB-231 cells (Wang & Wei, 2022). In addition, L-menthol, a major monoterpene constituent of *Mentha* species, has been reported to induce apoptosis through activation of caspase-10 and modulation of HSP90. The proposed mechanism involves downstream activation of caspase-3 and caspase-7, with mitochondrial cytochrome-c release and caspase-9 involvement contributing to the apoptotic response (Faridi *et al*., 2016).

Perillyl alcohol has been reported to interfere with Ras-related signaling and induce G0/G1 cell-cycle arrest in cancer cells (Cerda *et al*., 1999). Water and methanolic extracts of *M. longifolia* have also shown antimutagenic and anticancer activities (Al-Ali *et al*., 2014). In addition, *M. arvensis* leaf extracts exhibited anti-angiogenic activity in the chick chorioallantoic membrane assay (Sonawane *et al*., 2016), while *M. pulegium* essential oil showed cytotoxicity against SK-OV-3, HeLa, and A549 cancer cell lines (Shirazi *et al*., 2004). At the mechanistic level, essential oils and their constituents may induce apoptosis through oxidative stress, mitochondrial membrane disruption, cytochrome-c release, alteration of the Bcl-2/Bax balance, caspase-3 and caspase-9 activation, and PARP cleavage (Figure 1). They may also influence cell-cycle regulators and signaling pathways such as mTOR/PDK1/PKB and MDM2/p21, thereby promoting cell-cycle arrest and apoptosis (Raut & Karuppayil, 2014).

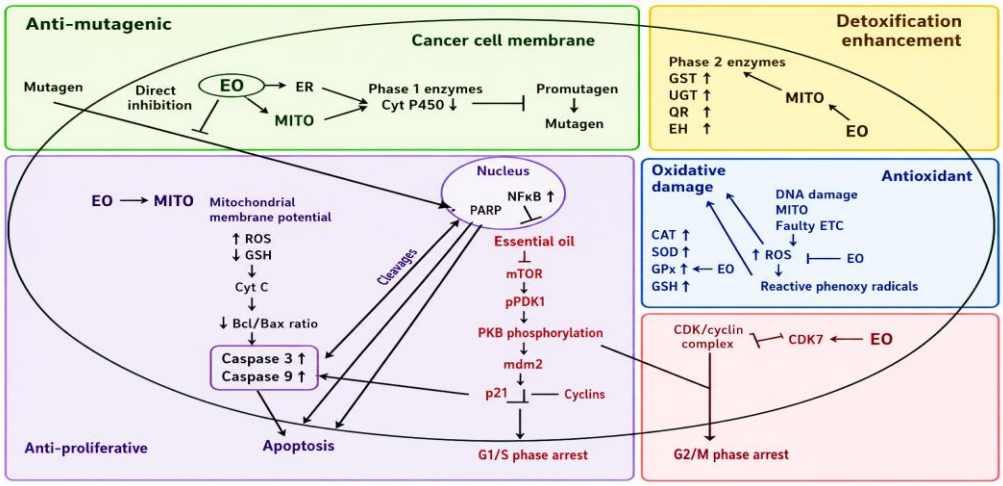


Figure 1. Various pathways targeting mint phytochemicals related to antimutagenic, antiproliferative, and detoxification properties. The formation of carcinogens is enhanced, detoxification is induced, mitochondrial-mediated apoptosis is

induced, oxidative stress is reduced, key oncogenic signalling pathways are inhibited by the various phytomolecules, and the cell cycle is arrested at both G1/S and G2/M checkpoints. All these activities lead to suppression of cancer initiation, progression, and proliferation.

CONCLUSION

Mint (*Mentha* spp.) is an important medicinal herb rich in essential oils, flavonoids, and phenolic compounds, contributing to its antioxidant, anti-inflammatory, antimicrobial, gastroprotective, neuroprotective, and anticancer properties. Peppermint oil has established clinical applications, particularly in functional gastrointestinal disorders, while researchers continue to investigate its potential for respiratory, oral, metabolic, and cognitive health. However, variations in phytochemical composition, lack of dosage standardization, limited safety evaluation, and a lack of large-scale clinical trials remain major challenges. Further research on standardized preparations, mechanisms of action, and well-designed clinical studies is needed to establish its therapeutic potential and safety.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declare that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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