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Bioactive compounds and therapeutic properties of *Carum carvi*

Abstract

Carum carvi L. (Apiaceae), commonly known as caraway, is a versatile biennial herb that has been revered since ancient times for its remarkable therapeutic potential. Widely recognized as a rich reservoir of bioactive compounds, it serves as a valuable source of both traditional remedies and modern pharmaceutical ingredients, nutraceuticals, and functional food components. The seeds are extensively used as a prized spice to impart a distinctive pungent aroma and warm flavour to beverages, baked goods, pickles, salads, and confectionery.

The phytochemical profile of *C. carvi* is dominated by its essential oil (1–9% yield), which is exceptionally rich in monoterpenes, particularly D-carvone and (+)-limonene. Other notable constituents include coumarins (umbelliferone, herniarin, and scopoletin), flavonoids, phenolic compounds, and lipid fractions such as glycerol esters and β-sitosterol, primarily accumulated in the roots. These diverse secondary metabolites — including terpenes, coumarins, flavonoids, and phenolics — confer potent biological activities, most notably broad-spectrum antimicrobial effects against both Gram-positive and Gram-negative bacteria, as well as strong antioxidant properties through free radical scavenging and enzyme modulation.

Owing to this unique chemical diversity, *Carum carvi* holds significant promise in food preservation, flavour enhancement, and the development of natural therapeutic agents.

Keywords: *Carum carvi*, caraway, essential oil, carvone, limonene, antimicrobial, antioxidant, phytochemistry, traditional medicine, nutraceuticals.

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Introduction

Carum carvi L., commonly known as caraway, is one of the most important ethnomedicinal plants with a long history of traditional use dating back to ancient times. Its curative properties are well documented in Ayurveda and other classical systems of medicine. It belongs to the Apiaceae family (also known as the Umbelliferae or spices family) and is commonly referred to by various vernacular names such as Persian cumin, Kala jeera, Siyah jeera, Shah jeera, and caraway seeds.[1] The chromosome number of *C. carvi* is 2n = 20.[2]

The genus Carum comprises about 25 species worldwide, of which *Carum carvi* is one of the most economically and traditionally significant species due to its seeds.[3] The plant is highly valued in the pharmaceutical and food industries because of its preventive health benefits and distinctive tangy, aromatic flavour. Traditionally, the dried fruits (mericarps) of *Carum carvi* are used as an appetizer, digestive stimulant, antispasmodic agent, and remedy for stomach ache, indigestion, flatulence, and various gastrointestinal disorders.[4,5]

Carum carvi holds considerable economic and medicinal importance both in India and several European countries. It has been cultivated in Europe since ancient times and is also grown commercially in Canada, the United States, and India. In India, it is primarily cultivated or found in the high-altitude regions of Jammu and Kashmir (where it is popularly known as Kashmiri jeera), along with parts of Himachal Pradesh and Uttarakhand.[6,7]

As a biennial crop, caraway is often grown as an alternative crop in the first year. If the taproot reaches a diameter of at least 6 mm by the end of the first growing season, the plant branches and flowers in the second year. Otherwise, it remains in a vegetative state for an additional year. Farmers commonly manage the crop over two successive years based on root development. Flowering typically occurs in May, with mature seeds harvested in early July. Some spring-sown or annual varieties show growth patterns similar to the typical biennial forms.[7,8]

Taxonomy

The caraway is categorized taxonomically as it belongs to the genus *Carum*, family Apiaceae, order Apiales, and species *carvi*. According to literature another synonym of *Carum carvi* mentioned in literatures Carum *officinale, C. decussatum, Apium carv*i, as per categorized as most aromatic and mild hot spices.[3]

Botanical description

Carum carvi plants have multibranched leaves and stem, it is biannual 100 cm tall, thick, and have tap root. Stem of *Carum carvi*is glaucous, straight. Leaves of *Carum* is tripinnate, cauline. Flower is umbel type and in white color, lateral type of branching, elongated elliptical shaped fruit is present, schizocarp, angular shape and black or dark brown in colour. The seed of *Carum* is yellow to brownish grey in color which is widely used in pharmaceutical field and in diverse uses for medicinal purposes. It has cooling, stimulant, gastritis properties. Oil of caraway is used in disease treatment.[7]

Phytochemistry of caraway

Carum carvi L. (Apiaceae) is recognized as one of the most phytochemically diverse members of the Apiaceae family, with its medicinal and commercial value primarily attributed to the seeds, although roots, leaves, and flowers also contribute bioactive metabolites. The seeds yield 1–9 % essential oil (EO) by hydrodistillation, with recent microwave-assisted hydrodistillation (MWHD) methods achieving yields up to 4.7 % while preserving

higher carvone content.[9] According to the European Pharmacopoeia, caraway fruit must contain at least 3 % EO, predominantly composed of monoterpenes. The two major constituents are D-carvone (typically 50–85.2 %) and (+)-limonene (up to 45 %), together accounting for over 95 % of the total EO in most chemotypes. [5,10,11]

Geographic and extraction-method variations are pronounced. Tunisian samples show carvone at 58.2 % and limonene at 38.5 %,[10] while Qinghai (China) seeds yield carvone 69.7 % and limonene 28.55 %.[11] Iranian and European cultivars can reach carvone levels of 77–85 % under optimized conditions such as direct induction heating with magnetic field or salted hydrodistillation.[5] Minor monoterpenes include γ-terpinene, β-pinene, p-cymene, myrcene, trans-dihydrocarvone, and trans-carveol (each <5 %). Non-volatile fractions contain fatty acids (oleic, linoleic, and petroselinic acids, 10–18 %), proteins (20 %), carbohydrates (15 %), and phenolic compounds. Flavonoids such as quercetin, isoquercitrin, and kaempferol-3-glucoside are concentrated in seeds and roots, while phenolic acids (e.g., caffeic acid derivatives) and coumarins (umbelliferone, herniarin, scopoletin) occur in trace amounts.[12,13]

Gamma irradiation (up to 10 kGy) has been shown to increase EO yield (to 3.5 %) and elevate phenolic and flavonoid content (13.70 and 7.38 mg/g oil, respectively), enhancing overall bioactivity without compromising safety.[14] Critical synthesis reveals that earlier reports[15] documented lower carvone:limeonene ratios (~70:30), whereas contemporary GC-MS analyses of commercial and wild samples demonstrate chemotypic plasticity driven more by location and cultivation practices than by genotype.[16] This variability underscores the necessity for standardized sourcing and extraction protocols to ensure reproducible therapeutic efficacy. Compared with related Apiaceae (e.g., cumin or coriander), caraway EO is uniquely carvone-dominant, conferring its characteristic pungent aroma and superior membrane-disrupting potential.

In addition, plant tissue culture techniques offer a sustainable and controlled alternative for the large-scale production and enhancement of secondary metabolites (such as carvone, limonene, and flavonoids) from *Carum carvi*, especially through elicitation and optimized culture conditions[17] (Table 1& Figure 1).

Table 1 Major bioactive compounds from *Carum carvi L.*, their occurrence, abundance, biological activities, and supporting literature.

Compound	Plant part	Major class	Typical abundance (%)	Reported biological activity (evidence level & quantitative data)	Key reference(s)
D-Carvone	Seeds (EO)	Monoterpene ketone	56.5–85.2	Antimicrobial (membrane disruption, MIC 0.029–0.469 mg/mL mixture); antioxidant (DPPH IC50 15 mg/mL); anti-QS	Ghannay et al.; Liu et al.; Bouyahya et al.[10,11,18]
(+)-Limonene	Seeds (EO)	Monoterpene hydrocarbon	16.2–38.5	Antioxidant; gastroprotective (in vivo); synergistic antimicrobial	Hajlaoui et al.[19]
γ-Terpinene, β-pinene, p-cymene	Seeds (EO)	Monoterpenes	1–31	Synergistic antimicrobial and antioxidant	Hajlaoui et al.[19]
Quercetin & derivatives	Seeds, roots	Flavonoids	Trace–moderate	Antioxidant (metal chelation, enzyme inhibition); anti-inflammatory	Al-Snafi.[12]
Kaempferol-3-glucoside	Roots	Flavonoid	Trace	Antioxidant; xanthine oxidase inhibition	Al-Snafi.[12]
Oleic/linoleic/ petroselinic acids	Seeds	Fatty acids	10–18	Nutritional; mild antimicrobial	Laribi et al. & Mahboubi. [5,13]

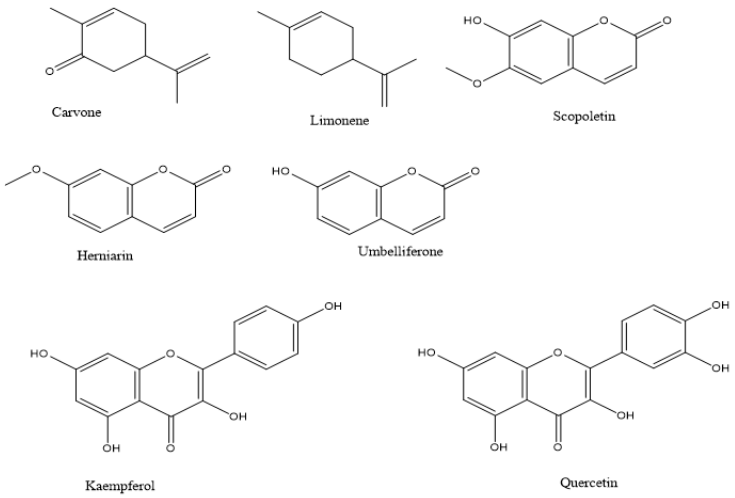

Figure 1 Some major componenets of *Carum carvi.*

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Importance of *Carum carvi*

Caraway is most important medicinal plant which is used to cure the diseases. All parts of caraway are important such as seeds, leaf, stem and roots. Seed of caraway is used in respiratory problem, gynecoproblem, gastritis, diarrhea, vomiting, loose motion. The leaves and seed both are used as tea or in decoction preparation for the treatment of cough and cold. It has high number of flavonoids so that it uses as flavoring agent in spices, meats, candies, and beverages. The volatile oil serves numerous uses such as mouth wash, bathing alterations, scents, detergent perfumed, and as parasitic agents. Caraway seed vapor might alleviate back pain and gout.The seeds have been utilized for the treatment of dermatitis. In western countries seeds are used as anti-diabetic and anti-hypertension products.[20] The importance of caraway is shown in (Figure 2).

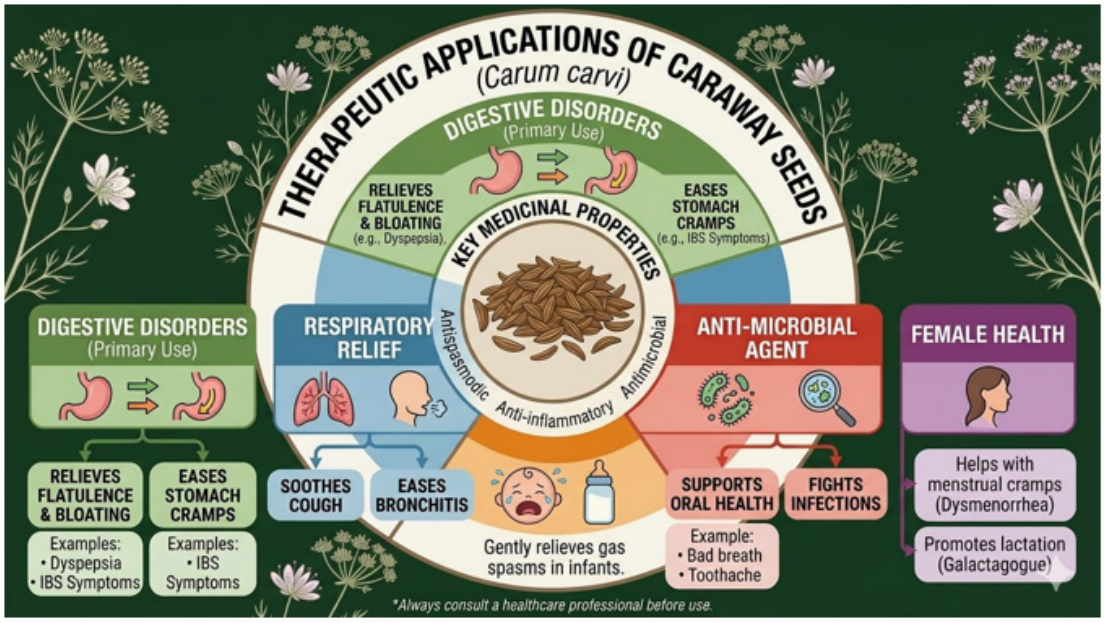

Figure 2 *Carum curvi* plants parts used as medicinal resources (AI-generated illustration created with Google gemini. The author(s) take full responsibility for its scientific accuracy and relevance.

Biological and pharmacological uses of caraway

Carum carvi exhibits a broad spectrum of pharmacological activities, yet the strength of evidence varies markedly across study types (*in vitro* >> *in vivo* >> clinical). Traditional Unani and Ayurvedic uses as a carminative, digestive aid, and appetite stimulant are now supported by modern pharmacological data, though overgeneralized claims must be tempered by the current evidence base.

Antimicrobial and Antifungal Activity: EO demonstrates potent broad-spectrum effects. *In vitro* studies report MIC values of 0.029–0.469 mg/mL and MBC 0.059–0.938 mg/mL against MRSA, *Vibrio* spp., *E. coli*, and *Candida albicans*, with the carvone/limonene chemotype showing superior activity after MWHD extraction.[9–11] Synergism with coriander EO further lowers MICs and expands spectrum.[19] Mechanism: membrane disruption + QS inhibition (see Mechanisms section).

Antioxidant and Anti-inflammatory Activity: Multiple assays confirm robust free-radical scavenging (DPPH IC50 15 mg/mL; FRAP EC50 11.33 mg/mL for mixtures), exceeding individual EOs and approaching synthetic antioxidants.[10,11] *In vivo* rodent models show hepatoprotective and anti-ulcerogenic effects at 100–200 mg/kg.[21] Phenolic/flavonoid enrichment via irradiation further amplifies activity.[14]

Gastroprotective, Antispasmodic, and Digestive Effects: Aqueous and EO extracts reduce ulcer index and improve motility in rodent models.[22] Traditional use for flatulence and dyspepsia aligns with EMA-approved indications for symptomatic relief of digestive discomfort.[23,25]

Antidiabetic and Other Activities: *In vivo* hypoglycaemic effects (20–60 mg/kg in streptozotocin rats) and α-glucosidase inhibition (IC50 0.75 mg/mL for mixtures) suggest potential.[19] Preliminary anticancer data show cytotoxicity against Caco-2 and HepG-2 lines, linked to apoptosis induction.[14]

Critical Evaluation and Limitations: While *in vitro* and acute *in vivo* data are consistent and promising, clinical evidence is sparse. One randomized trial (n=60 overweight women) demonstrated anti-obesity effects with aqueous extract (30 mL/day, ~1.5 g fruit equivalent) over 12 weeks, with no haematological/biochemical adverse effects.[25] No large-scale, dose-response trials exist for most indications. Confounding factors include variable EO composition (carvone 56–85 %), lack of standardization, and limited long-term safety data beyond EMA's 28-day rodent NOAEL (200 mg/kg EO).

Conclusion

In conclusion, this review synthesizes the rich phytochemical profile and multifaceted pharmacological potential of *Carum carvi* L., reaffirming its value as a traditional carminative and modern functional ingredient. Plants and plant-derived products have been cornerstones of Ayurveda and other traditional systems for millennia, offering fewer side effects and better human compatibility than many synthetic drugs for chronic conditions.

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Dosage and Clinical Relevance: Traditional and EMA-recommended doses include 0.5–2 g comminuted fruit as herbal tea (1–3 times daily) or 0.15–0.3 mL EO divided in 1–3 doses for adults.[23,24] These align with safe, effective use for digestive complaints. Rodent-effective doses (100–500 mg/kg) translate to approximate human equivalents of 1–8 g/day, but pharmacokinetic confirmation is essential.

Limitations of Current Studies and Knowledge Gaps: Most evidence derives from *in vitro* assays or acute rodent models using non-standardized extracts. Key gaps include: (i) head-to-head chemotype comparisons; (ii) human bioavailability and metabolite profiling of carvone/limonene; (iii) well-powered, long-term clinical trials for antidiabetic, anticancer, or anti-obesity claims; and (iv) systematic evaluation of herb–drug interactions and chronic toxicity. Environmental factors (location, irradiation, extraction method) cause substantial compositional variability, complicating reproducibility.

Future Directions: Standardized extracts, nano-formulations for improved bioavailability, and randomized controlled trials are urgently needed to translate traditional knowledge into evidence-based therapeutics. Such advances could position *Carum carvi* as a safe, multi-target nutraceutical in food preservation, pharmaceuticals, and functional foods.

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Conflicts of interest

The authors declare that there are not conflict of interest.

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