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Review Article

Ethnomedicinal, Phytochemical, and Pharmacological Properties of *Daucus carota* L.: A Narrative Review

Mukthiyar Ahamed[1*]

[1]Department of Pharmacognosy, Shantha College of Pharmacy, Peresandra, Chikkaballapur-562104, Karnataka, India

Abstract

Introduction: *Daucus carota* L. (carrot) is an important edible root crop recognized for its nutritional value and diverse therapeutic properties. It contains numerous bioactive phytochemicals responsible for a wide range of pharmacological activities. This narrative review critically summarized the ethnomedicinal uses, phytochemical composition, pharmacological properties, safety aspects, and future therapeutic potential of carrot.

Methods: A comprehensive literature search was conducted using PubMed, Scopus, Google Scholar, and ScienceDirect for studies published between 2000 and 2025. The search employed keywords such as "carrot", "ethnomedicine", "phytochemistry", "pharmacological activities", and "bioactive compounds," combined using the Boolean operators AND and OR. English-language original research articles, review papers, and experimental studies relevant to the objectives of this review were included.

Results: The available evidence demonstrates that carrots are rich in carotenoids, polyacetylenes, flavonoids, phenolic compounds, vitamins, essential oils, and other bioactive metabolites. Experimental studies have documented antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, gastroprotective, nephroprotective, and immunomodulatory activities. These effects appear to be mediated through multiple molecular pathways, including the regulation of oxidative stress and inflammatory signaling.

Conclusion: Carrot possesses significant ethnomedicinal importance and promising pharmacological potential. Nevertheless, additional well-designed clinical studies, standardized extracts, mechanistic investigations, and comprehensive safety evaluations are required to support the translation of these findings into evidence-based therapeutic and nutraceutical applications.

Keywords: *Daucus carota L.*, Ethnomedicinal, Phytochemicals, Pharmacological activities, Bioactive compounds, Antioxidant

***Corresponding Author:**
Mukthiyar Ahamed,
Email: mukthiyarahamed005@gmail.com

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Introduction

Fruits and vegetables are essential components of a healthy diet because they provide vital nutrients and numerous bioactive compounds that promote human health. Among root vegetables, *Daucus carota* L. (carrot), a member of the family Apiaceae, is one of the most widely cultivated and consumed crops worldwide. Beyond its nutritional value, carrot has attracted considerable scientific interest due to its diverse phytochemical composition and broad spectrum of pharmacological activities. It is an excellent source of carotenoids, dietary fiber, vitamins, minerals, polyphenols, and other antioxidant compounds that may contribute to the prevention of oxidative stress-related disorders and support overall health (1,2).

On the basis of root pigmentation and geographical origin, cultivated carrots are broadly classified into eastern and western types. Eastern carrots, believed to have originated in regions such as Afghanistan, are characterized predominantly by purple and yellow roots, whereas western carrots exhibit orange, red, white, and other color variations. Orange western carrots are the most extensively cultivated worldwide because of their high β-carotene content, favorable agronomic characteristics, and consumer preference. Differences among carrot cultivars influence not only their appearance but also their phytochemical composition and biological activities (2, 3).

For centuries, carrots have been used in traditional systems of medicine, including Ayurveda, Unani, Traditional Chinese Medicine (TCM), and various folk medicinal practices. Different parts of the plant—roots, seeds, leaves, flowers, and fruits— have been used for the management of digestive disorders, urinary tract diseases, inflammatory conditions, skin diseases, microbial infections, and reproductive disorders (4, 5). These traditional applications have stimulated extensive pharmacological investigations, which have

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reported antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, nephroprotective, gastroprotective, and immunomodulatory properties (6, 7).

The therapeutic potential of carrot is largely attributed to its diverse bioactive constituents, including carotenoids (β-carotene, α-carotene, lutein, and lycopene), polyacetylenes (falcarinol and falcarindiol), flavonoids, phenolic acids, vitamins, and essential oils (2, 4, 8). These compounds exert biological effects through multiple mechanisms, including the scavenging of reactive oxygen species (ROS), modulation of inflammatory signaling pathways, regulation of apoptosis, inhibition of microbial growth, and protection against cellular damage (9, 10).

Although a recent review by Kladar et al comprehensively summarized the phytochemistry and pharmacology of wild carrot, the rapidly expanding body of experimental evidence, together with emerging studies on cultivated carrot varieties, molecular mechanisms, safety considerations, and potential clinical applications, warrants an updated synthesis (4). Furthermore, many traditional claims remain insufficiently validated, and several reported pharmacological activities have not been critically integrated with current mechanistic evidence (11).

Therefore, the present narrative review aimed to comprehensively summarize and critically evaluate the ethnomedicinal uses, phytochemical composition, pharmacological activities, underlying molecular mechanisms, safety profile, and future therapeutic prospects of carrot. By integrating traditional knowledge with recent scientific evidence, this review provides an updated resource for researchers and healthcare professionals while identifying important gaps that require further investigation (4, 11).

Materials and Methods

Study Design

This study was conducted as a narrative review to comprehensively summarize the ethnomedicinal uses, phytochemistry, pharmacological activities, safety profile, and therapeutic potential of carrot.

Literature Search Strategy

A comprehensive literature search was conducted using PubMed, Scopus, Google Scholar, ScienceDirect, and Web of Science to identify relevant studies published between January 2000 and March 2025.

The search strategy employed combinations of the following keywords using Boolean operators AND and OR:

- "*Daucus carota*"
- "Carrot"
- "Ethnomedicine"
- "Traditional uses"
- "Phytochemistry"
- "Bioactive compounds"
- "Pharmacological activities'
- "Antioxidant"
- "Anti-inflammatory"
- "Anticancer"
- "Antidiabetic"

Example search string:
("*Daucus carota*" OR carrot) AND (ethnomedicine OR phytochemistry OR pharmacological activities OR bioactive compounds)

Inclusion Criteria

Studies were included if they met the following criteria:

- Were published in English.
- Reported ethnomedicinal, phytochemical, pharmacological, toxicological, or clinical information related to carrot.
- Included original research articles, review articles, books, or official pharmacopoeias.
- Contained scientifically relevant and sufficiently reliable information related to the objectives of the review.

Exclusion Criteria

The following publications were excluded:

- Articles published in languages other than English.
- Duplicate records.
- Conference abstracts without full-text availability.
- Editorials, opinion articles, and unpublished reports.
- Studies lacking sufficient scientific information relevant to the objectives of the review.

Study Selection

Retrieved articles were initially screened based on their titles and abstracts. Full-text articles that met the inclusion criteria were subsequently evaluated for relevance to the objectives of the review. The reference lists of selected studies were also examined to identify additional eligible publications.

Data Extraction

Relevant information, including ethnomedicinal uses, phytochemical constituents, pharmacological activities, experimental models, proposed mechanisms of action, safety data, and clinical evidence, was extracted and critically synthesized.

Quality Assessment

Priority was given to peer-reviewed publications from indexed scientific journals. Greater emphasis was placed on studies using validated experimental models, standardized extracts, and well-defined methodologies to improve the reliability and interpretability of the evidence summarized in this review.

Results

A comprehensive review of the published literature demonstrates that carrot is a rich source of nutritionally and pharmacologically important phytochemicals. The available evidence indicates that different parts of the plant, including the roots, seeds, leaves, flowers, and fruits, possess diverse biological activities supported by both traditional

knowledge and experimental studies. The major findings of this review are presented under taxonomic classification, vernacular names, botanical description, phytochemical composition, ethnomedicinal uses, and pharmacological activities.

Taxonomic Classification (1, 12)
Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Apiales
Family: Apiaceae
Genus: *Daucus* L.
Species: *Daucus carota* L.
Vernacular Names of Carrot (1, 13)
Hindi and Urdu: Gaajar
Kannada: Gajjari
Telugu: Gajjara gadda
English: Carrot
Tamil: Carrot/kerat
Malayalam: Carrot
Sanskrit: Grinjana

Botanical Description

Carrot is a biennial herb that generally reaches a height of 30–150 cm. It develops a thick fleshy taproot in cultivated varieties, whereas wild forms possess slender woody roots (1, 14). The stem is erect, branched, grooved, and covered with fine hairs. The leaves are alternate, finely divided, bipinnate to tripinnate, and feathery in appearance. Small white flowers are arranged in compound umbels and often possess a characteristic dark purple central flower. The fruits are dry schizocarps that split into two mericarps at maturity and possess hooked spines that facilitate seed dispersal (15).

Phytochemical Composition

Phytochemical investigations have demonstrated that carrot contains numerous biologically active constituents, including carotenoids (β-carotene, α-carotene, lycopene, lutein), polyacetylenes (falcarinol and falcarindiol), flavonoids, phenolic acids, vitamins (A, C, and E), essential oils, coumarins, terpenoids, polyphenols, and dietary fiber (2, 4, 8). These compounds have been associated with the antioxidant, anti-inflammatory, antimicrobial, anticancer, and other pharmacological properties reported for the plant (9, 10).

Differences Among Carrot Cultivars

The phytochemical profile varies considerably among carrot cultivars. Orange carrots are particularly rich in β-carotene, whereas purple carrots contain high concentrations of anthocyanins (8, 14). Red carrots are characterized by high levels of lycopene, while yellow carrots contain abundant lutein. Black carrots are also rich in anthocyanins and phenolic compounds. These compositional differences may influence their antioxidant capacity and potential therapeutic activities (9, 10).

Phytochemistry and Bioactive Compounds

Carrot is a rich source of diverse phytochemicals that contribute significantly to its nutritional and pharmacological properties. The concentration and composition of these constituents vary depending on cultivar, geographical origin, environmental conditions, and developmental stage. The principal classes of bioactive compounds identified in carrot include carotenoids, polyacetylenes, phenolic compounds, flavonoids, vitamins, essential oils, terpenoids, coumarins, and dietary fiber.

Carotenoids

Carotenoids are the major pigments responsible for the characteristic colours of carrot roots. Among these compounds, β-carotene is one of the predominant carotenoids and serves as an important precursor of vitamin A (2, 8). Other important carotenoids include α-carotene, lutein, lycopene, zeaxanthin, and β-cryptoxanthin (4). These compounds exhibit antioxidant properties through mechanisms that include scavenging ROS, reducing oxidative stress, and protecting cellular components against oxidative damage (6).

Polyacetylenes

Polyacetylenes, particularly falcarinol and falcarindiol, are important bioactive constituents of carrots. These compounds have attracted considerable scientific interest because of their reported anti-inflammatory, antimicrobial, and anticancer activities (4). Experimental studies suggest that falcarinol suppresses inflammatory pathways, induces apoptosis in cancer cells, and inhibits abnormal cell proliferation (10).

Phenolic Compounds and Flavonoids

Carrot contains a diverse range of phenolic acids and flavonoids, including chlorogenic acid, caffeic acid, gallic acid, ferulic acid, quercetin, kaempferol, luteolin, and apigenin (6, 9). These compounds contribute substantially to carrot's antioxidant capacity through mechanisms such as free-radical scavenging, metal-ion chelation, and inhibition of lipid peroxidation. In addition, they may modulate key inflammatory signaling pathways, including nuclear factor kappa B (NF-κB) and mitogen-activated protein kinase (MAPK) pathways (7).

Essential Oils and Terpenoids

Carrot seeds contain volatile essential oils rich in compounds such as limonene, sabinene, α-pinene, β-pinene, geraniol, linalool, caryophyllene, germacrene, and farnesol (4). These constituents have demonstrated antimicrobial, anti-inflammatory, antioxidant, and digestive activities. Terpenoids present in carrot may also contribute to its pharmacological effects (16, 17).

Vitamins and Other Bioactive Constituents

Carrot is an important source of vitamin A precursors, particularly provitamin A carotenoids, as well as vitamins C, E, and K, and several B-complex vitamins. It also

provides dietary fiber and essential minerals such as potassium, calcium, magnesium, and phosphorus (2, 8). Collectively, these nutrients support immune function, vision, cardiovascular health, and cellular protection against oxidative damage (6).

Carotenoid Biosynthesis

Carotenoid biosynthesis in carrot occurs primarily within plastids through the methylerythritol phosphate (MEP) pathway. This pathway involves the sequential conversion of geranylgeranyl pyrophosphate (GGPP) into phytoene, followed by the formation of lycopene, and its subsequent conversion into α-carotene and β-carotene. Carotenoid accumulation in carrot roots is influenced by genetic factors, developmental stage, environmental conditions, and cultivar characteristics. These factors collectively determine root coloration and nutritional quality (3, 12).

The diverse phytochemical profile of carrot provides a biochemical basis for its wide range of ethnomedicinal applications and pharmacological activities. Its bioactive compounds may act synergistically to produce antioxidant, anti-inflammatory, antimicrobial, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, nephroprotective, and anticancer effects (18).

Ethnomedicinal Uses

Carrot has been used as a medicinal plant for centuries in various traditional healthcare systems due to its nutritional value and therapeutic properties (9). Different parts of the plant, including the roots, seeds, leaves, flowers, and fruits, have traditionally been used to manage digestive disorders, urinary tract conditions, inflammatory diseases, skin disorders, respiratory ailments, metabolic diseases, and reproductive disorders. The widespread ethnomedicinal use of carrot across different geographical regions reflects its longstanding significance in traditional medicine, as depicted in Table 1 (6).

Traditional Uses in India

In Ayurveda, carrot is traditionally valued for its diuretic, digestive stimulant (carminative), stomachic, anti-inflammatory, and rejuvenating properties. Carrot roots are consumed to improve digestion, maintain visual health, and promote general well-being. The seeds have traditionally been used in the management of menstrual disorders, fertility-related conditions, and as a uterine stimulant. However, their use during pregnancy is generally discouraged because of their potential uterotonic effects.

Traditional Uses in China

In TCM, carrot fruits and seeds have been used as anthelmintic agents for the treatment of intestinal parasitic infections, including ascariasis and enterobiasis. Carrot preparations have also been used to improve digestion and support gastrointestinal health.

Traditional Uses in Turkey and the Middle East

Traditional medical practices in Turkey and several Middle Eastern countries employ carrot seeds and roots to manage digestive disturbances, cough, urinary tract disorders, kidney stones, and inflammatory conditions. Carrot-seed preparations have also been used to relieve abdominal discomfort and promote diuresis (19).

Traditional Uses in Europe

In European folk medicine, wild carrot has traditionally been used as a diuretic, antiseptic, expectorant, carminative, and wound-healing agent. The seeds have been employed in the management of urinary disorders, whereas poultices prepared from the roots have been applied to minor wounds, burns, ulcers, and skin infections.

Traditional Uses in Africa

In several African communities, carrot roots and seeds are traditionally used to manage digestive disorders, microbial infections, inflammatory conditions, nutritional deficiencies, and skin ailments. Fresh carrot juice is also commonly consumed as a nutritious tonic intended to promote general health and support immunity.

Common Ethnomedicinal Applications

Across various traditional medical systems, carrot has been reported for the management of:

- Digestive disorders
- Urinary tract infections and kidney stones
- Inflammatory diseases

Table 1. Ethnomedicinal Uses of Carrot in Different Traditional Medicinal Systems

Region/Traditional System	Plant Part Used	Traditional Uses	Conditions Treated	Reference
Ayurveda (India)	Root, seeds	Diuretic, carminative, stomachic, uterine stimulant	Indigestion, urinary disorders, menstrual disorders, kidney stones	(11-13)
Unani Medicine	Root, seeds	Digestive tonic, aphrodisiac, anti-inflammatory	Digestive disorders, gout, reproductive disorders	(11-13)
TCM	Fruits, seeds	Anthelmintic, digestive aid	Ascariasis, enterobiasis, tapeworm infections	(11-13)
Turkish Folk Medicine	Seeds, roots	Carminative, diuretic	Gastrointestinal disorders, respiratory ailments, urinary disorders	(11-13)
European Folk Medicine	Root, seeds	Diuretic, antiseptic, wound-healing agent	Wounds, burns, skin infections, urinary tract disorders	(11-13)
African Traditional Medicine	Root, seeds	Nutritional tonic, antimicrobial agent	Skin infections, digestive disorders, nutritional deficiencies	(11-13)
Middle Eastern Traditional Medicine	Seeds, roots	Digestive stimulant, anti-inflammatory agent	Abdominal pain, urinary disorders, inflammatory conditions	(11-13)

Note. TCM: Traditional Chinese medicine.

- Skin disorders and wound healing
- Cough and other respiratory ailments

Diabetes

- Hypertension
- Nutritional deficiencies
- Menstrual disorders
- General weakness and convalescence

Although some of these traditional applications are supported by experimental pharmacological findings, many therapeutic claims remain inadequately validated by well-designed clinical studies. Further mechanistic, toxicological, and clinical studies are therefore required to establish the efficacy, safety, and therapeutic relevance of carrot within modern evidence-based medicine.

Pharmacological Activities

The pharmacological potential of carrot has been extensively investigated in *in vitro* and in *vivo* studies, as well as in a limited number of clinical investigations. Its biological activities are primarily attributed to a diverse range of phytochemicals, including carotenoids, polyacetylenes (e.g., falcarinol and falcarindiol), flavonoids, phenolic acids, vitamins, and essential oils. These bioactive constituents exert therapeutic effects by scavenging ROS, regulating inflammatory mediators, modulating intracellular signaling pathways, inhibiting microbial growth, inducing apoptosis in cancer cells, and protecting tissues from oxidative damage. The major pharmacological activities of carrot are discussed below.

Antioxidant Activity

Oxidative stress plays a crucial role in the pathogenesis of numerous non-communicable and chronic diseases, including cardiovascular disorders, diabetes mellitus, neurodegenerative conditions, and cancer. Carrot exhibits marked antioxidant capacity owing to its rich profile of β-carotene, α-carotene, lutein, flavonoids, phenolic acids, vitamin C, and vitamin E (6, 7).

Experimental studies have demonstrated significant free-radical scavenging activity across standard analytical assays, including 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), ferric reducing antioxidant power (FRAP), and oxygen radical absorbance capacity (ORAC). Mechanistically, these phytochemicals neutralize ROS, inhibit lipid peroxidation, chelate transition metal ions, and enhance endogenous antioxidant defense enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx). Through these mechanisms, carrot-derived constituents protect cellular macromolecules against oxidative damage and reduce the risk of chronic diseases, as illustrated in Table 2 (20, 21).

Anti-inflammatory Activity

Inflammation is a protective physiological response to infection and tissue injury. However, unresolved chronic inflammation contributes to the development of numerous diseases, including arthritis, cardiovascular diseases (CVDs), diabetes mellitus, inflammatory bowel disease, and cancer. Carrot has demonstrated significant anti-inflammatory potential, which is attributed primarily to the presence of polyacetylenes (falcarinol and falcarindiol), carotenoids, flavonoids, phenolic acids, and vitamins (10, 22).

Experimental studies have shown that carrot extracts and isolated phytochemicals suppress the production of several pro-inflammatory mediators, including tumor necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), interleukin-6 (IL-6), nitric oxide (NO), and prostaglandin E_2 (PGE_2). Furthermore, these constituents inhibit the expression of cyclooxygenase-2 (COX-2) and downregulate inducible NO synthase (iNOS), thereby reducing the inflammatory responses (23).

The anti-inflammatory effects of carrot-derived compounds are primarily mediated through the inhibition of NF-κB and MAPK signaling pathways. Falcarinol and falcarindiol have also been reported to reduce oxidative

Table 2. Antioxidant Activity of Carrot and Its Major Phytoconstituents

Phytochemical/ Extract	Plant Part	Experimental Model	Dose/ Concentration	Major Findings	Proposed Mechanism	Reference
β-Carotene	Root	DPPH, ABTS, FRAP assays	Variable	Potent free radical scavenging activity	Scavenges ROS and inhibits lipid peroxidation	(6, 9)
α-Carotene	Root	*In vitro* antioxidant assay	Variable	Reduced oxidative stress biomarkers	Neutralizes ROS	(6, 9)
Lutein	Root	ORAC assay, cell culture	Variable	Protected cells against oxidative injury	Inhibits oxidative damage and stabilizes cell membranes	(6, 9)
Polyphenols	Root and leaves	DPPH, FRAP assays	Variable	High antioxidant capacity	Hydrogen donation and metal ion chelation	(6, 9)
Flavonoids	Leaves and seeds	DPPH, ABTS assays	Variable	Significant radical scavenging activity	ROS scavenging and inhibition of lipid peroxidation	(6, 9)
Vitamin C	Root	*In vitro* antioxidant assays	Variable	Reduced oxidative stress	Water-soluble antioxidant and regeneration of vitamin E	(6, 9)
Vitamin E	Root	Lipid peroxidation assay	Variable	Protected membrane lipids	Inhibits lipid peroxidation and stabilizes cell membranes	(6, 9)

Note. ABTS: 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); DPPH: 2,2-diphenyl-1-picrylhydrazyl; FRAP: Ferric reducing antioxidant power; ORAC: Oxygen radical absorbance capacity; ROS: Reactive oxygen species.

stress and suppress the production of inflammatory cytokines, thereby protecting tissues against inflammation-associated cellular damage.

Animal studies have further demonstrated that carrot extracts significantly reduce edema, inflammatory-cell infiltration, and oxidative tissue injury. These findings provide experimental support for the traditional use of carrot in the management of inflammatory disorders and suggest its potential as a natural source of anti-inflammatory agents. Nevertheless, additional well-designed clinical studies are required to establish the therapeutic efficacy and safety in humans.

Proposed mechanism

Carrot phytochemicals → Inhibition of NF-κB and MAPK pathways → ↓ COX-2 and iNOS expression → ↓ TNF-α, IL-1β, IL-6, NO, and PGE_2 production → Reduced inflammation and tissue damage (Table 3) (10).

Anticancer Activity

Cancer persists as a leading cause of morbidity and mortality worldwide, prompting continuing efforts to identify effective natural compounds with chemopreventive and therapeutic potential. Carrot has attracted considerable attention because of its rich content of carotenoids, polyacetylenes—particularly falcarinol and falcarindiol—flavonoids, polyphenols, lutein, and antioxidant vitamins, all of which have demonstrated promising anticancer properties in experimental studies (6, 10).

Among these, falcarinol and falcarindiol are considered the principal anticancer constituents of carrot. Preclinical investigations have demonstrated that these compounds significantly inhibit the proliferation of multiple transformed cell lines by inducing apoptosis, suppressing tumor growth, and inhibiting malignant cell-cycle progression. Furthermore, β-carotene, α-carotene, lutein, and other carotenoids contribute to cancer prevention by reducing oxidative DNA damage and maintaining cellular homeostasis (4).

The anticancer activity of carrot is mediated through multiple molecular mechanisms. These include activation of the intrinsic apoptotic pathway through increased expression of Bax and caspase-3 and decreased expression of the anti-apoptotic protein Bcl-2, ultimately resulting in programmed cell death. Carrot phytochemicals have also been reported to induce cell-cycle arrest at the G0/G1 and G2/M phases, thereby inhibiting uncontrolled cell proliferation. Furthermore, these compounds suppress NF-κB activation, reduce ROS-mediated cellular injury, and inhibit inflammatory mediators associated with tumor development.

Several *in vitro* and *in vivo* studies have demonstrated that carrot extracts and isolated phytochemicals can reduce tumor incidence, suppress cancer cell proliferation, and enhance antioxidant defense mechanisms. These findings suggest that carrot may serve as a promising functional food and complementary therapeutic agent for cancer prevention. However, large-scale clinical studies are still required to establish its efficacy, optimal dosage, and long-term safety in cancer management (10).

Proposed mechanism

Carrot phytochemicals (falcarinol, falcarindiol, β-carotene, lutein, flavonoids) → ROS scavenging and inhibition of NF-κB signaling → Cell-cycle arrest (G0/G1 and G2/M) → Activation of Bax and caspase-3 and reduction of Bcl-2 → Induction of apoptosis → Suppression of tumor growth and cancer cell proliferation (Table 4).

Antimicrobial Activity

Microbial infections caused by bacteria, fungi, and other pathogenic microorganisms remain a major global health concern. The alarming surge in antimicrobial resistance has intensified the search for plant-derived bioactive compounds as potential alternative therapeutic agents. Carrot exhibits broad-spectrum antimicrobial activity,

Table 3. Anti-inflammatory Activity of Carrot and Its Major Phytoconstituents

Phytochemical/ Extract	Plant Part	Experimental model	Dose/ Concentration	Major Findings	Proposed Mechanism	Reference
Falcarinol	Root	LPS-stimulated macrophages; animal inflammation models	Variable	Reduced production of inflammatory mediators and tissue inflammation	Inhibition of COX-2 and iNOS expression and suppression of NF-κB signaling	(6, 9)
Falcarindiol	Root	*In vitro* cell culture models	Variable	Suppressed inflammatory cytokines	Downregulation of TNF-α, IL-1β, and IL-6 through inhibition of the NF-κB pathway	(6, 9)
β-Carotene	Root	In vitro antioxidant and inflammatory models	Variable	Reduced oxidative stress-induced inflammation	ROS scavenging and inhibition of pro-inflammatory cytokines	(6, 9)
Polyphenols	Root and leaves	Cell-culture and animal studies	Variable	Decreased inflammatory response	Suppression of NF-κB and MAPK signaling pathways	(6, 9)
Flavonoids	Leaves and seeds	*In vitro* enzyme inhibition assays	Variable	Reduced cytokine release	Inhibition of COX-2, LOX, and related inflammatory pathways	(6, 9)
Vitamin C	Root	Experimental models of oxidative stress	Variable	Protected tissues from oxidative injury	Neutralization of ROS and enhancement of antioxidant defenses	(6, 9)
Vitamin E	Root	Lipid peroxidation models	Variable	Reduced inflammatory tissue damage	Inhibition of lipid peroxidation and stabilization of cellular membranes	(6, 9)

Note. COX-2: Cyclooxygenase-2; IL-1β\betaβ: Interleukin-1 beta; IL-6: Interleukin-6; iNOS: Inducible nitric oxide synthase; LOX: Lipoxygenase; LPS: Lipopolysaccharide; MAPK: Mitogen-activated protein kinase; NF-κ\kappaκB: Nuclear factor kappa-light-chain-enhancer of activated B cells; ROS: Reactive oxygen species; TNF-α\alphaα: Tumor necrosis factor-alpha.

primarily attributed to its diverse polyacetylenes, phenolic compounds, flavonoids, carotenoids, and essential oils (10, 16).

Experimental studies have demonstrated that extracts isolated from the roots, leaves, and seeds of carrot exhibit marked inhibitory activity against both Gram-positive (*Staphylococcus aureus*, *Bacillus subtilis*) and Gram-negative bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*). In addition, notable efficacy has been reported against fungal pathogens such as *Candida albicans* and *Aspergillus niger* (17).

The antimicrobial action of carrot is mediated through multiple cellular mechanisms. Falcarinol and falcarindiol can disrupt microbial cell membrane integrity, resulting in intracellular leakage and inhibition of microbial growth. Phenolic compounds and flavonoids may interfere with microbial enzymatic systems, alter membrane permeability, and disrupt nucleic acid and protein biosynthesis. Furthermore, essential oils present in carrot seeds may further exert antimicrobial effects by damaging microbial membranes and suppressing biofilm formation (10).

Several in vitro assays have demonstrated the concentration-dependent antimicrobial efficacy of carrot extracts against clinically important microorganisms. The effectiveness of these extracts varies according to the anatomical plant part, extraction solvent, phytochemical composition, and microbial species evaluated. Generally, ethanolic and methanolic extracts exhibit superior antimicrobial potency compared to aqueous extracts because of their higher extraction efficiency for certain bioactive constituents (11).

Overall, the available evidence underscores carrot as a promising natural source of antimicrobial agents with potential applications in pharmaceuticals, food preservation, and nutraceutical industries. Nevertheless, additional *in vivo* studies and well-designed clinical investigations are required to establish therapeutic efficacy and translational safety in clinical settings.

Proposed mechanism

Falcarinol, falcarindiol, flavonoids, phenolic acids, and essential oils → Disruption of microbial cell membrane → Inhibition of protein and nucleic acid synthesis → Suppression of microbial growth and biofilm formation → Antibacterial and antifungal activity (Table 5).

Antidiabetic Activity

Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from impaired insulin secretion, insulin resistance, or a combination of both. Owing to its rich and diverse phytochemical composition, carrot has been extensively investigated for its potential antidiabetic properties (4).

Experimental investigations have demonstrated that carrot extracts improve glycemic control through multiple biochemical mechanisms. Bioactive compounds such as

Table 4. Major Bioactive Compounds of Carrot With Anticancer Activity

Bioactive Compounds	Plant part	Experimental Model	Dose/ Concentration	Major Findings	Proposed Mechanism	Reference
β -Carotene	Root	*In vitro*/ Animal studies	Variable	Reduced oxidative DNA damage	Antioxidant activity and ROS scavenging	(6, 9)
Falcarinol	Root	Colon cancer cell lines	Variable	Inhibited cancer cell proliferation	Induction of apoptosis and cell-cycle arrest	(6, 9)
Falcarindiol	Root	*In vitro* studies	Variable	Suppressed tumor cell growth	Caspase activation and NF-$_{κ}$B pathway inhibition	(6, 9)
Lutein	Root	Cell culture	Variable	Reduced oxidative stress	Antioxidant and anti-proliferative activities	(6, 9)
Polyphenols	Root and leaves	*In vitro* studies	Variable	Inhibited tumour progression	ROS modulation	(6, 9)

Note. DNA: Deoxyribonucleic acid; NF-κ\kappaκB: Nuclear factor kappa-light-chain-enhancer of activated B cells; ROS: Reactive oxygen species.

Table 5. Antimicrobial Activity of Carrot and Its Major Phytoconstituents

Bioactive Compounds	Plant Part	Experimental Model	Dose/ Concentration	Major Findings	Proposed Mechanism	Reference
Essential Oil	Seeds	*Staphylococcus aureus*, *Bacillus subtilis*	Variable	Significant antibacterial activity	Disruption of bacterial cell membrane and inhibition of membrane permeability	(17, 20)
Essential Oil	Seeds	*Escherichia coli*, *Pseudomonas aeruginosa*	Variable	Inhibited growth of Gram-negative bacteria	Membrane damage and leakage of intracellular contents	(17, 20)
Falcarinol	Root	Bacterial culture assays	Variable	Broad-spectrum antibacterial activity	Disruption of microbial membrane integrity and inhibition of cell growth	(17, 20)
Falcarindiol	Root	*In vitro* antimicrobial assay	Variable	Inhibited bacterial proliferation	Alteration of membrane permeability and inhibition of microbial metabolism	(17, 20)
Phenolic Compounds	Root and leaves	*In vitro* antibacterial assay	Variable	Moderate antibacterial activity	Inhibition of essential bacterial enzymes and protein synthesis	(17, 20)
Flavonoids	Leaves and seeds	*In vitro* antimicrobial assay	Variable	Antibacterial and antifungal activities	Inhibition of nucleic acid synthesis and membrane destabilization	(17, 20)
Ethanolic Root Extract	Root	*Candida albicans*, *Aspergillus niger*	Variable	Significant antifungal activity	Cell membrane disruption and inhibition of fungal growth	(17, 20)

β-carotene, chlorogenic acid, flavonoids, polyphenols, and dietary fiber collectively regulate glucose metabolism. These phytochemicals may enhance insulin sensitivity, improve glucose uptake in peripheral tissues, reduce oxidative stress, and protect pancreatic β-cells against oxidative damage (6).

Furthermore, carrot polyphenols have been reported to inhibit key carbohydrate-digesting enzymes, including α-amylase and α-glucosidase, thereby delaying carbohydrate digestion and potentially reducing postprandial blood glucose levels. Carotenoids and flavonoids may also improve antioxidant defenses by increasing the enzymatic activities of SOD, CAT, and GPx, thereby reducing oxidative stress underlying diabetic complications (10).

In vivo animal studies have shown that the administration of carrot extracts can significantly decrease fasting blood glucose levels, improve glucose tolerance, enhance serum insulin concentration, and normalize lipid profiles. Collectively, these metabolic benefits underscore the considerable potential of carrot as a functional food and complementary therapeutic agent in diabetes management.

However, despite robust preclinical evidence, human clinical studies remain limited. Therefore, further randomized controlled clinical trials are required to substantiate therapeutic efficacy, establish optimal dosing regimens, and evaluate long-term clinical safety of carrot in patients with diabetes mellitus.

Proposed mechanism

Carrot phytochemicals (β-carotene, chlorogenic acid, flavonoids, polyphenols, dietary fiber) → Inhibition of α-amylase and α-glucosidase + improved insulin sensitivity + protection of pancreatic β-cells + reduction of oxidative stress → Enhanced glucose utilization and reduced blood glucose levels.

Cardioprotective Activity

CVDs remain the leading causes of morbidity and mortality worldwide. An expanding body of evidence suggests that the regular consumption of carrots may contribute to cardiovascular health through its antioxidant, anti-inflammatory, hypolipidemic, and antihypertensive properties. These beneficial effects are primarily driven by carotenoids, polyphenols, flavonoids, dietary fibers, potassium, and vitamins C and E (8).

Carotenoids, most notably β-carotene and lutein, reduce oxidative stress by scavenging ROS and preventing the oxidative modification of low-density lipoprotein (LDL) cholesterol, an important process in atherosclerosis. Polyphenols and flavonoids improve endothelial function, suppress vascular inflammation, and inhibit platelet aggregation, thereby potentially reducing the risk of cardiovascular complications (6, 9).

Dietary fiber derived from carrot helps lower serum total cholesterol and LDL cholesterol by inhibiting intestinal cholesterol absorption and promoting bile acid excretion. Furthermore, the substantial potassium content of carrot may contribute to blood pressure regulation by preserving fluid-electrolyte balance and facilitating vascular relaxation (21).

Experimental studies have demonstrated that carrot supplementation markedly improves lipid profiles by reducing total cholesterol, triglycerides, and LDL cholesterol while increasing high-density lipoprotein (HDL) cholesterol, concurrently reducing oxidative stress and enhancing vascular function in animal models.

Although epidemiological studies suggest that higher dietary intake of carotenoid-rich vegetables is associated with a lower incidence of CVDs, further randomized clinical trials are necessary to confirm the cardioprotective effects of carrot and establish evidence-based nutritional recommendations (17).

Proposed mechanism

β-Carotene, lutein, flavonoids, polyphenols, dietary fiber, and potassium → Reduced oxidative stress and LDL oxidation → Improved endothelial function and lipid metabolism → Decreased inflammation and blood pressure → Protection against atherosclerosis and CVDs.

Hepatoprotective Activity

The liver plays a key role in metabolism, detoxification, and systemic physiological homeostasis. Consequently, hepatic injury induced by oxidative stress, xenobiotics, alcohol, and drugs is associated with the development of several liver disorders. Carrot has demonstrated promising hepatoprotective efficacy, which is largely attributed to its abundance of carotenoids, polyphenols, flavonoids, vitamins, and complementary antioxidant phytochemicals (4).

Experimental studies have shown that carrot extracts protect hepatic tissues by reducing oxidative stress, inhibiting lipid peroxidation, and enhancing endogenous antioxidant defense systems. The bioactive constituents increase the activities of antioxidant enzymes, including SOD, CAT, and GPx, while decreasing the accumulation of ROS and malondialdehyde (MDA), thereby helping to prevent hepatocellular damage (6, 9).

Carotenoids such as β-carotene and lutein, together with phenolic compounds and flavonoids, have been reported to reduce serum hepatic biomarkers, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), and total bilirubin, indicating improved liver function. In addition, these phytochemicals may suppress inflammatory mediators, reduce hepatic fibrosis, and preserve the structural integrity of hepatocytes (3, 12).

Animal studies have demonstrated that carrot supplementation significantly attenuates liver injury induced by chemical toxins and oxidative stress. Histopathological analyses have revealed reduced hepatocellular degeneration, inflammatory cell infiltration, and necrosis in animals treated with carrot extracts compared with untreated controls (18).

Although the available preclinical evidence supports the hepatoprotective potential of carrot, clinical evidence remains limited. Therefore, well-designed randomized clinical trials are warranted to establish its clinical efficacy,

optimal dosage regimens, and long-term safety profiles for the prevention and management of liver diseases (15).

Proposed mechanism

Carrot phytochemicals (β-carotene, lutein, flavonoids, polyphenols, vitamins C and E) → Reduced oxidative stress and lipid peroxidation → Increased SOD, CAT, and GPx activities → Decreased ALT, AST, ALP, bilirubin, and inflammatory mediators → Protection of hepatocytes and improved liver function.

Neuroprotective Activity

Neurodegenerative disorders, including Alzheimer's disease, Parkinson's disease, and other age-related neurological conditions, are characterized by progressive neuronal loss associated with oxidative stress, neuroinflammation, mitochondrial dysfunction, and abnormal protein aggregation. Owing to its rich phytochemical composition, carrot has been investigated for its potential neuroprotective effects (6, 9).

The neuroprotective activity of carrot is mainly attributed to carotenoids (β-carotene, α-carotene, and lutein), polyphenols, flavonoids, vitamins C and E, and other antioxidant constituents. These bioactive compounds effectively scavenge ROS, reduce lipid peroxidation, and protect neuronal cells from oxidative damage (9). Furthermore, they enhance endogenous antioxidant defense by increasing the activities of SOD, CAT, and GPx.

Several experimental studies have suggested that carrot phytochemicals may suppress neuroinflammation by inhibiting the production of pro-inflammatory cytokines, including TNF-α, IL-1β, and IL-6, through modulation of the NF-κB signaling pathway. Carotenoids have also been reported to preserve mitochondrial function, reduce neuronal apoptosis, and improve cognitive performance in experimental models (10).

Furthermore, lutein and β-carotene may contribute to the maintenance of neuronal membrane integrity and synaptic function, thereby potentially reducing age-related cognitive decline. Preliminary evidence also suggests that carrot-derived phytochemicals may inhibit acetylcholinesterase activity, which could enhance cholinergic neurotransmission and support memory function. However, further mechanistic investigations are required to confirm these effects (6).

Although current evidence indicates the promising neuroprotective potential of carrot, the majority of available data are related to preclinical studies. Therefore, well-designed clinical trials are needed to establish its therapeutic efficacy and clarify its potential role in the prevention and management of neurodegenerative disorders (9).

Proposed mechanism

Carrot phytochemicals (β-carotene, lutein, flavonoids, polyphenols, vitamins C and E) → Reduced oxidative stress and neuroinflammation → Inhibition of NF-κB signaling and pro-inflammatory cytokines → Protection of neurons and mitochondria, reduced apoptosis, improved cognitive function → Neuroprotection against neurodegenerative disorders.

Gastroprotective Activity

Gastrointestinal disorders, including gastric ulcers, gastritis, and inflammatory bowel diseases, are commonly associated with excessive gastric acid secretion, oxidative stress, inflammation, and impairment of the gastric mucosal barrier. Carrot has demonstrated promising gastroprotective activity owing to its antioxidant, anti-inflammatory, and cytoprotective phytochemicals (24).

The gastroprotective effects of carrot are mainly attributed to carotenoids, flavonoids, polyphenols, dietary fiber, and vitamins C and E. These bioactive compounds may protect the gastric mucosa by scavenging ROS, reducing lipid peroxidation, and enhancing endogenous antioxidant defense systems. They may also suppress the production of pro-inflammatory mediators, thereby reducing inflammation and promoting mucosal healing (13, 25).

Experimental studies have reported that carrot extracts decrease gastric ulcer formation by enhancing mucus secretion, maintaining gastric mucosal integrity, and attenuating gastric acid-induced oxidative damage. Flavonoids and phenolic compounds may also inhibit inflammatory signaling pathways, including NF-κB, thereby reducing the expression of inflammatory cytokines and protecting gastric tissue against injury (6).

Furthermore, the dietary fiber in carrot may promote gastrointestinal health by improving intestinal motility, supporting beneficial gut microbiota, and promoting normal digestive function. Collectively, these effects may reduce the risk of gastrointestinal disorders and contribute to overall digestive health (21).

Although the available experimental evidence supports the gastroprotective potential of carrot, most studies have been conducted using animal models. Additional clinical studies are therefore required to confirm its therapeutic efficacy, determine optimal dosage, and evaluate its long-term safety in the prevention and management of gastrointestinal diseases (4).

Proposed mechanism

Carrot phytochemicals (β-carotene, flavonoids, polyphenols, vitamins C and E, dietary fiber) → Reduced oxidative stress and inflammation → Inhibition of NF-κB signaling and inflammatory cytokines → Enhanced gastric mucus secretion and preservation of mucosal integrity → Protection against gastric ulceration and gastrointestinal injury.

Nephroprotective Activity

The kidneys are essential organs responsible for maintaining fluid and electrolyte balance, excreting metabolic waste products, and regulating blood pressure. Renal injury resulting from oxidative stress, inflammation, diabetes, hypertension, or exposure to nephrotoxic agents may lead to the development and progression of chronic

kidney disease (CKD). Owing to its rich phytochemical composition, carrot has demonstrated promising nephroprotective potential in experimental studies.

The nephroprotective effects of carrot are primarily attributed to carotenoids, flavonoids, phenolic compounds, vitamins C and E, and other antioxidant constituents. These bioactive compounds protect renal tissues by scavenging ROS, reducing lipid peroxidation, and enhancing endogenous antioxidant defense mechanisms, including the activities of SOD, CAT, and GPx.

Experimental studies have demonstrated that carrot extracts reduce renal oxidative stress, suppress the production of inflammatory cytokines such as TNF-α, IL-1β, and IL-6, and inhibit activation of the NF-κB signaling pathway. These effects may help preserve renal structure and function while minimizing inflammation-induced tissue damage (6, 9).

Furthermore, administration of carrot extracts has been associated with reductions in serum creatinine, blood urea nitrogen (BUN), and other biomarkers of renal dysfunction in experimental models. Histopathological studies have also reported reduced tubular degeneration, glomerular damage, and inflammatory-cell infiltration following treatment with carrot-derived phytochemicals.

Although preclinical evidence supports the nephroprotective potential of carrot, clinical evidence in humans remains limited. Therefore, additional well-designed clinical trials are required to establish its efficacy and safety and to clarify its potential therapeutic role in the prevention and management of kidney diseases (5, 13).

Proposed mechanism

Carrot phytochemicals (β-carotene, flavonoids, polyphenols, vitamins C and E) → Reduced oxidative stress and lipid peroxidation → Inhibition of NF-κB signaling and inflammatory cytokines → Enhanced antioxidant enzyme activity (SOD, CAT, GPx) → Protection of renal tissues and preservation of kidney function.

Immunomodulatory Activity

The immune system plays a crucial role in protecting the body against infectious agents, preserving immune homeostasis, and modulating inflammatory responses. Impairments in immune function can increase host susceptibility to infections, chronic inflammatory disorders, autoimmune diseases, and certain cancers. Owing to its diverse phytochemical composition, carrot garnered substantial attention for its potential immunomodulatory effects (8).

The immunomodulatory actions of carrot are mainly mediated by carotenoids (β-carotene, α-carotene, and lutein), flavonoids, phenolic compounds, polyacetylenes, vitamins A, C, and E, and other antioxidant constituents. These bioactive compounds enhance immune function by mitigating oxidative stress, regulating cytokine production, and sustaining the normal function of immune cells (4, 6).

Experimental studies have demonstrated that carrot-derived constituents potently stimulate the functional activity of macrophages, lymphocytes, and natural killer (NK) cells, thereby improving both innate and adaptive immune responses. In addition, as an essential metabolic precursor to vitamin A, β-carotene regulates the differentiation and function of T and B lymphocytes while maintaining mucosal epithelial barrier integrity for host defense (16, 17).

The anti-inflammatory properties of carrot further contribute to immune regulation by suppressing the excessive production of pro-inflammatory cytokines, including TNF-α, IL-1β, and IL-6, while promoting a balanced immune response. Furthermore, the antioxidant activity of carrot phytochemicals helps protect immune cells against oxidative damage and preserve their functional integrity.

Although the available preclinical findings indicate promising immunomodulatory potential, robust clinical evidence in humans remains limited. Therefore, further mechanistic investigations and well-designed, randomized clinical trials are required to validate its efficacy, safety, and potential therapeutic applications in immune-related disorders (25).

Proposed mechanism

Carrot phytochemicals (β-carotene, lutein, flavonoids, polyphenols, vitamins A, C, and E) → Reduced oxidative stress and regulation of inflammatory cytokines → Enhanced macrophage, lymphocyte, and NK cell activity → Improved innate and adaptive immune responses → Maintenance of immune homeostasis and protection against infectious and inflammatory diseases.

Clinical Studies

Although numerous *in vitro* and *in vivo* investigations have demonstrated the pharmacological potential of carrot, clinical evidence remains relatively limited. The majority of available human studies have focused on the general nutritional benefits of dietary carrot intake rather than evaluating standardized carrot extracts as targeted therapeutic interventions (4, 8).

Clinical and epidemiological studies suggest that regular dietary intake of carrots correlates with a reduced risk of several chronic diseases, including CVDs, specific malignancies, type 2 diabetes mellitus, and age-related ocular disorders. These beneficial effects are primarily attributed to high concentrations of carotenoids, polyphenols, dietary fiber, and antioxidant vitamins present in carrots (9).

Dietary intervention trials have reported that carrot consumption improves plasma total antioxidant capacity, reduces systemic biomarkers of oxidative stress, and favorably modulates lipid metabolism by lowering LDL cholesterol and elevating HDL cholesterol levels. In addition, regular intake of carrot-enriched diets has been associated with improved glycemic regulation, enhanced immune responses, and the preservation of visual health via provitamin A carotenoid bioavailability (21).

Despite these promising findings, several methodological

limitations persist. Most clinical trials to date are characterized by relatively small sample sizes, short intervention durations, and considerable variability in carrot cultivars, preparation methods, administered doses, and outcome measures. Furthermore, few randomized controlled trials have evaluated standardized carrot-derived phytochemical formulations for specific clinical indications (16).

Therefore, future large-scale, multicenter, randomized controlled clinical trials are required to establish the therapeutic efficacy, optimal dosage, long-term safety, pharmacokinetic profiles of carrot, and its bioactive constituents. Such studies will facilitate the translation of encouraging preclinical findings into evidence-based clinical practice and support the development of carrot-derived nutraceuticals and phytopharmaceuticals (26).

Safety and Toxicity

Carrot is widely consumed as a food and is generally recognized as safe when incorporated into a balanced diet. Supported by a long history of dietary and traditional medicinal use, carrots exhibit a favorable safety profile with minimal adverse effects under standard dietary conditions. Nevertheless, excessive intake of whole carrots or concentrated carrot-derived products may lead to specific adverse effects (4, 15).

The most commonly documented adverse effect is carotenemia, a harmless clinical condition characterized by yellowish-orange discoloration of the skin resulting from excessive dietary intake of β-carotene. Unlike jaundice, carotenemia does not involve hepatic dysfunction and spontaneously resolves after the reduction of carotene intake (25).

Although allergic reactions to carrot are uncommon, hypersensitivity has been reported in susceptible individuals, particularly those with birch pollen allergy due to cross-reactivity (pollen-food allergy syndrome). Clinical manifestations typically include oral itching, swelling of the lips or pharynx, urticaria, and, in rare cases, systemic allergic reactions.

Carrot seeds have traditionally been used for fertility regulation and as a uterine stimulant. Consequently, carrot seed extracts and preparations should be strictly avoided during pregnancy, as they may exhibit uterotonic properties. Similarly, their use during lactation warrants caution due to the scarcity of clinical and safety data (4).

Available toxicological studies indicate that carrot extracts generally exhibit low toxicity in experimental animal models when administered at therapeutic doses. However, the safety profiles and therapeutic indices of concentrated extracts, essential oils, and purified phytochemicals require further evaluation through long-term in *vivo* toxicological studies and well-designed clinical trials. Developing standardized extraction protocols and dosage regimens is essential prior to the widespread therapeutic application.

Overall, the current body of evidence indicates that carrot is a safe medicinal and dietary plant when consumed appropriately. Nevertheless, careful consideration should be given to standardized dosage, pharmaceutical formulation, pregnancy stages, allergy history, and potential herb–drug interactions when carrot-derived products are used for medicinal purposes (15, 25).

Future Perspectives

The growing body of evidence regarding the ethnomedicinal applications and diverse pharmacological properties of carrot highlights its considerable potential as a source of novel therapeutic agents and functional food ingredients. Nevertheless, several key challenges must be addressed before carrot-derived bioactive compounds can be integrated into routine clinical practice.

Future research should focus on the isolation, purification, and structural characterization of specific bioactive constituents, particularly β-carotene, falcarinol, falcarindiol, lutein, and other polyphenolic compounds, to elucidate their precise pharmacological activities and molecular mechanisms. Advanced analytical techniques, including metabolomics, proteomics, and transcriptomics, may provide valuable insights into their biological functions and therapeutic targets.

Standardization of carrot extracts is another primary objective. Variations in cultivar genetics, geographical origin, cultivation practices, harvesting stage, processing methods, and extraction procedures can markedly influence phytochemical yields and biological activities. Therefore, the establishment of standardized extraction protocols and rigorous quality-control guidelines is essential to ensure reproducibility and consistent therapeutic efficacy.

Although extensive experimental studies have demonstrated promising bioactivities, well-designed multicenter randomized controlled clinical trials remain scarce. Future clinical trials should systematically evaluate the therapeutic efficacy, safety profiles, pharmacokinetics, optimal dosage regimens, long-term administration, and potential herb–drug interactions of standardized carrot preparations in patients with chronic diseases.

Emerging pharmaceutical drug-delivery systems, including nanoformulations, liposomal systems, and phytosome-based delivery, represent promising strategies for improving the bioavailability and therapeutic effectiveness of poorly soluble phytochemicals such as carotenoids and polyacetylenes. In addition, carrot has considerable potential for the development of functional foods, nutraceuticals, dietary supplements, and standardized phytopharmaceutical products targeting oxidative stress-related disorders, chronic inflammatory diseases, metabolic syndrome, neurodegenerative disorders, and cancer.

Overall, continued multidisciplinary research integrating phytochemistry, pharmacology, toxicology, clinical medicine, and pharmaceutical technology will be essential for translating traditional knowledge into evidence-based therapeutic applications and supporting the development of safe, effective, and standardized carrot-derived medicinal products.

Discussion

The present review highlights the considerable ethnomedicinal significance and diverse pharmacological potential of carrot, a botanical resource that has long been used in traditional healthcare systems and is increasingly recognized as a rich source of bioactive phytochemicals. The available evidence indicates that carrot contains diverse classes of phytochemicals, including carotenoids, polyacetylenes, flavonoids, phenolic compounds, vitamins, and essential oils, which collectively contribute to its broad spectrum of biological activities (4).

Experimental investigations consistently demonstrate that carrot-derived phytochemicals exert potent antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, gastroprotective, nephroprotective, and immunomodulatory properties. These pharmacological effects are mediated through multiple molecular pathways, primarily involving the scavenging of ROS, attenuation of lipid peroxidation, inhibition of inflammatory signaling pathways (e.g., NF-κB and MAPK), suppression of pro-inflammatory cytokines (e.g., TNF-α\alphaα, IL-1β\betaβ, IL-6), upregulation of endogenous antioxidant enzymes, and regulation of apoptosis and cell-cycle progression (6).

Although the majority of published literature reports beneficial pharmacological effects, considerable heterogeneity exists across studies regarding plant cultivars, plant parts, extraction methods, phytochemical composition, experimental animal models, dosage regimens, and outcome measures. Such methodological variability limits direct cross-study comparisons and highlights the critical need for standardized experimental protocols in future research. Furthermore, the prevailing evidence currently originates from *in vitro* and animal models, whereas well-designed human clinical trials remain comparatively scarce (21).

The present review also demonstrates that contemporary pharmacological findings support many traditional ethnomedicinal applications of carrot. However, some traditional therapeutic claims remain inadequately validated through rigorous scientific investigations. Consequently, additional mechanistic studies and randomized controlled clinical trials are necessary to confirm therapeutic efficacy, establish optimal contemporary dosage regimens, evaluate long-term safety and tolerability profiles, and determine potential herb–drug interactions (23).

Despite these limitations, carrot represents a promising medicinal resource with considerable potential and therapeutic utility for the development of functional foods, nutraceuticals, and standardized phytopharmaceutical products. Future multidisciplinary research integrating phytochemistry, pharmacology, toxicology, molecular biology, and clinical medicine will be essential to bridge the gap between experimental findings and evidence-based therapeutic applications (4).

Conclusion

Carrot is a nutritionally important vegetable and a valuable medicinal plant with deep roots in traditional healthcare systems. Current scientific literature demonstrates that its multifaceted therapeutic potential is primarily governed by a diverse range of bioactive constituents, including carotenoids, polyacetylenes, flavonoids, phenolic acids, antioxidant vitamins, and essential oils. These phytochemicals exhibit significant antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, gastroprotective, nephroprotective, and immunomodulatory properties through multi-target molecular pathways.

Despite extensive *in vitro* and *in vivo* studies supporting the pharmacological properties of carrot, the current evidence is largely preclinical, and high-quality human clinical trials remain limited. Substantial variability in carrot cultivars, extraction protocols, phytochemical profiles, experimental animal models, and dosage regimens further highlight the critical need for standardized methodologies to ensure reproducibility and facilitate meaningful comparisons across studies.

Overall, carrot represents a highly promising source of bioactive compounds for the development of functional foods, nutraceuticals, and phytopharmaceutical agents. Future research should prioritize standardized extract preparation, comprehensive toxicological evaluation, mechanistic investigations, pharmacokinetic evaluations, and well-designed randomized clinical trials to definitively substantiate its therapeutic efficacy and support its integration into evidence-based clinical practice.

Competing Interests

None.

Ethical Approval

Not applicable, as this study is a review based on previously published literature.

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