

Review Article

The Healing Touch of *Foeniculum vulgare* Mill. (Fennel): A Review on Its Medicinal Value and Health Benefits

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ABSTRACT

Foeniculum vulgare, commonly known as Fennel and Fenouil in English and French respectively. It is an annual shrub, herbaceous and fragrant plant of Apiaceae family with notched stems, alternating leaves, dark-colored feathery branches and enclosed petioles. It can grow up to 1-2m in height and native to Asia, Mediterranean and Europe. It exhibits diverse functional, therapeutic and antibacterial properties such as enhanced milk production and relieves anxiety, depression, diabetes and obesity. It is serving as an antioxidant, antifungal, acaricidal, anti-allergic and nootropic, hepato-protective properties and provides a broncho dilatory effect. It finds wide applications in animal husbandry and is used as food ingredients worldwide. bisexual, erratic or consistent, with golden canopies which mimic rectangular pearls. Their dimensions are approximately 8 mm long and 3 mm wide. slim, lengthy, ovoid and size of them vary with plant growth.

Keywords: Hepato-protective, Diabetes, Antifungal, Anxiety relief, Soil properties, Drought stress, Medicinal tea, Microbial role

INTRODUCTION

Foeniculum vulgare, commonly known as fennel, belongs to the Apiaceae family and is extensively cultivated in tropical and temperate regions globally (1). The kernels of *Foeniculum vulgare* are utilized to address various health issues, including digestive, endocrine, reproductive, and respiratory problems (2). Recognized as one of the world's foremost medicinal plants and among the oldest aromatic crops, fennel holds economic importance and is widely used in healthcare (3). Originally native to the Mediterranean coasts, fennel has become a global herb employed both in traditional medicine and gastronomy since ancient times (4). *Foeniculum vulgare* Mill., a perennial non-woody plant, is a vital resource in traditional medicines and seasonings worldwide (5). As a member of the Apiaceae family, fennel contributes valuable metabolites with applications in medicines, agrochemicals, flavors, perfumes, colors, biopesticides, and food additives (6). Widely recognized for its pharmacological benefits, fennel serves diverse purposes, including digestive aid, diuretic, asthma relief, support for breastfeeding women, diabetes management, lipid level reduction, treatment of edema, anxiety, depression, and gastrointestinal diseases (7).

This comprehensive review explores the multifaceted aspects of *Foeniculum vulgare* Mill. (fennel), a perennial herbaceous plant with diverse applications in traditional medicine and culinary practices worldwide.

PHYTOCHEMICAL COMPOSITION OF FENNEL

Fennel, extensively utilized across all its parts, showcases a rich nutritional profile. Its seeds contain 6.3% water, 9.5% protein, 10% fat, 13.4% minerals, 18.5% fiber, and 42.3% carbohydrates. The foliage contributes various essential elements such as calcium, potassium, salt, iron, phosphorus, thiamine, riboflavin, niacin, and vitamin C. Fennel fruits, containing 10 to 12% oil, exhibit diverse fatty acids, including 0.6% petrocyclic acid, 22% oleic acid, 14% linoleic acid, and 4% palmitic acid. The distinctive aromatic nature of fennel arises from its complex chemical makeup, featuring around 30 terpene compounds, with trans-anethole (50-80%) and limonene (5%) as key constituents. Additionally, volatile substances like tannin, coumarin, hydroxycinnamic acids, flavonoids, and phenolic acids contribute to its aromatic profile. Fennel seeds' methanolic extract is rich in phytochemicals, including phenols, alkaloids, terpenoids, flavonoids, glycosides, tannins, and saponins. Phenolic compounds, like 3-O-Caffeoylquinic acid and quercetin-3-rutinoside, exhibit antioxidant properties, preventing oxidative stress-related ailments. The diverse chemical components found in fennel underscore its significance in promoting overall well-being, making it a subject of interest for food investigators, nutritionists, and consumers alike. The exploration of naturally occurring compounds in fennel aligns with recent studies utilizing

such elements as medications for managing antioxidant-related illnesses and combating harmful free radical accumulation (8, 9, 10, 11).

FUNCTIONAL AND THERAPEUTIC PROPERTIES OF FENNEL

Fennel has a rich history spanning hundreds of thousands of centuries in herbal remedies, making it a staple in addressing diverse ailments. Revered for its soothing properties since the fifth century AD, fennel accrued medical virtues from the ninth to the fourteenth centuries. Ancient Romans were informed by (12) that fennel seeds could enhance vision. With applications ranging from aiding digestion to relieving bloating, fennel has been therapeutically harnessed since the 18th century, supported by extensive research. The plant's components are currently pivotal in managing a spectrum of ailments, particularly stomach issues, and exhibit efficacy against urinary tract infections, pneumonia, insulin resistance, and chronic cough (13). Fennel seeds, employed in cream-based dishes, showcase antihypertensive effects, contributing to the management of kidney and bladder diseases, nausea, vomiting, persistent fevers, and issues in the hepatic, digestive, respiratory, urinary, hormonal, reproductive, and digestive systems (14). Its role as a galactagogue during breastfeeding is noteworthy (14). Furthermore, the impact of temperature variations on physiological and metabolic processes in plants, including photosynthesis and respiration, is underscored (15).

ENCAPSULATION OF FENNEL ESSENTIAL OIL AND EXTRACT

Plant essential oils (EOs) serve as a valuable repository of biologically active compounds, yet their inherent instability and hydrophobic nature limit their application in pharmacology and food-related endeavors. Explored strategies such as encapsulation enhance the bioavailability and durability of these compounds. For instance, (15) developed thermoplastic nanocapsules (NC) using biocompatible poly(ϵ -caprolactone) containing fennel essential oil (FEO), exhibiting favorable physical and chemical attributes, enduring stability, and efficient performance in simulated gastrointestinal conditions. With a size of 210 nm, low polydispersity (PDI) of 0.10, zeta potential of 15 mV, and encapsulation effectiveness of 93%, the FEO-NCs demonstrated resilience under varying preservation temperatures. Notably, they showcased resistance to simulated gastrointestinal breakdown and achieved a 29% absorption rate in simulated bowel conditions. This nanosystem holds promise in nutritional and healthcare sectors. (16) Investigated the application of encapsulated fennel bioactives in the food industry, demonstrating its potential in preserving silver carp steaks and enhancing efficacy when encapsulated in liposomes. (17) Utilized permeable hydrogel/chitosan as a barrier for FEO in ground pork production, resulting in extended shelf life, antimicrobial properties, and reduced oxidation in the meat, showcasing the potential of encapsulated FEO in food preservation.

EFFECT ON MILK PRODUCTION

(18) Inclusion of fennel seed powder in goat diets, as noted, enhanced feed consumption, milk output, and impacted gut processing, influencing energy utilization post-delivery. Moreover, (18,19) Demonstrated that fennel medicinal tea, when appropriately and timely used, addresses insufficient milk volume, affecting breastfeeding indicators without adverse effects, including dimensions, head diameter, daily wet diapers, bowel movements, and newborn meals. (19) Suggested that milk supply growth may or may not align with increased blood prolactin levels (20,21), emphasizing the potential use of fennel to enhance lactation and, at times, prolactin concentrations in nursing women.

ANTI-ANXIETY AND ANTI-DEPRESSANT EFFECTS

Anxiety, characterized by overwhelming concern, often leads to anxiety disorders when excessive. Fennel, a traditional remedy for mental issues, has shown promise (22). A concentrated ethanol extract of fennel fruit demonstrated a calming effect equivalent to 1 mg/kg diazepam in mice (23). Additionally, oral administration of 250 and 500 mg/kg methanol fennel extract exhibited antidepressant effects in mice (24). Notably, a herbal medicine containing tarragon-derived substance significantly aided depressed postmenopausal women (25). (26) highlighted the potency of fennel seed oil, particularly trans-anethole, surpassing pharmaceuticals in sedative action, while the airborne component exhibited mild psychological effects.

ANTI-DIABETIC AND ANTI-OBESITY ACTIVITY

Fennel aromatic oil demonstrates protective effects against glucose and morphological abnormalities in diabetic mice through antioxidant actions and redox repair. In vivo studies on hyperglycemic rats confirm its potent anti-hyperglycemic action, associated with increased peroxidase activity and glutathione levels as antioxidants (27)(28). Nanoemulsion of fennel essential oil significantly reduces blood glucose concentration (28), while a water-soluble fennel extract in diabetic rats not only decreases blood glucose but

also exhibits a high inhibitory concentration of 50% radicals (29). Furthermore, the combined use of *F. vulgare* and black cumin in female patient food significantly impacts body composition (BMI) and saturated fat levels (30).

APPLICATION OF *F. VULGARE* IN ANIMAL HUSBANDRY

Various researchers have explored the use of plant-based phytobiotics, including fennel, to enhance animal health and performance (31-34). Incorporating fennel into broiler feed increased feed intake, potentially attributed to its palatability, aroma, and antibacterial properties, thereby enhancing digestibility and weight gain (35)(36). Effects, however, may vary across poultry species (37). Fennel supplementation increased feed intake in Holstein calves (38,39) and contributed to lamb weight gain (40). Certain fennel oils were found to influence behavior (40). Administration of fennel enhanced egg production in layers, positively affecting oviduct size, albumin synthesis, and more (41,42). Additionally, it facilitated yolk development (43) and promoted the growth of ovaries and oviducts in quail (44). Fennel also elevated antioxidant enzymes like SOD and glutathione peroxidase (34), while increasing blood proteins, RBC, HDL, and cholesterol (45,46).

ANTIOXIDANT ACTIVITY

Antioxidants are important to reduce harmful radical damage to human health (47). Studies assess fennel's antioxidant abilities, which may differ by location (48). Methanol extracts of Tunisian fennel seeds had varying IC50 values of 977.33 to 23.66 µg/mL (49). Moroccan fennel oil had mostly monoterpene hydrocarbons (49). The DPPH assay effectively measures antioxidant potential of plant materials (50). Pakistani fennel inhibited DPPH well, with IC50 of 23.61-26.75 µg/mL (51), containing the key phenolic cirsiol (52). Egyptian and Chinese fennel also showed strong antioxidant activities despite different IC50s (53). Wild fennel had greater DPPH radical scavenging (IC50 31 µg/mL) than cultivated fennel (83 µg/mL) (54). Other fennel extracts and parts showed similar trends to methanolic and ethanolic seed versions (55,56). Overall, assays demonstrate fennel extract has high antioxidant levels for medicinal use.

ANTI-FUNGAL ACTIVITY

Fennel extracts have antifungal activities against various fungi like *Aspergillus* species and *Candida albicans* (61). Studies found fennel extracts highly effective against the food-waste molds *Aspergillus niger* and *Fusarium oxysporum*, with minimum inhibitory concentrations of 750 and 250 µg/ml respectively (61). Fennel stalk derivatives also have antibacterial properties against molds like *Aspergillus niger*, *Bacillus subtilis*, and *Cladosporium cladosporioides* (62). The antifungal compound anethole was more potent than other fennel derivatives like scopoletin (62). One study showed fennel seed extract generated reactive oxygen species and increased nitric oxide production in macrophages, causing anti-candida effects. Overall, fennel extracts and compounds demonstrate potent anti-fungal activities (63).

ANTIBACTERIAL PROPERTIES

Fennel has antibacterial effects due to chemicals like linoleic acid, 1, 3-benzenediol, oleic acid, and 2,4-undecaprenyl (64). It contains 5-hydroxyfuranocoumarin, crucial for antimicrobial properties (64). One study found fennel aqueous extract inhibited *Escherichia coli*, *Shigella flexneri*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Salmonella typhi*, and *Enterococcus faecalis* (65). It prevented proliferation of most bacteria, except some *Klebsiella pneumoniae* and *Pseudomonas aeruginosa*, with minimum inhibitory concentrations of 20-80 mg/ml for water extract and 5-15 mg/ml for fermented seed extract (65). Another study showed fennel extract had antimicrobial action against hospital infection-causing *Acinetobacter baumannii* isolates (66).

USES OF *FOENICULUM VULGARE* AS A FOOD INGREDIENT WORLDWIDE

Foeniculum vulgare (fennel) is used in foods across countries. In Italy, it flavors olives and salty foods (67,68). In Spain, tender fennel stems and leaves are eaten in sauces or soups, and seeds flavor olives and dried figs (69). In Portugal, all fennel plant parts are used, including shoots, leaves, stems, flowers and seeds to flavor hazelnuts, cakes, teas and more (70). Fennel is given to cattle in India for diarrhea. It is used to treat conditions ranging from basic coughs/colds to complex cancer (71).

ANTIALLERGIC ACTIVITY

Methanolic extract from the fruit of *Foeniculum vulgare* restrain the oxidation of 2,4-dinitrofluorobenzene. It inhibits the development of physiologically caused edema. It implies that *Foeniculum vulgare* Mill's might possess immunological qualities. (72)

ANTISTRESS ACTIVITY

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NOOTROPIC ACTIVITY

Alzheimer's disease, one of the age-associated psychological illnesses, is characterized as Dementia. Methanol extracted from the total leaves of the plant of *Foeniculum vulgare* treated for eight days improved scopolamine action and anti-wrinkle effect in mice. As a type of nootropic and anticholinesterase drug, *Foeniculum vulgare* Mill's may be utilized for the management of mental problems i. e. Alzheimer's disease and dementia. (74)

BRONCHODILATORY EFFECT

Foeniculum vulgare on contracted guinea pig tracheal chains, a mixture of ethanol and *Foeniculum vulgare* vital oil demonstrated bronchodilatory activity. *Foeniculum vulgare* could be contributing to guinea pig respiratory tract depression. (75)

ACARICIDAL ACTIVITY

Foeniculum vulgare oil is effective towards *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae*. The least dangerous substance was P-anisaldehyde. P-anisaldehyde is far greater in effectiveness than thymol benzyl benzoate and estragol (76).

IMPACT OF SOIL PROPERTIES ON FOENICULUM VULGARE MILL. (FENNEL)

The impact of soil physical properties on *Foeniculum vulgare* Mill. (Fennel) is a crucial aspect influencing the growth and development of this aromatic herb. Soil physical properties, including texture, structure, and porosity, play a pivotal role in determining the availability of water, nutrients, and air to the plant roots. The specific requirements of Fennel, such as well-drained soil and adequate aeration, make soil physical characteristics particularly significant. Soil texture influences water retention and drainage, affecting the plant's water uptake and overall health. Additionally, soil structure influences root penetration and nutrient accessibility. An optimal balance of soil physical properties is essential to ensure Fennel's vigor, productivity, and resistance to environmental stressors. As such, understanding and managing these soil factors are integral components of cultivating healthy and thriving *Foeniculum vulgare* crops (77).

DROUGHT STRESS AND FOENICULUM VULGARE MILL. (FENNEL)

Zaib et al., (78) d expressed in one paper that drought stress poses a formidable environmental challenge with profound consequences for *Foeniculum vulgare* Mill. (Fennel) and other crops, exerting a significant toll on global agricultural productivity and food security. With the world's population expected to surge to 9 to 10 billion by 2050, as indicated by numerous reports, the imperative to address the escalating impact of drought stress on plants becomes a critical concern for researchers and policymakers alike. A myriad of global researchers is actively engaged in developing crop varieties resilient to water-deficient conditions. The escalating population and its corresponding demand for food exert substantial pressure on agricultural communities worldwide, compounded by challenges such as limited land availability, insufficient mechanization, and the prevalence of various biotic and abiotic stressors. Drought-induced abiotic stress stands out as a perennial factor contributing to significant reductions in agricultural production. The onset of drought conditions stems from diminished rainfall coupled with an upswing in dry periods. This study scrutinizes the physiological and biochemical responses of plants to drought stress, encompassing water-use efficiency, stomatal regulation, and osmotic adjustments. Furthermore, it explores the pivotal role of genetic and molecular mechanisms in endowing crops with drought tolerance. The review delves into an array of agronomic and management practices designed for drought adaptation, including the development of drought-resistant crop varieties, innovative irrigation techniques, and soil moisture conservation methods. Moreover, it underscores the promise held by modern biotechnological tools, such as molecular breeding and gene editing, in bolstering drought resilience.

ROLE OF MICROBES

The microbes play a pivotal role to the plant's growth, development, and overall ecological interactions. Microbes, particularly beneficial soil bacteria and mycorrhizal fungi, form symbiotic relationships with Fennel roots, enhancing nutrient uptake and promoting plant health. These microbes play a crucial role in nitrogen fixation, facilitating the conversion of atmospheric nitrogen into a form that is accessible to the plant. Additionally, mycorrhizal associations contribute to improved water absorption and stress

tolerance. The rhizosphere, where the roots and soil interact, becomes a dynamic microbial community influencing the plant's physiology and resistance to diseases. Furthermore, microbial interactions in the soil around Fennel may contribute to the plant's essential oil production, impacting its aromatic and medicinal properties. Overall, the intricate interplay between Fennel and microbes underscores the importance of these microorganisms in shaping the plant's ecological resilience and functional traits (79).

CONCLUSION

Foeniculum vulgare Mill, also known as fennel, is a perennial herbaceous plant used in traditional medicine and culinary practices worldwide. Its flowers are bisexual and have a pleasant aroma. Fennel plants have a long history of use in herbal remedies, treating a wide range of ailments. They are beneficial in treating persistent fevers, liver, digestive, respiratory, and urinary disorders, vision-related disorders, stomach ailments, hormones, reproduction, and digestion. Fennel is also known to enhance lactation and prolactin levels in nursing women and is used as a natural remedy for anxiety and mental health issues. Studies have shown that a concentrated ethanol extract of fennel fruit induces a calming effect in experimental mice. The essential oil of fennel can significantly lower blood glucose levels when used in nanoemulsion form. Fennel also exhibits liver-protective properties and antifungal activity against various fungi. It also has antibacterial effects due to its presence of chemicals. The aerial parts of fennel are used to flavor pickled olives, while the seeds are used in savory foods.

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