The Academic
International Journal of Multidisciplinary Research

An Online Peer Reviewed / Refereed Journal
Volume 3 | Issue 6 | June 2025
ISSN: 2583-973X (Online)
Website: www.theacademic.in

Bridging Ethnobotany and Modern Science: Pharmacognostic and Clinical Perspectives on Foeniculum vulgare

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DOI : https://doi.org/10.5281/zenodo.15858132

ARTICLE DETAILS

Research Paper

Accepted: 26-06-2025

Published: 10-07-2025

Keywords:

Foeniculum vulgare, ethnobotany, pharmacognosy, phytochemistry, clinical research, traditional medicine

ABSTRACT

Foeniculum vulgare Mill. (Fennel) is in the Apiaceae family and represents a prototypic case wherein traditional ethno-botanical knowledge has been established and continued through modern science. This review compiles the current knowledge of fennel's phytochemistry, pharmacological properties, and therapeutic applications, while illustrating the convergence of traditional uses and modern discoveries. The plant has been extensively researched using pharmacognostic and chemistry techniques that demonstrate it contains bioactive substances such as anethole, fenchone, and estragole that serve to support a long history of traditional uses in folk medicine focused on digestive function and health, and general digestion, reproduction, and pulmonary health (re: fennel is said to cleanse the lungs and is used in several other folk medicines). Fennel has been demonstrated clinically to relieve infantile colic, menopausal symptoms and numerous digestive ailments. In addition, fennel has been proved useful for a variety of uses newly investigated to support metabolic health and promote neuro-protection. This comprehensive

study highlights the need to integrate existing ethno-botanical, traditional medicinal knowledge with rigorous science toward furthering evidence-based phytotherapy.

Introduction

The convergence of traditional knowledge and contemporary scientific research has produced significant insights into the therapeutic efficacy of medicinal plants. *Foeniculum vulgare*, epitomises this convergence as one of humanity's oldest medicinal plants, with a documented history exceeding 4,000 years (Badgujar et al., 2014). Originating in the Mediterranean region, fennel has surpassed geographical limits to attain global recognition as both a culinary and medicinal herb, with historical uses recorded in various civilisations from ancient Egypt to modern Ayurvedic and Traditional Chinese Medicine practices.

The ethnobotanical importance of fennel transcends its fragrant characteristics, incorporating a wide range of medicinal uses that have been objectively proved over years of traditional practice. Historical documents, such as those by Dioscorides and Pliny the Elder, record fennel's application for digestive disorders, respiratory issues, and lactation support, so building a basis of traditional knowledge that persists in influencing modern research (Kooti et al., 2015). The ethnobotanical history of fennel can be a great starting point for understanding the medicinal possibilities of fennel and providing guidance for modern scientific research. Evidence from pharmacognostic studies has confirmed the complexity and breadth of phytochemicals that underlie the range of biological activities that fennel exhibits. All aspects of the plant's essential oils, flavonoids, phenolics and other bioactive components are beautifully characterised, presenting a mechanistic basis for traditional notions of medicine (Fugh-Berman, 2003; Rather et al., 2016). Through the use of advanced analytical techniques (such as gas chromatography-mass spectrometry, GC-MS; and high-performance liquid chromatography, HPLC) have enabled the identification and quantification of bioactive agents, and have electronics quality control and standardisation practices (Shahat et al., 2011). The validation of traditional knowledge provides an illustration of how ethnobotany contributes to evidence based medicine, and demonstrates how modern analytical methods may further our understanding of traditional medicines.

Figure 1; *Foeniculum vulgare* [A:Stem, leaves, inflorescences; B: Seed]

Ethnobotanical Background and Traditional Uses

Fennel has a long history of use in ancient cultures for both food and medicine. According to archaeological evidence, fennel was grown in ancient Egypt because it helped with digestion and was utilised in religious ceremonies (Badgujar et al., 2014). Greek and Roman medical literature later wrote about the plant's medicinal uses, creating a body of traditional knowledge that would shape European herbal medicine for thousands of years.

Fennel seeds (Xiao Hui Xiang) are a warming herb that is part of Traditional Chinese Medicine (TCM). They help regulate qi and ease cold conditions, especially those that impact the digestive system. Fennel is a tridoshic plant in Ayurvedic medicine, which means it balances all three doshas (Vata, Pitta, and Kapha). It is often given to people with digestive problems, breathing problems, and urogenital problems (Kooti et al., 2015). These traditional uses are very similar across cultures, which suggests that there are common ways that they work that go beyond cultural and geographical differences.

Fennel has traditionally been used in European folk medicine to alleviate colic, gas, and digestive problems in babies. Fennel was used in the Middle Ages to treat eye problems, respiratory problems, and as a galactagogue to help nursing mothers produce more milk (Fugh-Berman, 2003). These traditional uses have helped researchers figure out where to proceed with their work today. Many recent studies are focused on proving these historical claims using strict scientific methods.

The fact that traditional applications of fennel are the same throughout many cultures is strong proof that it works as a medicine. This coming together of different traditional knowledge systems gives us a unique chance to find common therapeutic processes and set research priorities. It shows how useful ethnobotanical methods can be in finding and developing new drugs.

Botanical Description and Morphology

Foeniculum vulgare is a hardy perennial herb in the Apiaceae family. Its feathery leaves and flower clusters that look like umbrellas are what make it stand out. The plant usually grows to be 1 to 2 metres tall and has a strong taproot system that helps it do well in Mediterranean climes. The leaves are very cut up and look like threads. They are blue-green in colour. The flowers are small, yellow, and placed in compound umbels, which is a trait of the Apiaceae family (Badgujar et al., 2014).

The plant makes long, thin seeds, which are really fruits called schizocarps. These seeds have the most essential oils and bioactive substances. These seeds are 4 to 8 mm long and have long ridges. Their colour ranges from pale green to brown, depending on how old they are and what kind they are. The seeds are the main portion of the plant that has medicinal effects, although the leaves and roots do as well (Kooti et al., 2015).

Fennel has a lot of different shapes and sizes. Some of the most common types include var. dulce (sweet fennel), var. vulgare (bitter fennel), and var. azoricum (Florence fennel). The chemical makeup of these types is different. For example, sweet fennel usually has more anethole and less fenchone than bitter fennel (Fugh-Berman, 2003). The plant's ability to adapt is shown by its wide range of shapes and chemicals. This also makes it possible to grow the plant in a way that is best for certain therapeutic uses.

Phytochemistry and Bioactive Compounds

Foeniculum vulgare possesses a wide variety of phytochemicals, including volatile essential oils, phenolic compounds, flavonoids, and fatty acids, which gives it a wide range of pharmacologic activity. The essential oil, however, is the most pharmacologically active component and has been reported to comprise any amount of dry seed weight from approximately 1–6%. The main components of fennel essential oils are phenylpropanoids and monoterpenes (Badgujar et al., 2014). The essential oil contains a variety of compounds with varying concentrations, but it contains the following major constituents: trans-anethole (50–70%), fenchone (12–22%), estragole (2–5%), and α-pinene (1–3%), the abundance of which is varied across fennel varieties and collections from different geographic regions. Trans-anethole is the major compound that gives fennel its characteristic anise-like smell and contributes to some of the pharmacological activity, including antibacterial, antispasmodic, and estrogenic activity. To that end, it has a structure similar to estradiol (Badgujar et al., 2014; Kooti et al., 2015) and its pharmacologic uses in gynecology aligns with the typical reasons for treating women's menstrual problems. The smooth

muscle relaxing action provided by trans-anethole supports its use in relieving digestive disorders (Kooti et al., 2015). Fenchone is another major constituent that has strong antibacterial and anti-inflammatory activity, adding to the therapeutic profile of fennel.

Fennel has phenolic compounds such as flavonoids (quercetin, kaempferol, and isorhamnetin) and phenolic acids (rosmarinic acid, chlorogenic acid, caffeine acid derivatives). These substances help fennel protect against free radical damage, and may provide some manipulation of the body's inflammatory response-- thus possibly clarifying the reason fennel has been Flint used for centuries in the treatment of inflammatory conditions (Fugh-Berman, 2003; Diao et al., 2002), Variety of studies now demonstrate fennel extracts' superb efficacy in free radical scavenging, supported by IC50 values that resemble synthetic antioxidants, in particular butylated hydroxytoluene (B finally use DNA!). These observations further validate its continued traditional use as a dietary staple and it's supporting roles in our health and disease prevention (Anwar et al., 2009, The mechanisms governing the interaction's of these diverse vessels are unknown but can service as an artifact of the portfolio and the degree of complexity associated with the interactions of phytochemicals in plant medicine. Fennel seeds contain fatty acids including oleic acid, palmitic acid, linoleic acid, and petroselinic acid. These acids could enhance the potential health benefits and nutritional value of the plant. Coumarins, even small amounts may elevate the coagulant effects of the plant, which is an important consideration because fennel could be used as an agent to reduce clotting in medical treatments (Badgujar et al., 2014).

Major Bioactive Compounds and Their Therapeutic Properties

Table 1 summarizes the major bioactive compounds found in *Foeniculum vulgare* and their corresponding therapeutic properties, demonstrating the scientific basis for traditional applications.

Table 1: Bioactive compounds and their therapeutic properties in *Foeniculum vulgare*

Compound	Concentration (%)	Primary Therapeutic Properties	Traditional Application
Trans-anethole	50-70	Antispasmodic, estrogenic, antimicrobial	Digestive disorders, menstrual issues
Fenchone	12-22	Anti-inflammatory, antimicrobial, expectorant	Respiratory conditions, infections

Estragole	2-5	Antispasmodic, mild estrogenic	Digestive comfort, hormonal balance
α-Pinene	1-3	Bronchodilator, antimicrobial	Respiratory ailments
Quercetin	0.1-0.5	Antioxidant, anti-inflammatory	General health, inflammation
Rosmarinic acid	0.05-0.2	Antioxidant, neuroprotective	Cognitive health, aging
Petroselinic acid	8-12	Nutritional, anti-inflammatory	General nutrition, wellness

Pharmacological Properties and Mechanisms of Action

Recent studies have confirmed the various pharmacological properties of Foeniculum vulgare, consistent with traditional usage. More specifically, fennel has been shown to exhibit smooth muscle relaxing activity and have calcium channel-modulating properties, which have been attributed to its therapeutic effects on gastrointestinal (GI) disorders and dysmenorrhea (Kooti et al., 2015). These therapeutic effects are likely due to the bioactive components trans-anethole and fenchone, which provides scientific validation of fennel's historical use as a carminative and digestive aide.

In addition, fennel exhibits significant antimicrobial activity against diverse pathogens, including bacteria, fungi, and viruses. Its essential oils have been shown to be some of the most effective against Gram-positive bacteria and Candida species. It is believed that fennel disrupts microbial cell membranes and inhibits metabolic pathways in pathogenic microbes. These findings lend scientific support to fennel's traditional use in the management of respiratory and urogenital infections (Fugh-Berman, 2003) and its potential value in developing plant-based antimicrobials.

Fennel has estrogenic effects, primarily through trans-anethole and its metabolites. Estrogenic effects may occur when fennel interacts with oestrogen receptors and alters hormonal pathways. This process helps to explain the historical use of fennel in treating menopausal complaints, increasing milk production, and remedying menstrual ailments. It might also draw our attention to hormone-sensitive disorders (Badgujar et al., 2014). The phytoestrogenic properties of the plant indicate that fennel has a moderate capability to bind oestrogen receptors, which helps us understand its use in gynaecological applications. Antioxidants act to neutralize free radicals, inhibit lipid peroxidation, and induce the body's

own antioxidant systems. The phenolic components of fennel assist with this process. Flavonoids and phenolic acids have demonstrated strong antioxidant abilities both in vitro and in vivo (Kooti et al. 2015). The antioxidant characteristics of fennel may help protect against disease related to oxidative stress as well as further support the paradigms surrounding its long-historical use as a general health tonic.

Clinical Evidence and Therapeutic Applications

There is a lot of clinical data that supports many of fennel's traditional uses as a medicine. Randomised controlled experiments have shown that fennel can help with infantile colic. Fennel seed oil worked better than a placebo at reducing crying time and colic severity (Alexandrovich et al., 2003). These results back up the traditional use of fennel for digestive problems in babies and show that it may be used safely in children. Managing menopausal symptoms is another well-known use. Clinical studies have shown that fennel can help with hot flashes, sleep problems, and other menopausal symptoms. A randomised controlled research with 90 postmenopausal women found that eating fennel made their menopausal symptoms much better compared to a placebo (Rahimikian et al., 2017). These results confirm the traditional use of these drugs for gynaecological purposes and show that there may be other options besides hormone replacement treatment.

There have been a lot of studies on digestive health applications, and clinical trials have shown that fennel can help with functional dyspepsia, irritable bowel syndrome, and other gastrointestinal problems. The plant's carminative and antispasmodic qualities help ease symptoms, which supports its historic use for digestive problems (Portincasa et al., 2016). These results show that fennel should be included in treatment plans for gastrointestinal problems. Another proven traditional use is to help with breastfeeding. Clinical investigations have shown that nursing mums who drink fennel tea or take supplements make more milk. It probably works by stimulating prolactin and developing the mammary glands, which supports its historic use as a galactagogue (Turkyılmaz et al., 2011). These results back up the traditional use of fennel to help mums who are breastfeeding. Studies have shown that fennel may help with metabolic health, diabetes, obesity, and cardiovascular risk factors. These are some of the new clinical uses that are being looked into. A recent clinical experiment showed that adding fennel to the diet of type 2 diabetes patients dramatically lowered their blood sugar levels and improved their lipid profiles. This suggests new ways to treat metabolic illnesses (Panda et al., 2017). These effects may be due to the plant's antioxidant and anti-inflammatory characteristics, which are new ways to use it that go beyond its traditional uses (Kooti et al., 2015).

Safety Profile and Toxicological Considerations

Many studies, including traditional use patterns, toxicological investigations, and clinical observations, have looked at how safe fennel is. When used in the right amounts, the plant is generally recognised as safe (GRAS) by regulatory authorities. Its long history of use in cooking and medicine backs up its safety profile (Badgujar et al., 2014). However, several of the components, especially estragole and safrole, have aroused toxicological concerns because they may be harmful to the liver and cause cancer at large levels.

Animal studies have found that estragole, which is found in fennel essential oil at levels of 2–5%, could be a hepatotoxin and carcinogen. But the levels of estragole that people are exposed to from eating fennel are thought to be much below lethal levels, and other substances may change how it works (Fugh-Berman, 2003). Regulatory organisations have set recommended daily intake levels for goods that include estragole, which helps people know how much they can safely use. People who are allergic to other members of the Apiaceae family, like celery, carrot, and dill, are more likely to experience an allergic reaction to fennel. There have also been reports of cross-reactivity with birch pollen and other allergens in the environment, which means that those with allergies should be careful (Kooti et al., 2015). These points show how important it is to assess and monitor each person individually in therapeutic settings. Another safety issue is drug interactions, especially because fennel may make anticoagulant drugs work better because it contains coumarin. The plant's estrogenic qualities may also affect treatments and disorders that are sensitive to hormones, thus they need to be carefully looked at in therapeutic settings (Badgujar et al., 2014). When recommending fennel supplements or preparations, healthcare professionals should keep these possible interactions in mind.

Research Opportunities

Foeniculum vulgare continues to provide new therapeutic opportunities where traditional medicine meets modern scientific research as current studies are revealing novel mechanisms of action and new clinical uses. It is especially interesting to note that recent literature cites its neuroprotective properties, as some preliminary results indicate that fennel may be useful in the management of neurodegenerative disorders and cognitive deficits (Kooti et al., 2015). These findings build on existing knowledge, and, as such, may offer exciting avenues for future investigations. Another rapidly evolving research domain involves the use of fennel in providing metabolic health, ostensibly channeling its effect to better manage diabetes and avoid obesity. The plant appears to act as an anti-inflammatory and antioxidant, with suggestions that

these features contribute to metabolic regulation, suggesting potential uses in therapeutic agents outside of traditional mechanisms of action (Badgujar et al., 2014). As it stands, it is important to recognize that in order to develop a bona fide evidence-based therapeutic plan, more extensive clinical trials are needed. Finally, Foeniculum vulgare also has antibacterial components in light of the significant impact antimicrobial resistance is having on global health, and could provide a needed solution. With future studies leading to standardized antimicrobial agents or potential combinations with other fennel extracts may offer effective treatment alternatives to existing antibiotics based on traditional and modern interventions (Fugh-Berman, 2003).

Conclusion

Foeniculum vulgare is a great example of how traditional knowledge and modern scientific research can work together. It illustrates how ethnobotanical knowledge can contribute to evidence-based medicine. The plant has a long history of traditional use that has informed modern studies, while contemporary scientific methods have enhanced our understanding of its healing properties. This overlap has validated many ancient uses and introduced new treatment possibilities. It supports ongoing research on medicinal plants as sources of safe and effective therapies. A thorough phytochemical analysis of fennel has shown that its medicinal effects stem from complex molecular structures. Its various pharmacological properties arise from its essential oil components, phenolic compounds, and other bioactive chemicals. Clinical studies that back traditional uses, like improving digestive health, managing menopausal symptoms, and boosting milk production, provide a solid foundation for evidence-based recommendations and emphasize the need for rigorous scientific proof. Future research in neuroprotection, metabolic health, and antibacterial uses presents these possibilities. This review emphasizes the importance of linking ethnobotany with current science to further our understanding of medicinal plants and their healing properties. The successful integration of traditional knowledge with modern research methods in this case can serve as a model for studying other medicinal plants and developing evidence-based phytotherapies that honor traditional practices while meeting contemporary scientific standards.

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