

Review article

Fennel (*Foeniculum vulgare* Mill.) in Polish herbaria of the 16th-18th centuries: An ethnopharmacological analysis in the context of contemporary knowledge

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ABSTRACT

*This study aimed to analyse the use of common fennel (*Foeniculum vulgare* Mill.) in Polish herbaria of the 16th-18th centuries and to compare historical ethnopharmacological knowledge with contemporary scientific data. The research involved a theoretical ethnopharmacological analysis based on the works of renowned Polish botanists such as S. Falimirz, H. Spiczynski, M. z Urzędowa, S. Syreński and K. Kluk. Digitised versions of herbaria, alongside modern scientific publications, were employed to assess the pharmacological properties of fennel. The primary objective was to compare historical data with contemporary publications, particularly those detailing fennel's chemical composition and pharmacological properties, including its key active compounds such as anethole, fenchone, and limonene. The results of the study indicated that fennel has traditionally been used as a remedy for the digestive and respiratory systems, a use that is corroborated by contemporary scientific data on its antimicrobial, antispasmodic, anti-inflammatory, and antioxidant properties. Historical records suggest that fennel was employed to alleviate pain and treat coughs, colic, and bloating. The study also revealed a significant nutritional content in fennel fruits, including proteins (15.8 g), fats (14.9 g), and carbohydrates (36.6 g) per 100 g, as well as essential oils, which contribute to its medicinal properties. Particular attention was given to the high concentration of trans-anethole (up to 83.1%) in sweet fennel, making it effective in treating stomach disorders, bloating, and other gastrointestinal issues. The findings underscore the importance of fennel as a modern herbal remedy with the potential for use in treating serious conditions such as oxidative stress and cancer. The study opens up opportunities for further research into the potential of this plant in modern medicine.*

Keywords: Antimicrobial properties, botany, digestive disorders, fennel, phytopreparations, traditional medicine,

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.) is a plant that has been an important part of traditional medicine in many cultures for centuries due to its healing properties. Its medicinal characteristics, such as antiseptic, anti-inflammatory and antispasmodic properties, have been known since ancient times, and it has been used to treat various diseases, including digestive and respiratory disorders. In view of this, fennel is a valuable plant not

only from a medical, but also from a cultural and historical point of view.

The relevance of the study is to compare historical knowledge about fennel with modern scientific data. In the 16th-18th centuries, fennel was widely used in Polish herbarists to treat a variety of ailments, which emphasizes its importance in folk medicine at that time (Komilova *et al.*, 2020). This study aims to analyze the use of fennel in Polish herbaria and compare this

historical data with modern scientific knowledge about the chemical composition and medicinal properties of the plant. Specific problems that this study seeks to address include the uncertainty in how ancient ethnopharmacological knowledge can be reconciled with the latest scientific discoveries. In addition, it is important to consider how changes in the growing conditions of fennel affect its chemical composition and, consequently, its efficacy for medicinal purposes. Another important issue is the need to investigate possible contraindications and side effects of fennel, as modern approaches to medicine emphasize the safe use of herbal remedies, especially in the context of modern diseases and therapies.

Common fennel (*Foeniculum vulgare* Mill.) is one of the most widely used medicinal plants, employed for centuries in various traditional medical systems, particularly in Europe. Its healing properties are extensively described in the studies of numerous botanists and herbalists from the 16th-18th centuries, including Falimirz(1534), Spiczyński(1542), Urzędowa(1595), Syreński(1613) and Kluk(1786). These scholars included fennel in their herbals as a remedy for digestive issues, respiratory ailments, and to alleviate inflammation. Their works made significant contributions to the development of European ethnopharmacology and continue to attract the attention of modern researchers seeking to uncover new applications for fennel based on historical knowledge. Traditionally, fennel has been used to treat a wide range of conditions, such as bloating, colic, coughs, and various digestive disorders (Jadid *et al.*,2023; Zotaj *et al.*, 2024).

Contemporary scientific research continues to contribute new insights into the study of fennel. Notably, Benabdallah *et al.*(2022) and Kishore and Verma(2022) have established that the primary biologically active components of this plant, such as anethole, fenchone, and limonene, are

responsible for its pharmacological properties, including anti-inflammatory, antispasmodic, and antibacterial effects. An important aspect is fennel's potential in cancer treatment, as demonstrated by the research of Amiza *et al.*(2022). Trans-anethole, the main component of fennel, has shown the ability to inhibit tumour cell growth and induce apoptosis (programmed cell death) in cancer cells. Although these studies have been conducted primarily at the preclinical level, they open new possibilities for the use of fennel in oncology and warrant further confirmation through clinical trials.

In addition to its anti-inflammatory and antispasmodic properties, fennel also possesses potent antioxidant activity. As noted in the research by Noreen *et al.*(2024), the essential oils of fennel, particularly limonene, exhibit high antioxidant potential, making this plant a promising agent for preventing oxidative stress and combating oncological diseases. Investigating the antioxidant properties of fennel is a crucial area of research, as it may contribute to the development of new phytotherapeutic agents for the treatment and prevention of various diseases, including chronic conditions associated with oxidative stress.

Despite significant advancements in fennel research, there remain certain unresolved questions requiring further investigation. For instance, Telci *et al.*(2009) highlight variations in the chemical composition of fennel based on climatic conditions, growth stage, and the origin of the raw material, which can influence its pharmacological activity and stability. This underscores the need for additional research to ensure the standardisation of fennel as a medicinal raw material and enhance its efficacy across diverse applications.

Furthermore, fennel has found its niche not only in medicine but also in cosmetics due to its antimicrobial and antioxidant properties. Its extracts are utilised in skincare products as they contribute to reducing inflammation and promoting skin rejuvenation, as detailed in the research of Badgajar *et al.*(2014).

These attributes further underscore the versatility of fennel as a plant with a broad spectrum of applications.

This study aimed to conduct a comprehensive analysis of common fennel (*Foeniculum vulgare* Mill.) based on Polish herbaria from the 16th-18th centuries and contemporary scientific research, to compare ethnopharmacological knowledge with current data on the pharmacological properties of this plant.

The research objectives encompass: conducting a historical analysis of 16th to 18th-century herbaria to explore traditional uses of fennel; comparing the pharmacological properties of fennel described in ancient sources with contemporary scientific data; and evaluating the potential of fennel for further research in modern medicine and cosmetics.

MATERIALS AND METHODS

The research into common fennel (*Foeniculum vulgare* Mill.) in Polish herbaria of the 16th-18th centuries was conducted in the format of theoretical ethnopharmacological analysis, based on existing historical and contemporary sources at the University of Agriculture in Krakow Faculty of Biotechnology and Horticulture.

The foundation for the historical analysis consisted of Polish herbaria of the 16th-18th centuries, created by prominent botanists of the Renaissance and later periods. Specifically, the research sample included works by the following authors: Falimirz (1534), Spiczyński (1542), Urzędowa (1595), Syreński (1613), and by Kluk (1786).

The following key electronic resources and software were employed to analyse historical sources, enabling access to digital versions of ancient herbaria and contemporary research articles: Polona – the National Digital Library of Poland, Jagiellonian Digital Library – the digital library of Jagiellonian University, Google Books – a

database of digital books, and Europeana – the European digital platform.

The following software was employed for text processing and analysis: Adobe Acrobat Reader was used to view, annotate, and work with digital PDF files of ancient herbaria. Zotero, a bibliographic management software, was used to organise research sources and create bibliographic references. NVivo, a qualitative data analysis software, enabled the coding and analysis of the content of digital herbaria, identifying key terms related to fennel, and comparing them across different sources.

The following databases were utilised for searching and collecting scientific literature: PubMed was employed to locate contemporary research articles on ethnopharmacology, pharmacognosy, and medicine related to the biochemical composition and modern uses of fennel. Google Scholar served as the primary tool for searching scientific papers, articles, and reviews, enabling the identification of the most relevant sources for comparative analysis of fennel. ScienceDirect, a database specialising in medical and pharmacological publications, complemented the data on the chemical properties and pharmacological applications of fennel.

The search queries included the following terms: “*Foeniculum vulgare*”, “fennel”, “ethnopharmacology”, “pharmacognosy”, “biochemical composition”, “pharmacological uses of fennel”, and various combinations of these terms. The primary criteria for inclusion in the sample were: articles containing original data on the biochemical composition and uses of fennel; publications in peer-reviewed scientific journals up to 2024; and open-access sources to ensure data verification. To compare and analyse the use of fennel in contemporary ethnopharmacology, scientific publications highlighting the biochemical composition, pharmacological properties, and modern medicinal applications of fennel were examined. Particular attention was paid to the key active compounds of the plant, such

as anethole, fenchone, and limonene, which corroborate traditional knowledge regarding the plant's medicinal properties.

A comparative method was employed to analyse data by contrasting ancient (16th-18th centuries) and modern pharmacological knowledge. The comparison was based on examining the similarities and differences between the properties of fennel described in ancient herbals and their scientific validation through contemporary research. The selection of materials for analysis was based on several inclusion criteria: Polish herbaria had to contain specific descriptions of the medicinal use of fennel; modern scientific articles had to illuminate the plant's chemical composition and pharmacological properties; ancient works where fennel was mentioned only in passing or without specific medical characteristics were excluded.

No physical equipment was used, as the research was entirely theoretical.

RESULTS AND DISCUSSION

Ethnopharmacology and contemporary pharmacology

Ethnopharmacology is considered an interdisciplinary field of science that combines natural and humanities disciplines. Its primary aim is to study and describe traditional knowledge concerning the use of medicinal plants and other natural materials in various ethnic groups, and to assess their efficacy from the perspective of modern pharmacology. Ethnopharmacology seeks to determine whether contemporary scientific data supports or refutes the traditional knowledge of plants used for medicinal purposes (Schapovalova *et al.*, 2022).

Pharmacology, the science of the effects of medicinal drugs on living organisms, began to develop significantly in the 19th century when biomedical sciences opened new avenues for studying plants, animals, and minerals used in traditional medicine. Consequently, pharmacology investigates substances that, through chemical reactions,

can stimulate or inhibit physiological processes in the body, influencing antigens or other pathogenic agents (Pencheva & Danyliv, 2022; Sanli & Ok, 2023).

Throughout the 19th century, considerable attention was given to plant extracts, particularly quinine, digitalis, and morphine, which formed the basis for further research in pharmacology. The rapid advancement of pharmacology as a science was driven by the discovery of new classes of drugs in the first half of the 20th century, which, in turn, led to significant breakthroughs in the treatment of various diseases (Gerasymchuk *et al.*, 2021; Somasiri *et al.*, 2024). At the present stage, ethnopharmacology primarily focuses on researching traditional medicines of non-European peoples; however, it also draws upon the experience of European traditional medicine as recorded in herbaria of the 16th-18th centuries, which serves as a fundamental source of knowledge regarding the use of medicinal plants. Documenting and restoring this knowledge are crucial tasks for ethnopharmacology.

Analysis of the use of fennel in Polish herbaria of the 16th-18th centuries

A study of common fennel (*Foeniculum vulgare* Mill.), based on an examination of Polish herbaria of the 16th-18th centuries, has confirmed the plant's significant role in traditional Polish medicine. It was widely used for treating gastrointestinal ailments, respiratory diseases, and to alleviate symptoms of inflammation and swelling. Falimirz, Spiczyński, Urzędowa, Syreński and Kluk emphasized fennel's role as a versatile medicinal remedy.

In folk medicine, fennel was used to relieve spasms, relieve inflammation, and as an expectorant for coughs (Topchubaeva *et al.*, 2020; Smiyan *et al.*, 2015). These properties have not lost their relevance in modern science, although today these statements are also supported by the results of clinical studies and scientific experiments. From a

modern point of view, fennel is a nutritious plant rich in vitamins, minerals, and fiber. According to the USDA, 100 g of fresh fennel contains 15.8 g of protein, 14.9 g of fat, and 36.6 g of carbohydrates. These nutritional components make fennel an important element of the diet, providing the body with essential macronutrients that support overall health and energy balance. The vitamin C it contains has powerful antioxidant properties that help protect cells from damage and support the immune system.

Fennel is also recognized by the European Food Safety Authority as a health benefit, particularly for improving digestion and supporting gastrointestinal health. The properties of fennel that help relieve bloating and discomfort are supported by modern scientific research. Fennel contains compounds such as anethole, which has an antispasmodic effect, reduces bloating and helps to normalize intestinal motility (Zubtsova & Skliar, 2023). Modern approaches to health emphasize the fight against inflammation, and fennel plays an important role in this context due to its anti-inflammatory properties.

Falimirz (1534), in his work "About Herbs and the Power of Them", describes fennel as one of the key remedies for improving digestion. He recommended it for the treatment of colic and bloating, while also emphasising its diuretic properties. The use of fennel for kidney cleansing and reducing swelling indicates its widespread application in addressing fluid imbalance within the body. Furthermore, Falimirz highlights fennel's ability to alleviate coughs, underscoring its role in the treatment of respiratory ailments, particularly colds and coughs.

Spiczynski (1542), in his work "About Local and Overseas Herbs and the Power of Them", pays particular attention to fennel's ability to treat stomach ailments and stimulate appetite. The author highlights its versatility, emphasising fennel's antiseptic properties. Its use for wound healing and

relieving abdominal pain in children is corroborated by contemporary scientific research. Modern studies suggest that these properties of fennel can be attributed to the presence of anethole in its essential oil, which exhibits potent anti-inflammatory and calming effects.

Similar findings regarding the properties of fennel are presented in "HerbarzPolski" by Urzędowa (1595), who also devotes significant attention to the treatment of digestive disorders, particularly colic and diarrhoea. The author recommends fennel to improve well-being after heavy meals, indicating its importance for maintaining digestive health. Additionally, he notes that fennel is effective in combating coughs and colds, particularly as an expectorant.

Syreński (1613), in his work "Herbarium", describes fennel as a remedy for improving appetite and treating stomach disorders. He recommends using fennel seeds to alleviate abdominal pain and prevent bloating. Modern science supports these properties of fennel, as it contains compounds such as fenchone and limonene, which have antispasmodic effects and promote digestion. Furthermore, Syreńskidescribes fennel as an effective remedy for treating eye infections, which is supported by contemporary knowledge of the antimicrobial properties of anethole.

Kluk(1786), in his work "Plant Dictionary", summarises the knowledge about fennel accumulated by the end of the 18th century and systematically categorises information about medicinal plants. He confirmed its significance as a medicinal plant for treating gastrointestinal disorders, inflammation, and respiratory infections. An important addition is the mention of fennel's use in veterinary medicine, indicating its value not only in human medicine but also in animal husbandry and agriculture.

These works demonstrate that fennel was an exceptionally important plant in early modern Polish medicine. Its versatility and medicinal properties were repeatedly

confirmed and have found support in contemporary scientific research.

Contemporary data on fennel (chemical composition and nutritional value)

Foeniculum vulgare, commonly known as fennel, has been extensively analysed to reveal its chemical composition, which exhibits a rich profile of nutrients and bioactive compounds. Chemical analysis by Bernáth *et al.* (1999) demonstrated that the chemical components within fennel vary depending on the source, plant morphotype, climate, and harvest stage. Per 100g of fennel fruit, there is approximately: 36.6 g of carbohydrates; 15.8 g of proteins; 14.9 g of fats; 8.8 g of water; 8.2 g of ash (containing 19 mg of iron, 1.2 g of calcium, 385 mg of magnesium, 1.7 g of potassium, 487 mg of fluorine, 88 mg of sodium, and 28 mg of zinc) 15.7g of fibre. Every 100g of fruit contains a certain amount of vitamins: niacin (6 mg), thiamine (0.41 mg), as well as vitamin A (135 IU) and riboflavin (0.35 mg), and a determined energy value of 1,440 kJ (Table 1). The primary constituents of fennel fruits are starch, mucilage, sugars, tannins, and essential oils. The most significant essential oils include oleic, petroselinic, palmitic, and linoleic acids. The studied plant also contains approximately 50% trans-anethole, 10-30% limonene, 10-20% fenchone (imparting a bitter taste to the fruits), 12-16% α -pinene with β -pinene, α -tujone, myrcene, estragole, and 1,8-cineole, and 3-11% α -phellandrene (Table 2). Fennel has a relatively high content of methyl chavicol (47.09%), as well as limonene (29.07%), α -terpinene (2.5%), fenchone (13.43%), fenchylacetate (1.95%), and cis- β -ocimene. Sweet varieties have a higher content of anethole (50-80%) and significantly lower concentrations of fenchone (5%, may be completely absent), with comparatively more safrole, limonene, pinene, and estragole.

Table 1: Chemical composition and nutritional value of different parts of

fennel: shoots, leaves, stems, and inflorescences (USDA, USA)

Fennel components	Per 100g edible portion	Fennel components	Per 100g edible portion
Energy (kcal)	19	Iron (mg)	2.7
Fats (g)	0.3	Vitamin A (mg)	783
Proteins (g)	1.4	Vitamin B1 (mg)	0.03
Carbohydrates (g)	2.8	Vitamin B2 (mg)	0.11
Dietary fibre (g)	2	Niacin (mg)	0.2
Potassium (mg)	395	Vitamin B6 (mg)	0.1
Calcium (mg)	38	Vitamin C (mg)	93
Magnesium (mg)	12	-	-

Source: compiled by the author based on Bernáth *et al.* (1999).

The high potassium content is particularly noteworthy, as potassium plays a crucial role in maintaining fluid balance and cellular functions. Fennel is also a good source of dietary fibre, which is well-known for its benefits in digestion, while its high phosphorus and magnesium content contributes to improved bone health and metabolic processes.

Table 2: Essential compounds obtained by distillation from sweet and bitter fennel fruits

Compound	Bitter fennel (%)*	Sweet fennel (%)**
Trans-anethole	55.0-75.0	79.8-83.1
Fenchone	12.0-25.0	4.6
Estragole	Max 6.0	3.9-5.1
α -pinene	1.0-10.0	0.3-3.6
Limonene	0.9-5.0	2.2-3.8
α -pinene/limonene	>1.0	-
CIS-Anethole	0.5% (max)	-
Anisaldehyde	2.0 (max)	-

Source: compiled by the author based on Baser *et al.* (2006).

The essential oils of both bitter and sweet fennel (Table 2) contain a range of

biologically active compounds whose concentrations vary depending on the plant's maturity stage and the time of year the fruits were harvested. Particularly significant are the differences in the concentrations of compounds such as trans-anethole and fenchone, as these influence the plant's taste and medicinal properties. Trans-anethole is the primary component of sweet fennel essential oil and is responsible for its sweet, anise-like flavour. The presented data show that trans-anethole concentration remains high at all stages of fruit maturation, especially in ripe and dry samples, where its content reaches 78.25% (January 2001) and 77.26% (May 2001). Fenchone, which is responsible for the bitter taste of bitter fennel, exhibits a significantly different

pattern. Its content is slightly lower in ripe and dry fruits, however, the maximum concentration of fenchone is observed in green fruits, where its proportion reaches 16.98% (May 2001). Such variations in chemical composition are important for the culinary and medicinal applications of fennel, as different concentrations of active components can influence the therapeutic efficacy of preparations or the flavour of spices produced from this plant (Table 3).

Table 3: Composition of the essential oil from three categories of fruits of *Foeniculum vulgare* var. *dulcis*

Compounds	Essential oil composition					
	January 2001			May 2001		
	Green	Mature	Dry	Green	Mature	Dry
α -Pinene	1.27	0.28	1.19	1.16	0.41	0.29
Mircene	0.93	0.50	0.72	0.95	0.49	0.41
Limonene	5.26	2.74	3.67	6.70	3.32	2.32
Fenchone	15.08	15.14	13.98	16.98	14.9	4.03
Methylchavicol	2.56	2.50	2.45	3.57		
Cis-Anethole	-	-	-	-	-	-
Trans-Anethole	73.81	77.67	78.25	69.67	76.01	77.26
β -Ocimene	-	-	-	-	-	-
γ -Terpinene	0.57					
Endo Fenchyl-acetate	-	-	-	-	-	-
ExoFenchyl-acetate	-	-	-	3.35	4.24	-

Source: compiled by the author based on Stefanini *et al.* (2006).

Therefore, the nutritional and chemical analysis of *Foeniculum vulgare* highlights its value as both a medicinal plant and a food additive. Its abundance of essential oils, particularly trans-anethole, indicates its anti-inflammatory, antimicrobial, and antioxidant properties. The high content of dietary fibre, vitamins, and minerals makes fennel a popular choice in traditional medicine, especially for improving digestion and supporting overall health. The data presented in the tables corroborate the historical use of fennel, as recorded in ancient herbaria of the 16th-18th centuries, and confirm its significance in modern medicine and nutrition.

The efficacy of fennel in treating diseases

Fennel (*Foeniculum vulgare*) has been used for centuries as an effective medicinal herb, particularly for the treatment of digestive and respiratory ailments. Its widespread use is supported not only by historical evidence but also by contemporary scientific research, which confirms the efficacy of this plant.

One of the primary historical and contemporary uses of fennel has been in the treatment of digestive disorders. Current research indicates that the active components of fennel, such as anethole and fenchone, possess spasmolytic properties, which help to relax the smooth muscles of the gastrointestinal tract. A study conducted by Portincasa *et al.* (2016), Rafieian *et al.* (2024) demonstrated that regular consumption of

fennel significantly alleviated the symptoms of irritable bowel syndrome, leading to an improved quality of life for patients. Fennel also plays a significant role in the treatment of respiratory ailments. Contemporary studies support these properties due to the high content of essential oils and flavonoids, which possess antibacterial and anti-inflammatory properties.

Fennel cultivation conditions, including soil type and climate, can significantly affect its chemical composition and, consequently, its medicinal properties. According to Telci *et al.* (2009), variations in these conditions can alter the concentration of active compounds in fennel, such as essential oils, flavonoids, and other bioactive components, which directly affects its therapeutic effects. The type of soil, in particular its pH, organic matter and mineral content, can affect plant growth and the synthesis of chemical compounds contained in fennel. For example, acidic soil can stimulate the accumulation of certain trace elements or compounds that contribute to the effectiveness of fennel when used as a medicinal plant. Although fennel is a widely used herb with numerous medicinal properties, its excessive use can cause side effects and contraindications. In addition, excessive consumption of fennel can lead to gastrointestinal disorders such as bloating, nausea, or even diarrhea, especially when using large doses. For people with sensitive digestive tracts or those with gastrointestinal conditions, fennel should be used with caution (Allaberdiev *et al.*, 2021; Niyazbekova *et al.*, 2023).

Furthermore, fennel has demonstrated effectiveness in treating infant colic. A randomised controlled trial by Attarha *et al.* (2008) showed that fennel significantly reduces colic in infants due to its spasmolytic properties. Fenchone, one of the active components of fennel, has been shown to decrease spasms in the smooth muscles of the intestines, alleviating pain and discomfort. Other studies have also indicated that fennel helps to reduce bloating,

particularly when consumed regularly as a tea or infusion.

Thus, it is evident that the efficacy of fennel in treating disorders of the digestive and respiratory systems is supported by both historical and contemporary scientific evidence. Its antibacterial, antispasmodic, and anti-inflammatory properties render fennel a significant component of modern phytotherapy, particularly in the management of gastrointestinal and respiratory disorders.

Differences between historical and contemporary perspectives on fennel usage

Fennel is known for its antiseptic and healing properties, which is why it has been used to treat wounds. Fennel is known to have been used to treat cuts and wounds, as its extracts help reduce inflammation and accelerate healing. This is also confirmed by medical records, which describe its use for external use, in particular in the form of compresses or decoctions for washing wounds. Another important use of fennel is as an expectorant. Due to its anti-inflammatory and antiseptic properties, fennel has been widely used to treat respiratory diseases, in particular to relieve cough and shortness of breath. It has been used as a natural sputum expectorant, making it an important element in the treatment of colds, bronchitis, and other respiratory conditions.

Combining these diverse medical uses, fennel in Polish folk medicine of the 16th-18th centuries was extremely important as a versatile remedy used to solve a wide range of health problems. Its use in the treatment of digestive disorders, wound healing, and respiratory diseases demonstrates a deep understanding of the multifunctionality of this plant. Due to its diverse properties, fennel gained popularity in folk medicine as a remedy that could help treat everyday ailments, improve quality of life, and maintain overall health. Its significance in historical Polish medicine can be assessed

not only through its specific therapeutic effects, but also through its role in shaping the holistic picture of folk medicine of the time.

While most properties of fennel described in ancient herbaria have been corroborated by modern science, new aspects of this plant's use have emerged. For instance, contemporary research, notably by Chebet *et al.* (2021) and Noreen *et al.* (2024), highlights fennel's potential in combating cancer cells due to its antioxidant properties. Such properties were unknown during the Renaissance but are now actively investigated in the context of oncology. The antioxidant properties of limonene and other components of fennel's essential oil make it a promising agent for preventing oxidative stress (Belov *et al.*, 2005; Akha *et al.*, 2014). It inhibits the spread of cancer cells and promotes apoptosis.

Based on the results of the study, it can be concluded that fennel remains a valuable medicinal resource in contemporary medicine. Its multifaceted properties, supported by both historical records and modern research, indicate its potential for further investigation, particularly in the fields of oncology and cosmetology. The findings from this study of fennel (*Foeniculum vulgare* Mill.) corroborate its significant role in traditional medicine and contemporary phytotherapy, particularly in the treatment of digestive and respiratory disorders, as well as in cosmetic applications. This research aligns with other scientific studies that underscore fennel's rich chemical composition and broad spectrum of pharmacological properties.

A study by Akbari *et al.* (2023) investigated the phenolic composition and antioxidant activity of various fennel populations. Their results revealed high concentrations of phenolic compounds, such as flavonoids, which are responsible for the plant's significant antioxidant properties. These conclusions are consistent with results from other research, which also identified fennel as being rich in flavonoids and phenolic

compounds. Antioxidant activity is a crucial component of fennel's therapeutic efficacy, as it reduces oxidative stress levels, which is particularly beneficial for patients with chronic conditions such as irritable bowel syndrome and bronchitis (Kosmuratova *et al.*, 2021). The significance of this research lies in demonstrating that different fennel populations have varying phenolic compound content, which opens avenues for further selective breeding of the most valuable populations for medicinal applications. This is consistent with research that has also highlighted the importance of standardising the bioactive compound content in different fennel varieties.

Abdesslem *et al.* (2021), Mehra *et al.* (2021) investigated the chemical composition and biological activity of essential oils in fennel, using ethanolic extracts from both organic and conventional crops. Their findings indicated that organic fennel contained higher concentrations of bioactive compounds such as trans-anethole and fenchone, which are primary components of essential oils. This finding aligns with other research that has also identified elevated levels of these compounds in fennel, which are crucial for its antibacterial and antispasmodic effects. A significant aspect of this research is the comparison of fennel grown under different conditions, confirming that organically grown plants exhibit higher biological activity.

A comprehensive review of the therapeutic and pharmacological potential of fennel was conducted by Kooti *et al.* (2015), focusing on its use in traditional medicine for the treatment of digestive and respiratory diseases. The review confirms that fennel is employed in the management of conditions such as bloating, cramps, cough, and bronchitis, which is consistent with the findings of this study. Notably, the research provides an in-depth examination of the antibacterial activity of fennel, which is crucial for its application in treating respiratory infections. This study underscores the significance of fennel in

contemporary medicine, affirming that its therapeutic potential could be harnessed for the development of new medicinal products based on natural components. Thus, the conclusions align with the data presented in this study and open new avenues for further clinical research.

The article of Bernáth *et al.* (1999) is fundamental, as it investigates the patterns of essential oil accumulation in fennel fruits at various stages of the plant's development. The study demonstrates that essential oil accumulates in the later stages of fruit maturation, which is linked to histological changes in the plant's structure. These results are significant for the research, as they confirm that the timing of harvesting the plant significantly affects the quantity and quality of essential oil, which may influence its therapeutic properties. Furthermore, the findings illustrate, that different stages of growth and harvesting of fennel can impact the activity of its components, thereby opening new avenues for optimising the production of fennel oil.

Baser and Kirimer (2006), Stefanini *et al.* (2006) conducted a study on the essential oils of plants in the *Lamiaceae* family, which includes fennel. The composition of the essential oils from various plants in this family was examined, revealing significant differences in chemical composition depending on climatic conditions and geographical location. These findings confirm that the essential oil of fennel may have a variable composition, as noted in the current study. The composition of fennel essential oil and its antifungal activity were studied by Mimica Đukić *et al.* (2003), who examined the impact of distillation conditions on the composition and antifungal properties of fennel essential oil. It was found that different distillation conditions can alter the composition and activity of the oil, which corresponds with data on the variability of essential oils based on cultivation and processing conditions. This study underscores the importance of technological aspects in the processing of

plant materials to optimise their therapeutic properties.

Diao *et al.* (2014), Ilić *et al.* (2019) investigated the enhancement of yield and antimicrobial activity of fennel essential oil through the grinding of seeds. It was established that pre-grinding fennel seeds could significantly increase the yield of essential oil and its antimicrobial activity. This conclusion aligns with data indicating that the mechanical processing of raw materials can substantially influence their bioactive properties.

Karami *et al.* (2023), Amudhamathi *et al.* (2024) conducted a study on the role of landforms in habitat suitability and connectivity of *Moringa peregrina* in southeastern Iran, highlighting the critical influence of environmental factors on the distribution and growth potential of medicinal plants. Their findings emphasize the importance of ecological conditions, such as soil composition, climate, and topography, in determining the quality and yield of bioactive compounds in medicinal species. This research is particularly relevant to study, as it underscores the significance of environmental factors in the cultivation and chemical composition of *Foeniculum vulgare* (fennel).

Given fennel's well-documented pharmacological properties, including its digestive, respiratory, and antimicrobial benefits, the insights from Karami *et al.* (2023) can aid in optimizing cultivation strategies to enhance the production of key bioactive compounds such as trans-anethole, fenchone, and limonene. Their study also suggests that habitat connectivity plays a crucial role in genetic diversity and plant resilience, which may have implications for sustainable fennel cultivation and the preservation of its medicinal qualities.

The analysed sources indicate a high medicinal and pharmacological value of fennel. Future research could focus on investigating the optimal conditions for the cultivation, processing, and extraction of

essential oil to maximise the preservation and enhancement of its bioactive properties. Particular attention should be given to the technological processes that may influence the chemical composition of the essential oil, as well as the potential applications of fennel in the treatment of infectious diseases.

CONCLUSION

The study revealed that *Foeniculumvulgare* (fennel) possesses significant pharmacological properties, as confirmed by both ethnopharmacological knowledge and contemporary research. Polish herbaria describe fennel as an effective remedy for digestive disorders, respiratory diseases, and as a natural antiseptic. Fennel contains a rich chemical composition, including essential oils such as trans-anethole, fenchone, and limonene, which exhibit anti-inflammatory, antimicrobial, and antioxidant activities. Important qualitative indicators include a high content of dietary fibre, minerals such as magnesium, potassium, and phosphorus, as well as vitamins, all of which contribute to overall health enhancement and the maintenance of normal bodily functions. The research confirmed that fennel exhibits significant effectiveness in treating digestive disorders, such as colic and bloating, due to its antispasmodic and anti-inflammatory properties. Furthermore, its application in respiratory diseases has also proven effective, attributed to its antibacterial and expectorant properties.

CONFLICT OF INTEREST STATEMENT

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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