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Review Article

Trachyspermum ammi (Ajwain): A comprehensive review of pharmacological property from traditional to recent developments

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Abstract

Scientific exploration of traditional knowledge and its allure use in the treatment of various ailments is one of the thrust areas of research. Herbal medicines are in excellent demand in developed as well as developing countries for primary healthcare by way of their expansive biological and medicinal benefits, higher safety borders and lower costs. In the list of medicinal plants, *Trachyspermum ammi* (Apiaceae) ajwain is a plant encompassing a good record as a traditional Persian and Ayurvedic cure. Essential oil obtained from fruits or seeds of ajwain, known as 'ajwain oil,' holds various phytoconstituents and shows numerous biological and pharmacological properties. The present review aims to investigate the medical significance of different diseases and metabolic disorders in human beings. The ajwain seeds and their extracts contain different chemical constituents, including thymol (a principal constituent), β-pinene, α-terpinene, α-pinene, p-cymene, γ-terpinene, etc., revealed to retain antibacterial, antifungal, antiviral, antiparasitic, antiplatelet, anti-inflammatory, antioxidant, spermicidal, antiepileptic, antitussive, ameliorative, antihypertensive, antispasmodic and anti-hyperlipidemic effects. They also show digestive stimulant and gastro-protective properties as well as broncho-dilatory effects. Due to the presence of a broad spectrum of pharmacological properties, this plant holds good potential for its utilization in novel pharmaceutical preparations in the future. The present review is, therefore, an effort to summarize the detailed literature on phytochemical constituents and the pharmacological properties of *T. ammi* to explore its possible therapeutic application.

Keywords: Essential oil, *Trachyspermun ammi,* Herbal medicine, Pharmacological property, Ajwain.

Introduction

Ethnomedicinal plants used by the villagers of district Udhampur, J&K, India. Plants are an essential part of life in many endemic communities (Sidigia *et al*., 1990). The use of plants as herbal medicines in healing several diseases goes parallel to human civilization. India is bestowed with a rich wealth of medicinal plants, being perhaps the largest producer and rightly acclaimed as the botanical garden of the world (Dubey *et al*., 2004).

Herbal remedies play a crucial role in the contemporary context of bioprospecting, which involves the exploration of biological resources, particularly plants, for commercially valuable genetic and biochemical properties. The importance of herbal remedies in this context can be understood through several key aspects like a source of novel compounds and leads for drug development. Besides, these remedies rely on the sustainable use of plant resources, and in most cases, ethnobotanical knowledge promotes the preservation of individual cultures and practices. With a growing interest in natural and holistic health approaches, herbal remedies are increasingly being integrated into mainstream healthcare systems. Herbal remedies are being explored for their potential to address modern health challenges such as antibiotic resistance, chronic diseases, and lifestyle disorders. This is supported by the fact that these practices have been the mainstay for primary health treatment worldwide due to their safety, efficacy and lesser side effects.

Numerous herbs have been used in traditional medicine and have yielded leads for modern medicine. *Trachyspermum ammi*, or ajwain, or nature's powerhouse, bridges traditional and modern medicine with its extensive therapeutic properties. Discover the incredible potential of ajwain, a tiny seed that packs a big punch. Rich in antioxidants, antimicrobial properties, and anti-

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inflammatory compounds, this natural wonder has been harnessing the power of nature to heal and nurture for generations. While traditionally revered for its digestive, antimicrobial, and analgesic benefits, modern research has provided a scientific basis for its continued use, particularly in gastrointestinal health, infection control, and pain management. Its phytochemical richness, particularly in thymol, underscores its potential in various therapeutic applications, making it a valuable plant in both ancient and contemporary medicinal practices.

T. ammi, commonly known as ajwain, belongs to the family Apiaceae and is an erect annual herb with a striate stem. The little fruit (seeds) is the most useful part of *T. ammi* plants used in kitchen recipes, flavoring of food bakery items and snacks. The plant is herbaceous, aromatic, profusely branched, 60 to 90 cm in height and erect with small, soft, fine hair. The fruits are 2 to 3 mm long, ovoid, small, muricate, and greyish-brown with five distinct ridges and tubercular surfaces. The fruit has a specific pungent aromatic taste and gives a strong aromatic odor that of thyme (*Thymus vulgaris*) in rubbed seeds (Asif *et al*., 2014). The plant is a native of Egypt and grows in different arid and semi-arid zones of Europe, Asia, India, Iraq, Afghanistan, Pakistan, and Iran (in the eastern part of Baluchistan). In India, the crop of ajwain is grown in Rajasthan, Gujarat, West Bengal, Madhya Pradesh, Uttar Pradesh, Maharashtra, and Bihar (ICAR - National Research Centre on Seed Spices (NRCSS) (2018). 'Package of Practices for Seed Spices.', n.d.) (Jeet *et al*., 2012).

The herb ajwain and its oil are used for the healing of diverse diseases and illnesses in humans. The seeds of ajwain contain 2 to 4.4% brown-colored oil known as ajwain oil and the main component present in this oil is thymol. Ajwain oil is used in the treatment of neurological disorders, including paralysis, tremor, and continual pains. The extracts of ajwain (*T. ammi*) have been reported for the treatment of ophthalmic infections and seeds in gastrointestinal diseases. Ajwain also has diuretic and aphrodisiac properties. The ajwain oil has antibacterial, antifungal, antiviral, antitussive, antioxidant, and analgesic properties. It is also used in the treatment of diarrhea, flatulence, and atonic dyspepsia (Durazzo *et al*., 2019; Bhadra, 2020; Saraswat *et al*., 2020; Subramaniyan *et al*., 2019).

Culinary and medicinal marvel experience the double delight of ajwain, a flavorful spice, and a medicinal marvel. This versatile herb adds zest to Indian cuisine while offering relief from digestive woes, respiratory issues, and more, making it a true gem in the world of wellness. Ajwain seeds are utilized in curries due to their sharp taste, as a flavoring agent and preservative in food, and for manufacturing the vital oil in the perfume industry and in the medicine industry (Kunwar *et al*., 2009). Ajwain oil (essential component thymol) is used in the healing of various gastrointestinal problems like diarrhea, dysentery, bronchial problems and lack of appetite. Chewing a pinch of ajwain seeds with common salt and clove can treat coughing caused by severe pharyngitis. Nasal blockage can be cured by smelling ajwain tied in cloth or by keeping ajwain in your pillow while sleeping. Ajwain seeds are also used as an anti-inflammatory agent, liver refresher and for removing paralysis. Ajwain is well thought-out for therapeutic and dietetic purposes (Meena *et al*., 2019). The present review documents the claimed therapeutic effects of the seeds and their scientific validation based on the literature collected and analysed from Scifinder database (Table 1). Trachysepmum ammi has been a integral constituent of many classical and proprietary formulations. A summery of these formulations has been tabulated in the review (Table 2).

Synonyms and taxonomical distribution of T. ammi

T. ammi have different vernacular names: *Ajwain* and *Jevain* in Hindi, *Yamini*, *Yaminiki* and *Yaviniki* in Sanskrit, Bishop's weed in English, *Omam* in Tamil, *Vamu* in Telugu, *Yamani*, *Yauvan, Yavan, Javan, Yavani* and *Yoyana* in Bengali, *Ajma, Ajmo, Yavan* and *Javain* in Gujrati, *Oman* and *Ayanodakan* in Malayalam, *Oma, Yom* and *Omu* in Kannada, *Juani* in Oriya, *Onva* in Marathi and Assamese in Jain (Kazemi Oskuee *et al*., 2011). It is also known as *Kammun* or *Al-Yunan* (Arabic), *Xi Ye Cao Guo Qin* (China), *Hounastan* (Armenian), Ajwan (Dutch), *Adiowan, Ajowan, Agyptischer* (German) (Lim, 2013).

Scientific classification of *T. ammi* (Ajwain) is as follows-.

Kingdom: Plantae (Plant)

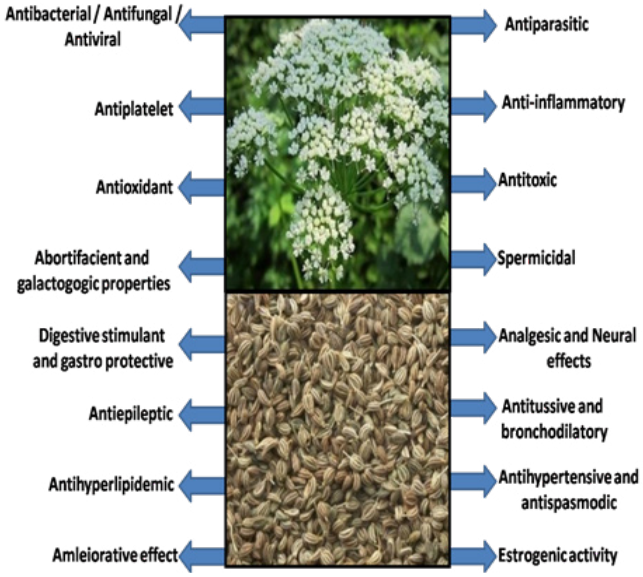

Figure 1: Pharmacological properties of *T. ammi* whole plant, seeds and essential oils

Subkingdom: Tracheobionta (Vascular plants)
Superdivision: Spermatophyta (Seed plants)
Division: Magnoliophyta (Flowering plants)
Class: Magnoliopsida (Dicotyledon)
Order: Apiales
Family: *Trachyspermum*
Species: *ammi*

Cultivation overview

T. ammi, is a hardy crop that thrives in semi-arid to subtropical climates, widely cultivated in India. It prefers cool, dry weather and is typically grown during the *Rabi* season (October–March). The ideal temperature for ajwain cultivation ranges between 15 to 25°C. Ajwain requires moderate rainfall, typically around 60 to 80 cm annually. Excessive rainfall or waterlogging can harm the crop, so proper drainage is essential. Though it grows well in a variety of soils, including loamy, sandy-loamy, and well-drained clay soils, the plant prefers soil with good organic content. The ideal pH range for ajwain cultivation is 6.5 to 7.5, slightly acidic to neutral. Ajwain is typically propagated through seeds, sown directly either through broadcasting or drilling rows (30–45 cm space) with a seed rate of about 3 to 4 kg per hectare, usually done during October-November, ensuring cooler months ahead. The plantation required moderate fertilization (10–15 tons/ha farmyard manure) and NPK (30:20:20 kg/ha) with 3 to 4 irrigations that are critical during germination, flowering, and seed formation. The crop is ready for harvest in 4 to 5 months, which follows cutting, drying, and thrashing that yields about 8 to 10 Qt/ha. Rajasthan is one of the largest producers of ajwain in India, particularly in the districts of Jodhpur, Nagaur, and Barmer. The state of Gujarat, especially the Saurashtra region, is another major producer of ajwain. (ICAR - National Research Centre on Seed Spices (NRCSS). (2018). 'Package of Practices for Seed Spices.', n.d.)

Essential oil content (Phytochemical constituents of ajwain)

The ajwain seed contains 2 to 4% brownish essential oil that can be obtained by hydrodistillation using a Clevenger-type apparatus. A study to analyze the volatile oil of *T. ammi* by simultaneous distillation extraction (SDE) and gas chromatography-mass spectrometry (GC-MS) yielded 81 prominent peaks, the major volatile flavor compounds being thymol (49.30%) >ρ-cymene (24.58%) > γ-terpinene (16.87%) > β-pinene (3.84%) > carvacrol (1.53%) (Khan *et al*., 2020) (Fig. 2). The major constituents of Ajwain seed oil are the phenols (thymol) (35–60%) and some carvacrol. In the non-thymol fraction, the remainder of the oil contains thymine(s) like p-cymene, γ-terpinene, ß-pinenes, di-pentene and camphene, myrcene and D3-Carene in very minute amounts. An ajwain seed analysis revealed it to contain different chemical components like moisture (8.9%), tannins, fiber (11.9%), fat (21.1%), carbohydrates (24.6%), glycosides, protein (17.1%), saponins, flavones and other components (7.1%) involving thiamine, calcium, iodine, manganese, phosphorous, iron, cobalt, copper, riboflavin and nicotinic acid are of reported phytochemical components of ajwain oil. Fixed oil of ajwain seeds also contains palmitic acid, resin acids, oleic acid, petroselenic acid, and linoleic acid. The chemical constituents of *T. ammi* may vary based on the topographical conditions of plants, extraction procedure, etc.

GC-MS analysis of *T. ammi* oil shows the presence of various compounds including two aromatic terpenes along with thymol and carvacrol. The aromatic terpenes of the oil constituted about 37.38% of thymol. However, the most important elements are acyclic monoterpene, monocyclic monoterpenes and bicyclic terpenes. The monocyclic monoterpenes are m-cymene (21.44 %), γ-terpinene (26.01%), 4- terpinenol (0.81%), β-phellandrene (1.60%) and the bicyclic terpenes are α-pinene and β-pinene, four-caren, β-pinene, and α-thujen. Similarly, the crucial oil of the ajwain seeds additionally contained a few non-terpenoid kinds of components that are 1-(3-isopropylidene-2.2- di-methylcyclopropyl) - isopropanon; 14.6.6- trimethyl - bicyclo [three.1.1]-hept-three-ene-2- one; 6-methyl-octene-1; 2.2-dimethyl-four.5-bis-1- propene-1.three-dioxalane (Hanif *et al*., 2021)

Therapeutic properties

Antibacterial properties

The antibacterial property of ajwain (acetone and aqueous extracts) was monitored against *Klebsiella pneumonia*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Enterococcus faecalis*, *Shigella flexneri*, *Staphylococcus aureus* and *Salmonella Typhimurium*, using agar disc diffusion assay (Zaidi *et al*., 2009). Apart from these, the compounds have antibacterial properties against a variety of other bacteria, including food-borne pathogens. The study demonstrated that acetone methanolic extract shows a more effective and broad spectrum of antibacterial activity than the aqueous extract. The antimicrobial action of *T. ammi*, in food preservation and protection against microbial spoilage have also been investigated at a very earlier time. The chemical constituents or compounds like thymol of

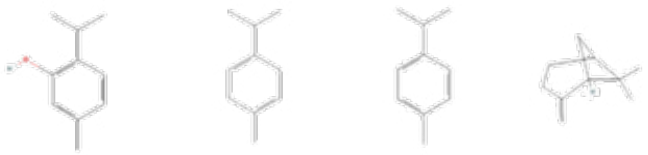

Figure 2: Structure of T. *ammi* major constituents according to area percentage

Table 1: Summary of the reported biological activities of *T. ammi*

S. No.	Therapeutic properties	Extract/Oil	Method	References	Observation/Conclusion
1.	**Antibacterial properties** *Staphylococcus aureus Salmonella Typhimurium, Escherichia coli Pseudomonas aeruginosa*	Seed (acetone and aqueous extracts) and leaf extracts	Disc diffusion assay & minimum inhibitory concentration	Zaidi *et al*., 2009 Paliwal *et al*., 2023 Nag, K., & Gupta, C. 2023	Solvent extraction used, hydrodistillation process is a preferred method for oil extraction.
2.	**Antifungal properties** *(Candida copticum)*	Methanol extract	Disc diffusion assay	Pirbalouti *et al*., 2009	Methanol extract will not yield the optimum bioactives. The bioactivity might yield better results with other methods of extraction.
3.	**Antiviral properties** (Hepatitis C Virus (HCV) protease)	Methanol extract	*In-vitro* assay	Hussein *et al*., 2000	
4.	**Antiparasitic properties** *(Plasmodium falciparum)*Anti-leishmaniasis activity *A. aegypti* mosquito larvae Insecticide	Ethyl acetate extract of *T. ammi* seed Hydroalcohol extract *T. ammi* oil	*In-vitro* assay	Kamaraj *et al*., 2012 Kheiri manjili *et al*., 2012 Yeom *et al*., 2012; Seo *et al*., 2012	The method of extraction is very important to achieve an optimum biological activity
5.	**Antiplatelet aggregation properties**	Dried ethereal extract of *T. ammi* seeds	*In-vitro* assay	Srivastava, 1988	Aqueous or hydroalcohol extract would be more acceptable for this activity
6.	**Anti-inflammatory properties**	Alcoholic extract and total aqueous extract	*In-vivo*	Mathew *et al*., 2008; Thangam & Dhananjayan, 2003	*In-vivo* assay yields more reliable activity if translation is to be achieved
7.	**Antioxidant properties**	*T. ammi* methanol extract *T. ammi* oil, with thymol	DPPH, radical scavenging activity	Aftab & Usmanghani, 1995 Alma *et al*., 2003; Quiroga *et al*., 2015; Vitali *et al*., 2016.	*In-vitro* assays will generally yield free radical scavenging activity, however if lipid peroxidation assays *in-vivo* would yield more conclusive results.
8.	**Anti-toxic effects** *Aspergillus flavus* and *Aspergillus parasiticus* *A. flavus*	*T. ammi* seed extract	Reduced aflatoxin activities Reduction of caspase-3 and apoptosis completely stopped the production of aflatoxin B1	Velazhahan *et al*., 2010, Deb *et al*., 2012 Safari *et al*., 2020	The essential oil possesses potential anti-fungal activity and the fungus considered in this case are potent producers of aflatoxin.
9.	**Analgesic and neural effects**	Ethanolic extract of *T. ammi* is comparable with morphine	Alleviating rheumatic, joint pain, headache, and neuralgic pain	Hejazian, 2006; Dashti-Rahmatabadi *et al*., 2007	This activity can be utilized for the formulation of anti-nociceptive formulations
10.	**Antitussive and bronchodilatory effects**	Aqueous and macerated extracts of ajwain seeds and decocted extract of ajwain	Significant reduction of cough number	Boskabady *et al*., 2003 Boskabady *et al*., 2007	Similar traditional infusion practices have been documented for similar activity
11.	**Anti-hypertensive and antispasmodic property**	*T. ammi* methanolic and aqueous extract of seed	Dose-dependent downregulation of blood pressure and inhibits the bronchoconstriction	Thangam & Dhananjayan, 2003	*In-vivo* assays can substantiate the assays carried out to claim the activities
12.	**Estrogenic activity**	Ajwain seeds	Phytoestrogen content evaluated and found 473 ppm	Kaur, 1998	
13.	**Digestive stimulant and gastro-protective property**	Crushed ajwain seeds	Increase the secretion of bile acids, gastric acid and the activity of digestive enzymes. Reduce the transit time of food in the digestive system increases the effectiveness of pancreatic lipase and amylases	Vasudevan *et al*., 2000; Platel & Srinivasan, 2001; Ramakrishna Rao *et al*., 2003	The seeds are traditionally used as a digestive and anti-flatulant

T. ammi are also able to kill antibiotic-resistant bacteria (Khanuja SPS, Srivastava S, Shasney AK, Darokar MP, Kumar TRS, Agarwal KK, Ahmed A, Patra NK, Sinha P, Dhawan S, Saikia D., 2004) (Khanuja *et al*., 2004). The antimicrobial activity of various extracts and essential oils of *T. ammi* against several microorganisms has been reported through various studies (Moein *et al*., 2015; Asif *et al*., 2014; Khan & Jameel, 2018; Zarshenas *et al*., 2013). The zone of inhibition formed by disc diffusion assay having *T. ammi* essential oil was considered to calculate the antimicrobial activity of essential oil and also the quantitative determination of *T. ammi* essential oil through minimum inhibitory concentration (Paliwal *et al*., 2023). The antibacterial activity of the *T. ammi* leaf extracts was determined by the disc diffusion method. They were most effective against *E. coli* (NCIM 5346), followed by *Pseudomonas aeruginosa* with inhibition zone diameter (IZD) of 35.0 and 30.0 mm, respectively (Nag, K., & Gupta, C. 2023).

Antifungal properties

Antifungal action of volatile constituents of *T. ammi* seeds on 10 fungi (*Acrophialophora fusispora*, *Fusarium chlamydosporum*, *Curvularia lunata*, *F. poae*, *Papulaspora sp.*, *Myrothecium roridum*, *Alternaria grisea*, *Drechslera tetramera*, *A. tenuissima* and *Rhizoctonia solani*) were tested, which resulted in the inhibition of growth of all tested fungi by 72 to 90%. (Singh *et al*., 2004; Singh *et al*., 1979). The antifungal properties of *T. ammi* were also documented against *Aspergillus* species, 900 ppm concentration showed fungitoxicity behavior against *Epidermophyton floccosum*, *Trichophyton mentagrophytes* and *Microsporum canis* (Singh *et al*., 1986; Anilakumar *et al*., 2009). Antifungal properties against *Candida copticum* by agar disc diffusion assay were also reported (Pirbalouti *et al*., 2009). An *in-vitro* study of the methanolic extract showed more effective killing against *Candida albicans* and *C. utilis* when compared to *Saccharomyces cerevisiae*. Phenolic extract compounds like thymol and carvacol showed bacteriostatic or bactericidal behavior depending upon the concentration used, as (0.0625–1 µL/mL) essential oil of *T. ammi* showed fungistatic behavior against *Aspergillus* and *Candida* (Moein *et al*., 2015; Anilakumar *et al*., 2009). Essential oil of *T. ammi* was found to be effective against pathogenic yeast: *Candida albicans* ATCC 10231, *C. krusei* PTCC 5295 and other vaginal pathogens (Mehri Ardestani *et al*., 2020).

Antiviral properties

In-vitro assay performed for evaluating the antiviral properties of *T. ammi* methanolic extract showed significant inhibitory effects against hepatitis C virus (HCV) protease (Hussein *et al*., 2000). The antiviral activity of *T. ammi* essential oil was also studied against the Japanese encephalitis virus and observed 80 and 40% virus inhibition in 0.5 mg/mL (Roy *et al*., 2015).

Antiparasitic properties

T. ammi and its chemical substituents thymol, and carvacrol showed various, anti filarial, nematicidal, insecticidal and larvicidal activities. *In-vitro* and *in-vivo* studies of *T. ammi* fruit extract showed anti-filarial actions. The components thymol and carvacrol showed macro-filaricidal effects against adult bovine filarial worm *S. digitata* under *in-vitro* studies. In addition, the plant increased mortality and infertility of female worms of human filarial worm *Brugia malayi* under *in-vivo* studies (Mathew *et al*., 2008). *In-vitro* antimalarial activity of ethyl acetate extract of *T. ammi* seed with values of 25 μg/mL were also reported against *Plasmodium falciparum* (causing agent of malaria) protozoans (Kamaraj *et al*., 2012). *T. ammi* (hydroalcoholic extract) showed anti-leishmaniasis activity with IC_{50} of 15.625 μM which was less than IC_{50} for macrophage cell line (43.76 μM) (Kheiri manjili *et al*., 2012). The anthelmintic effect of *T. ammi* on sheep infected with mixed nematode was also studied and showed *T. ammi* powder resulted in a dose-dependent reduction in eggs per gram of feces more potent than levamisole (an anti-helminthic and immunomodulator drug) (Ribero *et al*., 2011). *T. ammi* also showed anti-helminthic activity against specific helminth *Haemonchus contortus* in sheep and *Ascaris lumbricoides* in humans (Jabbar *et al*., 2006). *T. ammi* also has a significant role in the removal of hydatid cysts and parasitic diseases (especially in dirty and unsanitary areas) *in-vitro* (Moazeni *et al*., 2012). *T. ammi* oil (thymol and carvacrol) has a significant effect on nematodes. Its effect was also studied on *B. xylophilus* (pinewood nematodes) under *in-vitro* conditions (Park *et al*., 2007). Ajwain has also been exhibited as a crude drug to enhance the body's resistance and is prescribed for amebiasis in the Unani system. Apart from these *T. ammi* extract has effects on adult male and female German cockroaches by inhibition of acetylcholine esterase (AChE). In addition, *T. ammi* oil, 0.1 mg/mL, caused 100% larval mortality against *Aedes aegypti* mosquito larvae and can be used as a botanical insecticide (Yeom *et al*., 2012; Seo *et al*., 2012). Larvicidal effects of *T. ammi* oils were also studied against *Anopheles stephensi* (Torabi-Pour *et al*., 2017).

Antiplatelet aggregation properties

The antiplatelet aggregatory property was monitored using blood from human volunteers, with dried ethereal extract of *T. ammi* seeds under *in-vitro conditions*, suppressed aggregation of platelets induced by arachidonic acid, collagen and epinephrine (Srivastava, 1988).

Anti-inflammatory properties

The anti-inflammatory property of *T. ammi* seeds was investigated using total alcoholic extract and total aqueous extract, which showed anti-inflammatory

activity in the rat model. The weights of the adrenal glands were found to be significantly increased in both extract-treated animals. In conclusion, both alcoholic and aqueous extracts showed vital anti-inflammatory potential (Mathew *et al*., 2008; Thangam & Dhananjayan, 2003).

Antioxidant properties

T. ammi methanol extract possesses strong antioxidant activity against DPPH and could be used as a natural antioxidant in food, pharmaceutical and other industries (Aftab and Usmanghani, 1995). The *T. ammi* oil, with thymol as its major constituent, showed significant radical scavenging activity & exhibited a major contribution to the antioxidant potential (Alma *et al*., 2003; Quiroga *et al*., 2015; Vitali *et al*., 2016).

Antitoxic effects

T. ammi seed extract has been reported to possess a destructive effect on aflatoxin produced by *Aspergillus flavus* and *A. parasiticus* and significantly reduced aflatoxin activities down to more than 65% (Velazhahan *et al*., 2010). The effect of *T. ammi* extract as an inhibitor of chromium toxicity has also been evaluated, as *T. ammi* extract can increase cell *via*bility and decrease DNA damage by reduction of caspase-3 and apoptosis, an increase of the mitochondrial membrane potential and reduction in reactive oxygen species (Deb *et al*., 2012). In a recent study, a plant extract of *T. ammi* (2 mg/mL) completely stopped the production of aflatoxin B1, without inducing significant changes in *A. flavus* growth (Safari *et al*., 2020).

Abortifacient and galactagogue properties

According to a survey conducted in 1987, it was recognized that the *T. ammi* seed was used for abortion in a few cities of India, especially in the metropolis Lucknow. In 50 of 75 pregnant women who were surveyed (of a total of 155 women in the fertile period) claimed to have used *T. ammi* seed for abortion. From the survey, it was clear that the herb was not good and there was a risk of potential human fetotoxicity of ten plants, including *T. ammi*, based on teratogenicity observed in rat fetuses (Nath *et al*., 1997). The National Dairy Research Institute in India (NDRI) investigated the estrogenic content of some herbs (including *T. ammi*) that are used to increase milk yield in dairy cattle. *T. ammi* has also been traditionally used as a galactagogue in humans (Kaur, 1998).

Table 2: Commercial formulations with *T. ammi* for various indications

S. No.	*Formulation*	*Purpose*	*Company*	*Ingredients*
1.	Bonnispaz Drops	It supports healthy digestion and helps relieve discomfort in kids	Himalaya	Bishop's Weed, Caraway and Ginger
2.	Vansaar Gut Relief	Effective relief from constipation. Natural stool softener	Baidyanath	Isabgol, Senna leaves, Ajwain, Choti Harre, Amaltas, Mulethi & Sonth.
3.	Zandu Pancharishta Sugar Free Tonic	It increases digestive capabilities and avoids repetitive stomach disorders like acidity, gas, indigestion, bloating and constipation.	Zandu	Lavang, Ajwain, Triphala and Draksha
4.	Pancharishta Good Gut Detox Shots	Reduces acidity Improve digestion Relieves gas Helps with constipation	Zandu	Draksha, Ghritkumari, Ajwain, Triphala and Laung.
5.	Dabur Hingoli	Stimulates digestive power	Dabur	Nimbu satva (lemon extract), ajwain satva (carom seeds), and suddha hingu (asafoetida),
6.	Dabur Janma Ghunti	It is effective in treating constipation, indigestion, diarrhea, flatulence, and vomiting.	Dabur	Anjeer, Draksha/Kishmish, Ajwain, Palas Beej & Bidang, Vach, Amaltas, Sanai, Saunf, Unnab & Gulab Jal.
7.	Dabur Aampachak kadha	Digestive issues like indigestion, bloating,	Dabur	Jeerak,Shunthi,Bhumiamla Harad,Pippali,Ajwain
8.	Dabur Nature Care Kabz Over	It helps to maintain gastrointestinal health. Used to treat acidity and flatulence	Dabur	Senna, Lavan Kala, Saunf, Ajwain, Haritaki, Sendha Namak, Sunthi, Castor Oil.
9.	Jawarish Zaruni	It strengthens kidneys, bladder, intestines, liver and brain. It helps to treat polyuria, headache, productive cough and gout.	Hamdard	Ajwain, celery seed, dodder seed, caroot seed, melen Kernel, cucumber Kernel, Cinnamom
10.	Ajwain Natural Honey	Proper functioning of digestive system and also helps in reducing weight. Provides energy and strengthens immunity.	Super Bee	Ajwain

Spermicidal activity

Spermicidal properties of *T. ammi* oil were determined *via* an *in-vitro* study, where it was observed that the volatile oil possessed potent spermicidal action (Buch *et al*., 1988).

It was supposed that the oil may be used as a natural contraceptive agent. Another *in-vitro* study of *T. ammi* oil to determine the spermicidal and contraceptive efficacy on human sperm and found that 125 µg/mL minimum effective dose (MED) of oil-induced instant immobilization of human spermatozoa irreversibly. The study indicates that the essential oil of *T. ammi* possesses spermicidal properties, which may be explored as an effective constituent of vaginal contraceptives (Paul and Kang, 2011). In a very recent study, the effects of oil from Iranian *T. ammi* plants were evaluated on the *via*bility of spermatogonial stem cells under *in-vitro* & it found that *T. ammi* oil can be a promising agent in the conservation of fertility in patients who suffer from malignancies. Further *in-vivo* and trial studies are recommended concerning the protective properties of the plant (Omidpanah *et al*., 2020).

Digestive stimulant and gastro-protective property

The digestive stimulant property of *T. ammi* has been recommended traditionally, and now it is proved that ajwain has properties to increase the secretion of bile acids, gastric acid, and the activity of digestive enzymes. It can also reduce the transit time of food in the digestive system and increase the effectiveness of pancreatic lipase and amylases, which may support the digestive stimulant activity (Vasudevan *et al*., 2000; Platel & Srinivasan, 2001; Ramakrishna Rao *et al*., 2003).

Its traditional remedy may also be used in abdominal pain, respiratory and digestive infections and in other treatments (Platel & Srinivasan, 2001; Ramaswamy *et al*., 2010). The alcoholic extract of *T. ammi* seed showed a significant reduction in an animal model of gastric ulcer (Ramaswamy *et al*., 2010). Aqueous extract of *T. ammi* seed is also helpful in the improvement of peptic ulcers induced by ibuprofen in rats. The antiulcer property of *T. ammi* seed extracts is possibly due to their antioxidant properties (Komeili *et al*., 2012).

Oral administration of *T. ammi* was reported to be helpful in paracetamol (1-gm/kg) lethal dose and CCL_4 mediated liver injury by reducing liver enzymes alkaline phosphatase, ALP and aminotransferases (ALT and AST) (Gilani *et al*., 2005).

Analgesic and neural effects

Pain is a universal problem and complaint that needs a pain-relieving agent. *T. ammi* has been studied as a usual medicine for alleviating rheumatic joint pain, headache, and neuralgic pain. The analgesic effect of ethanolic extract of *T. ammi* is comparable with morphine. This effect is suggested to be because of its para-sympathomimetic through downward pain modulating trials (Hejazian, 2006; Dashti-Rahmatabadi *et al*., 2007). The analgesic effect of *T. ammi* essential oil *via* formalin test was also studied and found that essential oil affected the late phase of pain by formalin compared to morphine. The mechanism of this effect of the plant was not due to opioid receptors because it was not reversed by naloxone (Ghannadi *et al*., 2012).

A study on morphine withdrawal syndrome in mice showed that *T. ammi* leads to the suppression of morphine withdrawal. It was suggested that this effect was modulated *via* potentiation of GABA neurotransmission and suppression of glutamate receptors and nitric oxide pathway (Gilani *et al*., 2005). In another randomized controlled placebo control clinical trial, the herb essential oil was studied for the analgesic effect on neuropathic foot burn and revealed that ajwain essential oil significantly reduced the foot burn compared to placebo (Petramfar *et al*., 2013).

Antiepileptic effect

Epileptic disorder is an important healthcare issue. Approximately 0.5 to 1% of the world's population is suffering from epilepsy, and this is the second most common neurological disorder after stroke (Shorvon, 1990). The methanolic extract of *T. ammi* was studied as an antiepileptic agent (Perez-Saad & Buznego, 2008; Rajput *et al*., 2013). Tests were conducted with single- and multiple-dosing schedules of *T. ammi*, using a strychnine-induced seizure model for epilepsy in experimental animals. An animal study (*T. ammi* extract) showed antiepileptic effects and with several other studies, concluded that *T. ammi* possesses an antiepileptic effect similar to diazepam. However, further studies are required to understand the exact mechanism of action (CH & Patil, 2018).

Antitussive and bronchodilatory effects

The antitussive effect of aqueous and macerated extracts of ajwain seeds, as well as carvacrol, codeine, and saline, were evaluated by counting the number of coughs produced and found a significant reduction of cough numbers due to its antitussive properties. In another study, respiratory and bronchodilatory effects of different fractions of ajwain were studied, and found that the relaxant and bronchodilatory effects were observed. This may be due to the amount of carvacrol (Boskabady *et al*., 2003).

The bronchodilatory effect of decocted extract (0.125 and 0.25 mL/kg of 10 g%) of ajwain was also studied on asthmatic patients and found that the extract displayed a relatively bronchodilatory effect on asthmatic airways compared to the effect of theophylline drug 6 mg/kg concentrations (Boskabady *et al*., 2007).

Anti-hyperlipidemic properties

Ajwain also possesses anti-hyperlipidemic properties. Ajwain seeds powder is very effective on lipid profile and able to decrease total cholesterol, LDL-cholesterol, triglycerides and total lipids. Organic extract of seeds reduced the atherogenic index and increased the level of HDL-cholesterol in albino rabbits (Javed *et al*., 2006).

Antihypertensive and antispasmodic property

Antihypertensive and antispasmodic activity of *T. ammi* methanolic and aqueous extract of seed was studied to rationalize the traditional hypothesis and found that the extract causes dose-dependent downregulation of blood pressure and inhibits the bronchoconstriction (Thangam & Dhananjayan, 2003). *In-vivo* study was also performed to evaluate the antihypertensive effect of *T. ammi* administered intravenously. *In-vitro* study of antispasmodic effect was also studied to promote the antihypertensive and antispasmodic properties of *T. ammi* (Gilani *et al*., 2005).

The *T. ammi* extract administered intra-veins were found to cause a portion-dependent hypertensive outcome. Acetylcholine additionally caused a hypotensive impact at 1-µg/kg equal in level to the impact of *T. ammi* removed at 30.0 mg/kg (Dashti-Rahmatabadi *et al*., 2007).

Ameliorative effect

The effect of *T. ammi* extract was studied on hexachlorocyclohexane-induced oxidative stress and toxicity in rats was monitored. Ajwain extract-fed rats showed increased GSH, GSH peroxidase, G-6-PDH, SOD, catalase, and glutathione S-transferase (GST) activities, whereas hepatic levels of lipid peroxides decreased. In conclusion, hexachlorocyclohexane administration causes hepatic free radical stress, resulting in toxicity, which could be reduced by the dietary intake of *T. ammi* extract (Anilakumar *et al*., 2009).

Estrogenic activity

The phytoestrogen content of dry ajwain seed was evaluated and found 473 ppm and *T. ammi* herb contains the second highest in the list of plants tested for total phytoestrogen content. Since traditional times, it is noted that the herb has been employed for the treatment of different ailments (Kaur, 1998).

Conclusion

T. ammi (Ajwain) has emerged as a significant medicinal herb with profound preventive and curative effects on human health. Its rich phytochemical profile, dominated by thymol, carvacrol, p-cymene, and γ-terpinene, underpins its broad-spectrum pharmacological properties. Preventively, ajwain offers potent antioxidant and antimicrobial activities, enhances gastrointestinal health, and provides respiratory relief, positioning it as a natural shield against oxidative stress, infections, and digestive disorders. Curatively, its applications extend to treating menstrual cramps, acid reflux, bloating, coughs, colds, and various skin conditions, making it invaluable in traditional and contemporary medicine.

Despite its extensive therapeutic benefits, caution is advised in its use. Excessive consumption of ajwain can stimulate uterine contractions, posing risks during pregnancy, and may cause skin irritation or allergic reactions in sensitive individuals. Thus, regulated use and further clinical validation are essential to maximize its potential while ensuring safety.

The findings of this review emphasize the integration of ajwain into evidence-based healthcare frameworks and encourage further exploration of its phytoconstituents for future therapeutic innovations.

Future Directions

Scientific studies always have a scope of increasing the knowledge base and thus, there are some gaps that can be addressed by future researchers, which have been mentioned below:

Clinical validation

Conduct rigorous clinical trials to establish the safety, efficacy, and therapeutic dosages of *T. ammi* for diverse health applications.

Formulation development

Develop standardized formulations integrating ajwain's bioactive compounds for preventive and curative healthcare, including pharmaceutical and nutraceutical products.

Molecular mechanism studies

Explore the molecular pathways underlying its pharmacological properties to facilitate targeted drug development.

Biotechnological advances

Employ biotechnological tools to enhance the yield and quality of its essential oils and active phytochemicals.

Global integration

Promote the integration of ajwain-based remedies into modern healthcare systems, emphasizing sustainable cultivation and conservation of its genetic resources.

Toxicological studies

Undertake comprehensive toxicological assessments to mitigate risks associated with long-term or excessive usage.

Author Contributions

The first author drafted the manuscript based on the literature survey done by the corresponding as well as first author. The corresponding author made the final draft before communication.

Conflict of Interest

The authors have no conflict of interest except the fact that the first author is working on the plant for her doctoral degree.

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