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Pharmacognosy and phytochemistry of coriander (*Coriandrum sativum* L.)

S.N. Saxena* and Dolly Agarwal

ICAR-National Research Centre on Seed Spices, Tabiji, Ajmer, India

Abstract

Coriander (*Coriandrum sativum* L.) is an important seed spice crop grown extensively in India and Indian sub continent for its pleasant herbal aroma and used in traditional Asian cuisine. Apart from its culinary use it has significant medicinal qualities whether used as leaves or intact seeds in ground form. Various literatures are available for its uses. Many studies conducted to signify coriander uses as medicinal crop. In present review such work based on authentic scientific background were collected and discussed for adoption of this crop as a potential source of high value phytochemicals.

Key words : Coriander (*Coriandrum sativum* L.), medicinal qualities, phytochemicals, therapeutic food, volatile compounds

Spices have been known for ages as effective therapeutic food. The power of spices to impart biological activity is slowly emerging as an area of interest for human health. The seed spices constitute an important group of agricultural commodities and play a significant role in our national economy. Historically, India has been recognized as the land of spices. The states, Rajasthan and Gujarat have together contributed more than 80 per cent of the total seed spices production in the country. Coriander (*Coriandrum sativum* L.) is one of the important seed spices among many others grown in India. It is also commonly grown in Pakistan, Bangladesh, Russia, Central Europe, Morocco, and China. It is an annual herb in the family *Apiaceae* also known as Chinese parsley or, particularly in the America, cilantro. Coriander is native to southern Europe and North Africa to south-western Asia. It is a soft, hairless plant growing to 50 - 100cm tall. The leaves are variable in shape, broadly lobed at the base of the plant, and slender and feathery higher on the flowering stems. The flowers are borne in small umbels, white or very pale pink, asymmetrical. Coriander is an important spice crop having a prime position in flavouring food. The whole plant has a pleasant aroma. Inflorescence is a compound umbel comprises 5 smaller umbels. Fruit is globular, 3 to 4mm diameter. Seeds have delicate fragrance and pale white to light brown in colour.

Coriander seed oil is an aromatic stimulant, a carminative (remedial in flatulence), an appetizer and a digestant stimulating the stomach and intestines. It is generally beneficial to the nervous system. Its main use is in masking foul medicines, especially purgatives, where it has anti-griping qualities. In Asia, the herb is used against piles, headache and swellings and the fruit in colic, piles and conjunctivitis. The essential oil is used in colic, rheumatism and neuralgia. The seeds are being used as a paste for mouth ulceration and a poultice for other ulcers. Recent studies have supported its use as a stomach soother for both adults and colicky babies. Coriander contains an antioxidant that helps prevent animal fats from turning rancid. It also contains substances that kill meat-spoiling bacteria and fungi. These same substances in Cilantro also prevent infection in wounds. Coriander has been shown to improve tummy troubles of all kinds, from indigestion to flatulence to diarrhoea. Weak coriander tea may be given to children under age 2 for colic. It's safe for infants and may relieve their pain and help you get some much-needed sleep. Cilantro and Coriander contain substances that kill certain bacteria and fungi, thereby preventing infections from developing in wounds. Sprinkle some coriander Seed on minor cuts and scrapes after thoroughly washing the injured area with soap and water. Intriguing new studies suggest that coriander has anti-inflammatory effects. Since the pain of arthritis is cause by inflammation coriander oil may help you (http://www.pharmatips.in/Articles/Pharmacognosy/Herbal-Drug/Coriander-Pharmacognosy-Medicinal-Uses.aspx).

There exist very different uses of coriander and these are based on different plant parts. The traditional uses of the plant, which are based on the primary products, i.e. the fruits and the green herb, are two-fold: medicinal and

*Corresponding author email: shail.nrcss@gmail.com

culinary. During industrialization, the specific chemical compounds of coriander were recognized and identified, and these became important as raw materials for industrial use and further processing. The essential and fatty oils of the fruits are both used in industry, either separately or combined. After extraction of the essential oil, the fatty oil is obtained from the extraction residues either by pressing or by extraction.

In present review scientific studies conducted by various researchers have been compiled which describe the pharmacognosy and phytochemistry of coriander (*Coriandrum sativum* L.). The work done on phytochemical analysis and medicinal properties of coriander genotypes in author's laboratory was also included in this review. The most important bio molecules including phenolics flavonoids antioxidant compounds, essential oil and the fatty oil were analyzed in different studies.

Volatile oil and Fatty Acid Methyle Esters (FAME)

Coriander seeds, leaves and stem are praised for sweet and pleasant aroma due to the presence of volatile essential oil. The essential oil and fatty oil content of ripe and dried fruits of coriander vary between 0.01 and 2.6% (Saxena *et al.*, 2016; Singh *et al.*, 2006) and 6.0 and 22.53% (Annonymous 2017) respectively. Many researchers analyzed seeds, leaves, stem and roots of coriander for presence of essential and total oil content. Ramdan and Morsal, 2002 reported as high as 28.4% fatty oil in coriander fruits from Germany while Tunisia and Indian coriander showed fatty oil up to 23% (Sirti *et al.*, 2011 and Annonymous 2017) . Major constituents of these oils were also analyzed using GC-MS technique. Ramadan and Morsel (2002) extracted coriander (*Coriandrum sativum* L.) seeds with chloroform/methanol (2:1, v/v) and found the amount of total lipid was 28.4% of seed weight. The major fatty acid was petroselinic acid (65.7% of the total fatty acid methyl esters) followed by linoleic acid. Chromatography on a silica column with solvent of increasing polarity yielded 93.0% neutral lipids, 4.14% glycolipids, and 1.57% phospholipids.

Singh *et al.,* (2006) analyzed the seed essential oil of coriander (*Coriandrum sativum*) showed the presence of 52 components, accounting for 98.45% of the total oil. The major components were linalool (75.30%), geranyl acetate (8.12%) and α-pinene (4.09%). Its oleoresin showed the presence of 28 components. Oleic acid (36.52%), linoleic acid (33.2%) and palmitic acid (11.05%) were the major components. Effect of developmental stages on essential oil composition of coriander (*Coriandrum sativum* L.) was analyzed by Pande *et al.,* (2010) after extracting oil from fruits at three stages of maturity by hydro distillation. Essential oil yields showed marked increase during maturation process and forty one compounds were identified. Geranyl acetate (46.27%), linalool (10.96%), nerol (1.53%) and neral (1.42%) were the main compounds at the first stage of maturity (immature fruits). At the middle stage, linalool (76.33%), cis-dihydrocarvone (3.21%) and geranyl acetate (2.85%) were reported as the main constituents. Essential oils at the final stage of maturity (mature fruits) consist mainly linalool (87.54%) and cis-dihydrocarvone (2.36%).

Bhuiyan *et al.,* (2009) also analyzed essential oils from leaves and fruits of *Coriandrum sativum* L. by gas chromatography mass spectroscopy (GC-MS). The leaf oil contained 44 compounds mostly of aromatic acids containing 2-decenoic acid (30.8%), E-11-tetradecenoic acid (13.4%), capric acid (12.7%), undecyl alcohol (6.4%), tridecanoic acid (5.5%) and undecanoic acid (7.1%) as major constituents. The seed essential oil contains 53 compounds where the major compounds are linalool (37.7%), geranyl acetate (17.6%) and α-terpinene (14.4%). The compositions of both oils varied qualitatively and quantitatively. Linalool, as the major compound in the whole fruit, seed and pericarp was reported 86.1%, 91.1% and 24.6% respectively by Sriti *et al.,* (2009a, b). Fatty acid composition of pericarp and seed lipids was investigated by gas chromatography. Petroselinic acid was the main compound of fruit and seed, followed by linoleic and oleic acids. Palmitic and linoleic acids were estimated in higher amounts in pericarp lipids.

Later, Moser and Vaughn *et al.,* (2010) evaluated coriander (*Coriandrum sativum* L.) seed oil methyl esters as an alternative biodiesel fuel and contained an unusual fatty acid hitherto unreported as the principle component in biodiesel fuels: petroselinic (6Z-octadecenoic; 68.5 wt%) acid. Most of the remaining fatty acid profile consisted of common 18 carbon constituents such as linoleic (9Z, 12Z-octadeca-dienoic; 13.0 wt %), oleic (9Z-octadecenoic; 7.6 wt%) and stearic (octadecanoic; 3.1 wt%) acids.

Anwar *et al.,* (2011) described the physiochemical composition of the essential oil derived from the seeds of coriander (*Coriandrum sativum* L.) cultivated in Pakistan. Hydrodistilled essential oil content from coriander seeds was found to be 0.15%. A total of 48 chemicals constituents representing 90% of the essential oil tested were identified using GC-FID and GC-MS. Linalool with contribution of 69.60% was found to be the principal constituent. Other important components identified were: geranyl acetate (4.99%), γ -terpinene (4.17%), α-pinene (1.63%), anethol (1.15%) and p-cymene (1.12%). The analyzed essential oil mainly comprised of oxygenated monoterpene hydrocarbons (80.83%), followed by monoterpene hydrocarbons (8.00%), sesquiterpene hydrocarbons (0.47%) and oxygenated sesquiterpene hydrocarbons (0.35%). Overall, the physicochemical attributes and chemical profile of the tested essential oil from Pakistan were reasonably comparable with those investigated for coriander seed essential oils from other regions of the world suggesting its potential for functional foods and cosmetics applications.

Coriander leaves are traditionally being used for garnishing the dishes with other herbs due to its sweet aromatic quality. In Indian subcontinent fine paste of coriander leaves with other spices is a very common recipe. In a study, Rathore *et al.,* (2015) extracted essential oil from leaves of three coriander genotypes namely ACr-1, Cor-50 and exotic cultivar and analyzed using GC-MS. Maximum essential oil in leaves was observed in Cor-50 (0.029%) followed by ACr 1(0.025 %) and exotic cultivar (0.023 %). Essetial oil constituents were differing with that of seed essential oil. Major constituents present in three genotypes were trepine-4-ol, carvone and geraniol, while minor constituents were α-pinene, β-pinene, myrcene, γ- terpinene, cymol, limonene, fenchon, linalool, camphor, anethole, eugenol, and geranyl acetate. In ACr 1, major constituent was geraniol (21.36 %) while in Cor-50 geraniol was only 10.14% and it was absent in exotic cultivar. In exotic genotype carvone was the major constituent (17.79%).

While analyzing effect of cryogenic grinding on essential, total oil and phenolic compounds of nine prominent coriander varieties, Saxena *et al.*, (2015) reported variation in essential oil content from 0.14% in genotypes RCr 436 and RCr 435 to a maximum of 0.39% in genotype Sindhu. Similarly, seed oleoresin content was ranging from a minimum of 5.39% in Swati genotype to a maximum of 15.53% in Sindhu genotype. Also, the essential oil of these genotypes evaluated for its constituents by Saxena *et al.*, (2014) and found linalool as main constituent in all the samples, the content of which ranging from 73.49% in genotype Swati to 87.69% in genotype RCr 436. α-Pinene and geranyl acetate were another constituent showed large variation. Genotypes from North Indian origin like ACr 1, RCr 41, Rcr 435 and RCr 436 showed less variation in geranyl acetate content as compare to the genotypes, Sindhu, Sadhna and Swati of South Indian origin. Later, in an elaborative analysis Saxena *et al.*, (2016) evaluated 140 coriander germplasm for essential oil constituents and grouped the germplasm as per major essential oil constituents. Essential oil content was ranging from 0.01to 0.2% while fatty oil content was found in the range of 6.0 to 22.53. Major constituent of essential oil was linalool present from a minimum of 16.60 to maximum 96.70.

In a recent report Agarwal (2017) analyzed essential oil and fatty oil content of five popular coriander genotypes. Twenty five compounds belongs to the group of the terpenic hydrocarbons, alcohol, aldehyde, ether and ester were identified in the essential oil from coriander seeds. Major compounds identified were Linalool which was found maximum (79.52%) in genotype Azad Dhania-1. Maximum α-pinene in genotype RCr-436 (13.627%), γ-terpinene in genotype ACr-1 (7.277%) and Geranyl acetate was found maximum (19.81%) in genotype Hisar Sughandha. In case of coriander leaf fifteen compounds were identified. Major compounds identified were 6-methyl-1, 5-heptadiene was found maximum (38.236%) in genotype GCr-1, 4-methyl-1, 5 heptadiene in genotype Hisar Sughandha (49.207%), Geraniol in genotype ACr-1(19.76%) and linalool in genotype ACr-1 (4.306%). Sixty two compounds were identified in oleoresin of coriander. Major compounds were 6-octadecenoic acid (Elaidic acid) which was maximum (88.23%) in GCr-1, 9,12-octadecadienoic acid (linolenic acid) (11.922%) in genotype Azad Dhania-1 and Hexadecanoic acid (palmitic acid) was found maximum (6.328%) in genotype Hisar Sughandha (Agarwal 2017).

The studies conducted by various researchers showed variation in essential and total oil constituents with similar composition. Coriander grown at higher altitude such as USSR showed very high volatile oil content as compare to the coriander grown in plains and lower altitudes Weiss E.A. (2002). The essential oil content of coriander fruits varies from very low (0.03%) to a maximum report of 2.7% (Purseglove *et al.*, 1981; Bandara *et al.*, 2000). Dobos and Novak (2005) reported a range of variation of oil content between 0.2 and 1.3% among 36 different coriander accessions from Austria. It is well documented that genetic constitution and environmental condition influence the yield and composition of volatile oil produced by medicinal plants (Omidbaigi, 2007; Ramezani *et al.*, 2009).

Medicinal and Pharmacological Properties of coriander

Coriander has been used in medicine for thousands of years (Mathias 1994). The first medicinal uses of the plant were reported by the ancient Egyptians. General references to coriander's medical uses are also found in classical Greek and Latin literature (Manniche 1989). Coriander seeds have a health-supporting reputation that is high on the list of the healing spices. In parts of Europe, coriander has traditionally been referred to as an "anti-diabetic" plant. In some parts of India, it has traditionally been used for its anti-inflammatory properties. Coriander has recently been studied for its cholesterol lowering effects (Massada *et al.*, 2007; Rathore *et al.*, 2013). Sahib *et al.*, (2013) published a review to signify the coriander (*Coriandrum sativum* L.) as a potential source of high-value compounds for functional foods and nutraceuticals. They advocated further research on its medicinal use as carminative, prokinetic and antiulcer activities to be carried out. In preceding paragraphs studies made to establish the coriander (*Coriandrum sativum* L.) as a potential natural source of medicinally important compounds have been compiled.

Phenol, flavonoid and antioxidant properties

Naturally occurring antioxidants are always preferred over synthetic antioxidants keeping the safety issue in mind. Thus, effort is being made to search for natural anti-oxidant (Reische *et al.*, 2002). Plants bioactives including polyphenos and flavonoids are of interest as potential therapeutic agents in the treatment of cancer and other chronic diseases due to their antioxidant and chelating activities. Administration of coriander seeds in rats diet along with other high fat content showed increased activity of antioxidant enzymes as well as decrease in peroxides levels, free FA and glutathione (Chithra and Leelamma, 1999). Wangensteen *et al.*, (2004) analyzed the anti-oxidant potential of seed and leaves extracts and oil of coriander in different polarity solvents. The study concluded that the coriander leave extracts showed stronger anti-oxidant activity as compared to the seed extract. In other related study Wong and Kitts, (2006) assessed antioxidant potential of aqueous and methanolic extracts of coriander leave and stem and found leaf extract being more active in scavenging free radicals. Sriti *et al.,* (2011) examined the essential oil composition, phenolic contents and antioxidant activity of the essential oils and methanol extracts from two coriander fruit samples from Tunisia (*Tn*) and Canada (*Can*). The total phenol content was more in *Can* sample (15.16 mg GAE g^{-1}) compared with *Tn* (12.10 mg GAE g^{-1}). At the same time Deepa and Anuradha (2011) studied antioxidant and free-radical scavenging property of coriander seeds and also investigated whether the administration of seeds curtails oxidative stress in the kidney of *streptozotocin*-induced diabetic rats. Incorporation of seed powder in the diet led to marked lowering of blood glucose and a rise in the levels of insulin in diabetic rats. A parallel beneficial effect was observed on oxidant-antioxidant balance in the kidney. Addition of coriander seed powder not only inhibited the process of peroxidative damage but also significantly reactivated the antioxidant enzymes and antioxidant levels in diabetic rats. The total polyphenolic content of the seeds was found to be 12.2 Gallic Acid Equivalents (GAE) g^{-1} while total flavonoid content was found to be 12.6 quercetin equivalents g^{-1}. The seeds also showed scavenging activity against superoxide and hydroxyl radicals in a concentration-dependent manner. Maximum free radical scavenging action and free radical reducing power of coriander seed extract was observed at a concentration of 50 µg GAE. In an another study.

Al-Juhaimi and Ghafoor (2011) used leaves and stems of three different herbs from two different families to extract phenolic compounds and the bioactivity of the extracts was evaluated by using 1, 1-diphenyl-2-picrylhydrazyl (DPPH) scavenging ability. Extract from leaves of mint, which belongs to *Lamiaceae* family contained more phenolic compounds and antioxidant activity than extracts from coriander and parsley, both of which belong to *Apiaceae* family. Extracts of leaves from these herbs showed more quantity of total phenols and higher antioxidant activities than extracts from stem parts, however both leaves and stems of these three herbs grown in Saudi Arabia contained good quantities of total phenols (>1.02 mgGAE/100 mL) and showed more than 18.3% free radical scavenging activity. In a recent report Saxena *et al.,* (2016) evaluated total phenolic, flavonoid content and antioxidant activity of crude extract of seeds, roots, stem and leaves of coriander plant. Maximum phenolic content was observed in distilled water extract of fresh and dried roots followed by methanol extract. Ethyl acetate extract showed more phenolics in dried stem and leaves as compared to green stem and leaves. Distribution of flavonoids content in different green as well as dried plant parts and different solvents showed less variation in phenolic and flavonoid contents. DPPH scavenging as a measure of antioxidant capacity was more in distilled water extract of green stem (94.49%) followed by methanol crude extract (76.256%) and ethyl acetate extract (59.706%).

Agarwal (2017), one of the authors of this review carried out detailed analysis of phenolic, flavonoid content and antioxidant properties of leaves and seed extracts of five popular varieties grown in India. Crude extract was prepared in four solvents of different polarity. Hexane seed extract of ACr-1 showed seed maximum total phenol content(7.15 mg GAE g^{-1}) while total flavonoid content was maximum (2.08 mg QE gm^{-1}) in hexane extract of GCr-1. Aqueous extract of seeds of genotype Azad Dhania-1 showed maximum antioxidant content (0.57 mg BHTE gm^{-1} seed). DPPH Scavenging percentage was also maximum in D/W extract of Azad Dhania-1. In case of leaf extract maximum (10.08 mg GAE gm^{-1} leaf) total phenolic content was found in DMSO extract of genotype Hisar Sughandha while total flavonoid content was maximum (65.5 mg QE gm^{-1} leaf) in Hexane extract of GCr-1 which also showed maximum antioxidant activity in DMSO extract along with genotype RCr-436. However DPPH Scavenging percentage was maximum in DMSO extract of ACr-1 (91.54%) (Agarwal *et al.*, 2016).

The effect of polyphenolic extract of coriander seeds was assessed on hydrogen peroxide (H_2O_2)-induced oxidative stress in human lymphocytes by Hashim *et al.*, (2005). Treatment with polyphenolic fractions of coriander seeds (50 mg mL^{-1}) effectively protected human lymphocytes from H_2O_2-induced oxidative stress and restored oxidative stress to that of normal cells.

The anti-oxidant activity of leaves and shoot extract of coriander has been attributed to its high phenolic content. The principal phenolic anti-oxidants identified includes, caffeic acid, protocathenic acid and glycitin (Melo, 2002; Melo *et al.*, 2005). The protective effect of aqueous suspension of coriander seeds against ulcers was attributed to the free radical scavenging capacity of anti-oxidants in the seeds and the hydrophobic interactions of anti-oxidant compounds to form protective layers (Al-Mofleh *et al*., 2006). However, in a study essential oil from coriander seeds showed pro-oxidant activity both *in vitro* and *in vivo* (Samojlik *et al.*, 2010). Similar to this in a previous study Wangensteen *et al*., (2004) also reported that coriander oil and lipophilic extracts failed to showed anti-oxidant properties *in vivo* study. This necessitate more precise studies under *in vivo* conditions. The studies conducted by Ramadan *et al.*, (2003) and Ramadan and Wahdan (2012) explored the possibility of blending coriander seed oil with other non traditional edible oils such as corn oil. Their findings based on functionality, stability and radical scavenging activity of the oil blends (10-20% coriander oil) showed enhanced oxidative stability and DPPH free radical scavenging capacity as compared to corn oil alone. This increased oxidative stability may be due to the presence of desirable fatty acids profile and other antioxidants such as tocopherols in coriander oil. Similar effect was also observed in blended sunflower oil (Ramadan, 2013). In a study conducted by Saxena *et al.*, (2015) on cryogenic grinding technology of spices is helpful in retention of flavour and medicinal properties of coriander irrespective of genotypes from diverse origin showed significantly increase in oleoresin content, total phenolic contents, flavonoids and antioxidant properties.

Antibacterial and antifungal properties

Coriander essential oils from commercial samples showed antibacterial, antifungal and antioxidant activities and showed a high degree of inhibition against twenty-five genera of bacteria and one fungal species *Aspergillus niger* (Baratta *et al.*, 1998a, 1998b).

Hassanen *et al.,* (2015) investigated the essential oil constituents, antioxidant and antimicrobial activity of celery (*Apium graveolens*) and coriander (*Coriandrum sativum*) herb and their seeds and advocated the use of these essential oils as natural antimicrobial and antioxidant in industrial food and drugs. Limonene was major constituent in celery herb and seed essential oil while it was linalool in case of coriander seed essential oil. Essential oils from celery and coriander showed significant antioxidant activity whether used individually or mixed. The antimicrobial effects of celery, coriander herb and seeds essential oils at concentrations of 0.3, 0.6, 0.9, 10, 50 and 100% were determined in comparison with phenol, at concentration of 1.0 and 10%, against five bacterial strains, two yeast strains and five mold strains. The inhibitory effect of the four essential oils was ranked coriander seed > coriander herb > celery seed > celery herb essential oils.

Several researchers evaluated antibacterial and antifungal activities of coriander seed extract. Cao *et al.,* (2012) extracted freeze-dried coriander by petroleum ether, 95% ethanol, and water, respectively. Antibacterial experiment indicated that only water extract presented significant antimicrobial activity and the minimum inhibition concentration (MIC) was below 10% of original extract. The inhibition effect of coriander extracts on microorganisms and the effects of pH, temperature and NaCl concentration on its antimicrobial activities were also evaluated. The results showed that antibacterial activity of coriander extracts was stable under heating and had the best antibacterial effects at pH 6 with 2.0% NaCl concentration.

Ratha bai and Kanimozhi (2012) investigated the antimicrobial activity of Ethanol, Methanol, Acetone, Chloroform, Hexane and Petroleum ether extract of *Coriandrum sativum* against infectious disease caused by bacterial pathogens such as such as *E.Coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Klebsiella Pneumonia* fungus like *Aspergillus niger*, *Candida albicans*, *Candida kefyr* and *Candida tropicalis.* The Methanol extract showed more activity against *Staphylococcus aureus*, *Candida albicans* and *Aspergillus niger* as compared to other solvent extracts. The Methanolic extract of sun dried *Coriandrum sativum* showed better activity against the most tested organism**.** Earlier also Uma *et al.,* (2009) studied preliminary phytochemical and *in vitro* antimicrobial activity of *Coriander sativum* against some pathogens isolated from patients with infectious diarrhea. The various solvents extract like aqueous, methanol, chloroform, petroleum ether and hexane were screened for antimicrobial activity against *Enterotoxigenic E.coli, Enteropathogenic E.coli,, Salmonella typhimurium, Salmonella entertidis, Shigella dysentriae, Shigella flexineri, Candida albicans, Candida tropicalis* and *Candida krusei* isolated from diarrhoeal patients. The results revealed that methanol extract of the plant exhibit good activity compared to chloroform and aqueous extracts to E.coli, Salmonella sp and Shigella sp. The antimicrobial activities of extracts were compared with standard antibiotics.

Silva and Domingues (2017) reviewed medicinal properties of coriander and highlighted coriander oil antimicrobial activity and possible mechanisms of action in microbial cells and discusse the ability of coriander oil usage as a food preservative, pointing out possible paths towards a successful development of a food preservation strategy using coriander oil.

The antibacterial effects of coriander seed extracts were investigated by Agarwal (2017) using Agar Diffusion test (Mueller-Hinton test) on two species of gram-positive bacteria (*Staphylococcus aureus, Streptococcus pyogenes*) and two species of gram-negative bacteria (*Escherichia coli, Pseudomonas aeruginosa*). In this study, methanol extract of coriander genotypes displayed a variable degree of antibacterial activity on different bacterial strain. Hexane extract also showed anti bacterial effect on both Gram positive and Gram negative bacteria. Comparatively methanol extract showed high amount of anti-bacterial activity as compared to hexane.

Hypolipidemic activities

Hypolipidemic agents, are a diverse group of pharmaceuticals that are used in the treatment of high levels of fats (lipids), such as cholesterol, in the blood (hyperlipidemia). They are called lipid-lowering drugs. In ayurveda tradition of treatment, many botanicals have been used for this purpose such as haritaki (*Terminalia chebula*), Asoca (*Saraca asoca*) etc. Coriander is also possessing hypolipidemic properties which is evident by studies conducted by various researchers. Metabolism of lipids in rats fed a high fat diet with added cholesterol was studied by Chithra and Leelamma (1997). Coriander showed significant hypolipidemic action. The levels of total cholesterol and triglycerides decreased significantly in the tissues of the animals of the experimental group which received coriander seeds. The level of LDL + VLDL cholesterol decreased while that of HDL cholesterol increased in the experimental group compared to the control group. Similarly, Lal *et al.,* (2004) showed *C. Sativum* at a dose of 1 g kg^{-1} body weight reduced cholesterol and triglycerides levels in both synthesis and excretory phases in rats, and the results were comparable with that of Liponil, a commercially available herbal hypolipdemic drug. The results suggested that coriander decrease the uptake and enhances the breakdown of lipids. From the study it can be assumed that coriander has the potential to be popularized as a household herbal remedy with preventive and curative effect against hyperlipdemia.

As per Dhanapakiam *et al.,* (2008), *Coriandrum sativum* has been documented as a traditional treatment for cholesterol and diabetes patients. The seeds had a significant hypolipidemic action. In the experimental group of rats (tissue) the level of total cholesterol and triglycerides increased significantly. There was significant increase in b-hydroxy, b-methyl glutaryl CoA reductase and plasma lecithin cholesterol acyl transferase activity was noted in the experimental group. The level of low density lipoprotein (LDL) + very low density lipoprotein (VLDL) cholesterol decreased while that of high density lipoprotein (HDL) cholesterol increased in the experimental group compared to the control group.

Results of experiments conducted by El-Kherbawy *et al.,* (2011) indicated that adding parsley or coriander at 10, 15 and 20% showed significantly ($P<0.05$) lower body weights and feed efficiency ratios compared with the corresponding values of normal or hypercholesterolemic rats. Serum lipids (TC, TG, LDL-c, VLDL-c) and LDL/HDL of hypercholesterolemic rats fed on diets with either parsley or coriander were significantly lower ($P<0.05$) compared to their corresponding values of the positive control but higher than those of negative control. No significant differences were found among AST values of the other experimental groups. While, the Histopathological studies in rats fed on diets with either parsley or coriander exerted protective effects on liver.

Joshi *et al.,* (2012) also studied hypolipidemic and antioxidant action of *Coriandrum sativum* in cholesterol-fed rabbits. Cholesterol feeding (500 mg kg^{-1}.b.wt day^{-1}) for 120 days caused a significant increase in serum total cholesterol, phospholipid, triglyceride, and LDL-cholesterol and VLDL-cholesterol levels whereas HDL ratio was decreased significantly when compared with control group. Administration of coriander reduced serum lipid profile and elevated HDL ratio. *C. sativum* extract feeding increased the faecal excretion of cholesterol and phospholipids. The study exhibited that *C. sativum* is a potent hypolipidaemic agent.

Anfenan (2014) studied the effect of coriander and vitamin B_6 and their combination on the nutritional value, lipid parameters, liver function and antioxidant enzymes of rats suffering from hyperlipidemia. The results revealed that, all treated groups reduced serum cholesterol (CHO), triglycerides (TG), low density lipoprotein cholesterol (LDLc), very low density lipoprotein (VLDLc), liver function enzymes activity and liver cholesterol and also atherogenic indices, while increased in serum high density lipoprotein cholesterol (HDLc).

Antidiabetic properties

Early studies suggested that coriander has been advocated as an anti-diabetic remedy (Farnsworth & Segelman, 1971; Lewis & Elvin-Lewis, 1977). In countries like Saudi Arabia and Morocco, coriander seeds are still used as a medicine for hyperglycemia (Al Rowais, 2002; Tahraoui *et al.*, 2007). Early experiments involving administration of coriander fruit as a decoction did not reveal effects on fasting blood sugar levels of normal and alloxan diabetic rats, but demonstrated alleviation of adrenaline-induced hyperglycaemia (Sharaf *et al.*, 1963). Subsequent studies involving longer term administration of coriander seed in the diet showed that the plant purported as a traditional treatment for diabetes indeed decreased the hyperglycaemia of streptozotocin-diabetic mice (Swanston-Flatt *et al.*, 1990). Linalool, the major constituent of coriander essential oil is reported to have hypoglycemic effect in diabetic rats (Afifi *et al.,* 1998). Waheed *et al.,* (2006) also reported that *Coriandrum sativum* has significant hypoglycemic activity in high dose and can be successfully combined with oral hypoglycemic agents in type-2 diabetic patients whose diabetes is not controlled by these agents.

The study conducted by El-Soud et. al., (2007) confirmed anti-hyperglycaemic action where the elevated glucose level in streptozotocin induced diabetic rats returned to normal level after treatment with coriander oil. It was found that linalool reduced the plasma glucose level by increasing insulin levels. In addition, it was observed that linolool could promote glucose utilization by cells (Deepa and Anuradha, 2011). Gray and Flatt (1999) also found *Coriandrum sativum* as a traditional treatment of diabetes. When coriander incorporated into the diet (62×5 g kg^{-1}) and drinking water (2×5 g l^{-1}), prepared by 15 min decoction reduced hyperglycaemia of streptozotocin-diabetic mice. Sequential extraction with solvents revealed insulin-releasing activity in hexane and water fractions indicating a possible cumulative effect of more than one extract constituent. These results demonstrated the presence of antihyperglycaemic, insulin-releasing and insulin-like activity in *Coriandrum sativum*. A supplementation of 200 and 250 mg kg^{-1} of ethanolic extract of seeds caused a decrease in serum glucose concentration and increased activity of beta cells as compared to a diabetic control (Eidi *et al.*, 2009).

Naquvi *et al.,* (2012) studied antidiabetic activity of aqueous extract of *Coriandrum sativum* L., on streptozotocin induced diabetic rats. In doses of 250 mg kg^{-1} and 500 mg kg^{-1} the aqueous extract showed significant decrease in blood glucose level. It also decreased total cholesterol level and increased high density lipid cholesterol significantly.

Recently, Aissaoui *et al*., (2011) validated the medicinal use of coriander seeds in management of diabetes in Morocco. An aqueous extract of coriander seeds (20 mg kg^{-1}) was fed to obese-hyperglycemic-hyperlipidemic rats at a single dose in a sub-chronic study for 30 days. The results showed that the coriander extract suppressed hyperglycemia, with a normal blood glucose level reached after 4 h of dosing, with no effect on lipids. The sub-chronic supplementation of coriander extracts for 30 days reduced plasma glucose and was able to maintain normal glycemia as from day 21. Insulin, insulin resistance and lipid parameters including total cholesterol, low density lipoproteins (LDL)-cholesterol and triglycerides were reduced. In both the single dose experiment and sub-chronic study, the effect of coriander extract was found to be comparable to that of glibenclamide. The mechanism of the anti-hyperglycemic action was partly investigated by Chithra and Leelamma (1999). Pretreatment with coriander seed powder caused changes in carbohydrate metabolism; increased concentration and activity of hepatic glycogen and glycogen synthase were observed. Therefore, decreased glycogenolysis and gluconeogenesis and enhanced activities of glucose-6-phosphate dehydrogenase along with other glycolytic enzymes might all be an indication of the antihyperglycemic activity of coriander seeds. This supports the potential uses of coriander seeds for development of anti-diabetic functional foods and nutraceuticals.

Anti-inflammation

Due to ill effect of non-steroidal anti-inflammatory drugs causing gastrointestinal tract irritation (Graham *et al.*, 1988) and other toxicity, there is an increasing demand of plant origin natural and safer anti-inflammatory drug. The use of coriander as anti-inflammatory agent is evident by a traditional Ayurvedic formulation *Maharasnadhi Quather (MRQ),* containing coriander seeds as one of its principal component.

Ammar (1997) used several edible plants in traditional medicine for the treatment of inflammatory conditions. The anti-inflammatory activity of some bioactive fractions isolated from the seeds of *Trigonella foenum groecum* L., the roots of Glycyrrhiza glabra, L., and the fruits of

Coriandrum sativum L., were determined using the carragenan induced oedema method in comparison with two reference synthetic anti-inflammatory drugs. The petroleum ether and the aqueous methanolic extract of fenugreek and liquorice as well as the whole powdered fruit of coriander in a dose of 200 mg kg^{-1} exhibited a significant reduction in the volume of inflammation with variable degrees.

A poly-herbal formulation, consisting of coriander as one of the constituents, showed inhibitory effect against inflammatory bowel disease. The activity was comparable to that of prednisolone (Japtap *et al.*, 2004). Anti-inflammatory effect of coriander oil was also reported by Reuter *et al.*, (2008). Coriander oil showed mild anti-inflammatory effect with good skin tolerance at both concentrations. Neha Mohan (2013) investigated the anti-inflammatory activity of ethanolic extract of *Coriandrum sativum* L. using carrageenan induced paw edema in albino rats. The anti-inflammatory activity was more effective in rats of group with oral administration of *Coriandrum sativum* ethanolic leaf extract of 400mg kg^{-1} i.p as compared to Carrageenan subcutaneously induced along with the oral administration of *Coriandrum sativum* ethanolic leaf extract of 200mg kg^{-1} i.p. In other report Bhat *et al.,* (2014) evaluated the analgesic and anti-inflammatory activities of aqueous and ethanolic extracts of *Coriandrum sativum* seeds. Both the aqueous and ethanolic extracts of *C. sativum* seeds showed significant analgesic activity in acetic-acid induced writhing method and significant anti-inflammatory activity in Carrageenan-induced paw oedema while only the high-dose aqueous group exhibited significant results in Cotton-pellet granuloma model when compared to the respective control group. However, further evaluation is required for analysis of phytochemical constituents involved in these activities.

Analgesic and antipyretic activities of coriander seed extract may further be enhanced by cryogenic grinding technology. Saxena *et al.*, (2014) analyzed seed extracts of coriander genotypes RCr 436 and Sudha showed considerable analgesic and antipyretic activities. Results indicated that seed extract of cryo ground seeds of genotype RCr 436 was more effective than non cryo ground seeds. Seed extract of non cryo ground seeds of genotype RCr 436 when administered as drug was able to reduce the rectal temperature of albino mice by 0.330C after 5 hrs while seed extract of cryo ground seeds of genotype RCr 436 was able to reduce the rectal temperature up to 0.60C which was at par with paracetamol-150 where rectal temperature was reduced up to 0.850C after 5 hrs.

In a recent study by Agarwal (2017) analyzed five coriander genotypes for their anti-inflammatory properties on albino mice. Methanol and hexane extract of coriander seeds were prepared and tested two doses 200 and 200mg kg^{-1} i.p by oral administration. Results indicated that methanol and hexane extract of seeds of genotype Hisar Sughandh showed maximum anti-inflammation activity at par with standard drug in carrageenan induced paw edema in rats.

Hepatoprotective

In a elaborative study Pandey *et al.*, (2011) described the hepatoprotective activity of *C. sativum* against carbon tetrachloride (CCL4) intoxication *in vivo* with estimation of serum glutamyl oxaloacetic acid transaminase (SGOT), serum glutamyl pyruvate transaminase (SGPT), alkaine phosphatase (ALP) and bilirubin, and with liver histopathology. Ethanolic seed extract of coriander was found to contain good quantity of alkaloids, phenolic compounds and flavonoids. High performance liquid chromatography (HPLC) showed the presence of iso-quercetin and quercetin. Hepatoprotection property was signified by reducing the liver weight, activities of SGOT, SGPT, and ALP, and direct bilirubin of CCl 4 intoxicated animals. The results of this study showed that ethanolic extract of *C. sativum* possesses hepatoprotective activity which may be due to the presence of antioxidant potential of phenolic compounds such as quercetin, caffeic acid and/or active constituents like linalool, which have been shown to be hepatoprotective in earlier studies (Gilani *et al.*, 1997; Janbaz *et al*., 2003, 2004).

Coriander seeds and herbs have also been tested for their effects as diuretic, anti-hypertensive, anticonvulsant, anxiolytic, sedative, anti-depressant, cognitive, and anti-mutagenic activity. Some earlier studies (Grieve 1971; Eddouks *et al.*, 2002) reported coriander as a traditional diuretic. Later, Aissaoui *et al.*, (2008) and Jabeen *et al.*, (2009) used methanolic and aqueous extract of coriander seeds and found diuretic effect in conscious rats. Jabeen *et al.,* (2009) found that coriander fruit exhibits gut stimulatory, inhibitory and hypertensive effects mediating possibly through cholinergic, Ca^{2+} antagonist and the combination of these mechanisms respectively. Diuretic activity adds value to its use in hypertension. Coriander has long been used in Iranian traditional medicine as anticonvulsant, anti-depressant and for its nerve soothing, sedative and anxiolytic properties Sahib *et al*., (2013).

Hosseinzadeh and Madanifard, (2000) assessed aqueous and ethanolic extracts of coriander seeds for their anticonvulsant activity and found a dose of 5 mg kg^{-1} showed protective effect at par with standard drug phenobarbitural (20 mg kg^{-1}). Later these findings were endorsed by Ghoreyshi and Ghazal, (2008) where they reported a dose-dependent protection against PTZ-induced tonic convulsions and found aqueous extract was more active than essential oil.

These extracts were also evaluated for their sedative activity using mice and observed sedative component might be present in higher amount in the polar fractions (Ghoreyshi and Hamedani, 2006). To assess the anxiolytic activity of coriander seeds extract Emamghoreishi *et al.*, (2005) used elevated plus maze model in mice and anxiolytic effect, comparable to standard drug diazepam (0.3mg kg^{-1}). Similar results on anti-anxiety effect were reported by Mahendra and Bisht (2011) while anxiety and pain by Pathan *et al.*, (2011). Aanalgesic activity was noticed at dose of 200 mg kg^{-1}.

Coriander green plant extract was also assessed for anti-depressant activity in mice by Kishore and Siddiqui, (2003). The aqueous and diethyl ether extracts of coriander showed significant anti-depressant like activity, comparable to fluoxetine and imipramine, commonly used anti-depressant drugs in the clinical settings. Later, Kharade *et al.*, (2011) explained that coriander extract inhibited monoamine oxidase- B enzyme (MAO-B) which is a key enzyme in the pathogenesis of depression.

Fresh leaves of coriander are able to reverse the memory deficit (Mani *et al.*, 2011). Memory deficit was shown to be successfully reversed in old animals supplemented with the leaves for 45 days. The study also revealed possible neuro-protective effect of the coriander leaves.

The essential oil of coriander showed significant inhibitory effects on mycelial growth and toxin produced by *A. ochraceus* (Basilico and Basilico, 1999). The potential of coriander oil has been demonstrated in control of *A. niger*, *Saccharomyces cerevisiae*, *Mycoderma* sp., *L. acidophilus* and *Bacillus cereus* (Meena and Sethi, 1994).

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