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Chemistry and biological activities of *Anethum graveolens* L. (dill) essential oil: A review

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Abstract
Anethum graveolens L. commonly known as dill belonging to the family Umbelliferae, is one of the most useful essential oil bearing spices as well as medicinal herb. Dill is cultivated throughout the world as a medicinal plant. Dill seeds are used as a flavouring agent. Essential oil can be extracted from various parts of plant and chiefly consisted of dill carvone, limonene, dill apiol and α-phellendrene. The essential oil and extracts of dill plant possess promising antibacterial, antifungal, antioxidant, insecticidal, anti-inflammatory, antidiabetic, antispasmodic, hypolipidemic activities etc.

Keywords: *Anethum graveolens* L., composition, biological activity, dill essential oil

1. Introduction
History of essential oils is very ancient, the Egyptians, Hindus, Greeks and Arabs were much familiar with extraction and use of essential oils. Essential oils are volatile secondary metabolites that are produced by plants for their own need other than for nutrition. An essential oil may contain 20-60 aromatic compounds and this advanced mixture of compounds offers the oil its characteristic fragrance and flavor. Essential oils extracted from aromatic plants of many genera, which are distributed worldwide. The essential oils and extracts of wide range of aromatic plants and spices have been used in food preservation, pharmaceuticals, alternative medicine and natural therapies (Schiller and Schiller, 1994; Wildwood, 1996) [56,75]. Currently, it is necessary to investigate those plants scientifically, for the composition of essential oil and its biological activities, which have been used in traditional medicine to improve the quality of healthcare. The essential oil contents in different species are varied inherently, influenced greatly by culture conditions and environment, as well as by crop and post-crop processing, and hence evaluation of these essential oils from many medicinal plants are being conducted. One of the most useful essential oil bearing spices as well as medicinal plants is *Anethum graveolens* L. (dill) containing essential oil in its leaves, stem, flowers, fruits and seeds, and thus updates on its usefulness, based upon the scientific studies, are required for its better maintenance and medicinal use for the mankind.
A. graveolens commonly known as dill is an annual aromatic herb belonging to family Umbelliferae originated from Mediterranean and West Asia. The generic name *Anethum* is derived from the Greek word anethon and the common name dill comes from the Norse word dylla or dilla which probably means to soothe (Singh and Panda, 2005) [63]. It is commonly known as dill (English), Shatpushpaa (Ayurvedic), Soyaa (Unani), Sadakuppai (Siddha), Sthatpushpi (Sanskrit), Sowa (Hindi) and soya (Punjabi). Dill is also known as Shapt or dill-weed. Dill plant has a long history of cultivation and use as culinary and medicinal herb. It is widely cultivated in Pakistan, India, Afghanistan, Middle East, Russia, Iran, Egypt, Thailand, Africa, China, USA, Canada, Hungary, Bulgaria, Turkey and Uzbekistan. The Indian dill plant usually known as sowa is cultivated throughout India, chiefly in Punjab, Uttar Pradesh, Gujarat, Maharashtra, Assam and West Bengal. A large number of varieties of dill (dukat, bouquet, fernleaf, tetra goldkrone, ella organic superdukat, delikat, vierling and hercules) are known (Randhawa *et al*. 1995) [48].

2. Taxonomic, Distribution and traditional uses
It belongs to Kingdom-Plantae, Division -Magnoliophyta, Class-Magnoliopsida, Order-Apiales, Family-Apiaceae, Genus-Anethum and Species- *graveolens*. Dill is an annual herb usually grows to a height 50-150 cm. It is characterized by hollow, furrowed, branched stems and tripinnate leaves with linear leaflets. The yellowish flowers are arranged in compound terminal umbels, which produce a dried ripe fruit commonly called schizocarps (Warrier *et al*. 1994) [74].

The fruit is brown, oval, compressed, winged about one-tenth inch wide with three longitudinal ridges on the back, three dark lines between them and two on the flat surface. Dill seeds have a strong spicy odour, therefore used as a flavouring agent in the food industry for salads, sauces, soups, tea, sea foods and especially in pickles (Babri *et al*. 2012; Slupski *et al*. 2005; Isbilir and Sagiroglu, 2011) [1, 64, 21]. It is also used in perfumery to aromatize cosmetics, detergents and soaps. The fresh aerial parts of plant are used as an edible vegetable (Peerakam *et al*. 2014) [45]. The leaves of dill are rich in minerals like phosphorus, potassium and magnesium and used in salads and tea. Dill seeds are commonly used for bladder inflammation, liver diseases and insomnia (Kaur and Arora, 2010) [23]. Furthermore, the dill essential oil has hypolipidemic activity, could be used as a cardio-protective agent in decreasing blood cholesterol (Hajhashemi and Abbasi, 2008) [16]. In Europe dill was mentioned as brain tonic in 17th century (Stannard, 1982) [65]. Dill can also be used as galactagogue and for the treatment of vomiting (Stavri and Gibbons, 2005; Zargari, 1991) [66, 81]. Moreover, it is used as an antispasmodic agent, anticonvulsant, anti-emetic and anticramp (in children) remedy and also recommended topically as a wound healer (Naseri *et al*. 2012) [40].

3. Phytochemical analysis

Phytochemical analysis of dill plant revealed the presence of alkaloid, carbohydrate, resin, terpenoids, flavonosides, saponin, steroid, tannin, flavanoid and absence of reducing sugar, glycosides, anthraquinone, phlobatanins (Dahiya and Purkayastha 2012; Pathak *et al*. 2014) [7, 44].

3.1 Physiochemical constituents: Dill oil contained various saturated and unsaturated fatty acids such as lauric (1.29%), stearic acids (0.9-3.86%), capric (5.97%), myristic (0.08-0.25%), palmitic (2.31-4.66%), oleaic (36.38-53.87%), linolenic (0.26-0.4%), linoleic (5.8-45.13%), palmitoleic (0.2%), eicosenoic (0.04%) and arachidoic acids (0.1-1.32%) (Nazish *et al*. 2008; Orhan *et al*. 2013) [41,42]. A number of phenolic acids like vanillic, caffeic, protocathechuic, p-coumaric, ferulic, chlorogenic, syringic, rosmarinic, o-coumaric and trans-cinnamic acid were found in ethanol extracts of dill (Orhan *et al*. 2013) [42]. Different physiochemical parameters of dill oil were reported (Table 1).

3.2 Essential oil content: The essential oil can be extracted from various parts of plants including the leaves, flowers and seeds however; the yield of the essential oil varies among different parts of the same plant. The yield of essential oil from fruits, aerial parts and roots of the dill plant were 2.0, 0.3 and 0.06% (v/w), respectively, whereas that of the hairy root cultures was only 0.02% (v/w) (Santos *et al*., 2002) [55]. Similarly among aerial parts *viz.* leaves, flower and seed essential oil varied in its content. Essential oil obtained from dill seed had different content (3.4%) from the essential oil of dill flower (3.2%) as well as fruit (1.2%) (Radlescu *et al*. 2010) [47]. The yield of essential oil fractions was slightly different during summer (0.65%) and winter (0.56%) plant material (Vokk *et al*. 2011) [73]. Yield of essential oil also varied with method of extraction. The yield of essential oil extracted from dill fruits using hydrodistillation (2.01%) was different form steam distilled oil (1.02%) (Ruagamart *et al*.2015) [52]. Chubey and Dorell (1976) [6] reported that oil extracted from fresh and wilted dill plant was varied in their content by small amount (0.02%). Method of cultivation also influenced yield of essential oil such as yield of air-dried aerial parts of dill cultivated under organic condition and dill cultivated under conventional condition were 0.07 and 0.23%, respectively (Orhan *et al*. 2013) [42]. The yield of essential varied with different geographic regions like dill seed essential oil from different countries was different: Algeria (2.1%) (Khaldi *et al*. 2015) [25], China (1.8-3.5%) (Tian *et al*. 2011; Ma *et al*. 2015) [69, 31], Turkey (0.23%) Orhan *et al*. 2013) [42], Uzbekistan (4.2) (Yilli *et al*. 2009) [79], Iran (1.2%) (Salehiarjmand *et al*. 2014) [54], Pakistan (0.66%) (Babri *et al*. 2012; Nazish *et al*. 2008) [1, 41], Thailand (1.5%) (Peerakam *et al*. 2014) [45] and Egypt (2.4%) (Mahran *et al*. 1992) [35].

Table1. Different physiochemical parameters of dill

S. No.	Physiochemical parameters	Concentration (%)
1	Loss on Drying	7.86
2	Acid insoluble ash	4.12
3	Water insoluble ash	6.63
4	Total ash	14.5
5	Alcohol soluble extractive	11.8
6	Water soluble extractive	17.5
7	n-hexane soluble extractive	2.4
8	Chloroform soluble extractive	19.6
9	Petroleum ether soluble extractive	9.1

Source: Tripathi *et al*. 2016 [70]; Pathak *et al*. 2014 [44]

The essential oil of dill seed was pale yellow in color, with specific gravity, refractive index and acid value of 0.66, 1.5, 1.49 and 0.58%, respectively (Nazish *et al*. 2008) [41]. Dill seed essential oil was pale yellow with refractive index, density, optical rotation and pH of 1.48, 0.88 g cm^{-3}, +87. 4′ and 6.0, respectively (Chahal *et al.*2016) [4].

3.3 Chemical Composition: Essential oil can be extracted from various parts of plant such as seed, leaf and flower. The chemical composition varied with the plant part from which it was extracted. Some broad variations were seen in the relative amounts of the main components of the essential oils from different parts of dill, attributed to different geographic origins, genetic variability, growing conditions, organ development, seasonal variation, treatments prior to isolation and isolation procedures. A comparison of data indicated that both the qualitative and quantitative composition of the principal essential oil components of dill growing in different geographic zones differed considerably (Table 2). Comparison of studies revealed that major compounds of dill seed essential oils were carvone and limonene whereas dill apiole, *trans*-dihydrocarvone and α-phellandrene were present in appreciable amounts. Trace amounts of α-thujene, α-pinene, sabinene), myrcene, *p*-cymene γ-terpinene, dill ether, iso-dihydro carveol, trans-carveol and anethole were also present in essential oil (Figure1).

The chemical composition of dill volatile oil varied depending on the plant parts. The essential oils from dried leaves, flowers and fruits of dill cultivated in Romania were analyzed for their chemical composition. The percentage of α-phellandrene and limonene varied in leaves (62.71 and 13.28) and flowers (32.26 and 33.22), respectively. Dill ether was present in leaves (16.42%) and flowers (22%), but was not found in fruit oil. The main compound in fruits essential oil was carvone (1, 75.21%), and the content of α-phellandrene and limonene was 21.56 and 0.12% (Radlescu *et al*. 2010) [47].

Santos *et al*. 2002 [55] studied the variation in chemical composition of essential oils from the fruits, aerial parts, and roots of the parent plant and hairy root cultures of dill. Carvone (67%) and limonene (23%) were the main

components of the dill fruit oil, whereas the herb oil dominated by α-phellandrene (62%). Other major components of herb oil were dill apiole (10%) and myristicin (7%). Carvone, limonene, α-phellandrene and falcarinol (28, 16, 15 and 11%, respectively) were isolated from the parent plant roots. Apiole (40%) being main component of the hairy root oil isolated three weeks after subculture. Falcarinol (21%) and dill apiole (14%) constituted the second and third most important components of this oil. Myristicin (8%) also present in hairy root oil.

The essential oils obtained from vegetative herb, flowering herb and the seeds of dill were examined for their chemical composition. The main components of the vegetative herb essential oils were α-phellandrene (46.33%), limonene (13.72%), β-phellandrene (11.01%) and *p*-cymene (17.88%); Carvone (13.10%), p-cymene (33.42%) and dillether (19.63%) were the main components of the flowering herb, whereas, carvone (62.48%), dillapiole (19.51%) and limonene (14.61%) were identified as the major compounds in seed essential oil (Husssein *et al*. 2015) [20]. The highest percentages for α-phellandrene (46.33%) and β-phellandrene (11.01%) in the vegetative stage and lowest percentages (0.59; 2.70%) in the flowering stage, respectively were reported. Carvone and dillapiole showed reverse behavior. The highest concentration of carvone (62.48%) and lowest of dillapiole (4.16%) was in the fruiting stage, respectively and the highest of dillapiole (19.51%) and lowest of carvone (2.11%) were in the vegetative stage. The highest (19.63%) and lowest (0.45%) percentages of dill ether were obtained from dill plant at flowering and vegetative stages, respectively and the medium percentage (1.64%) was in the fruiting stage.

Some broad variations can be seen in the relative amounts of the main components of the essential oils from dill plant growing under different conditions. Chemical composition of essential oil of air dried aerial parts of dill cultivated under organic (AG-O) and conventional (AG-C) conditions was studied by Orhan *et al*. 2013 [42]. Monoterpenes dominated in both the essential oils, where the α-phellandrene was the leading compound in both of the oils (47.75% for AG-O and 27.94% for AG-C). However, rest of the compositions differed in both oils. For instance; sabinene (0.12% AG-O and 6.8% for AG-C), ocimene (0.3% AG-O and 17.7% AG-C), and trans-anethol (9.4% AG-O and 0.32% AG-C) was remarkably dissimilar in both essential oils. AG-C essential oil components such as trans-limonene oxide, carvomenthone, trans-cyclohexanone, piperitol, cryptone, β-cubebene and phellandral did not even exist in the AG-O oil sample; β-phellandrene and *p*-cymene were not present in AG-C essential oil.

Hariri *et al*. 2014 [17] studied the change in chemical composition of dill oil obtained from Iran at different stages of growth *i.e* flowering stage and beginning of seed formation-1, seed formation before fully ripening-2, full ripening-3. The major compounds in all three stages were carvone (48.82-64.86%), trans–dihydrocarvone (2.22-10.60%), limonene (14.21-17.71%), dill ether (1.49-15.71%) and α-phellandrene (5.63-19.2%) and found that higher content of dill ether and α–phellandrene was present at stage-1; at stage -2 carvone and limonene were present in greater amount whereas higher content of trans-dihydrocarvone was found at stage-3.

The dill fruit oil contents and compositions varied with extraction method. Ruangamnart *et al*. 2015 [52] studied the chemical composition of essential oil extracted by steam distillation and hydrodistillation from dill fruits cultivated in Thailand. The main constituents of dill oils were dillapiole (19.98-48.9%), carvone (18.05-28.02%) and limonene (26.96-44.61%). Minor components, β-pinene (0-0.79%), β-myrcene (0.16-0.21%), decane (0.44-0.49%), 1,5,8-p-menthatriene (0.19-0.27%), undecane (0.34-0.38%), naphthalene (1.63-2.11%), *cis*-dihydrocarvone (0.38-0.95%), *trans*-dihydrocarvone (4, 1.49-1.57%) and myristicin (12, 0.67-1.41%). The essential oil extracted using steam distillation contained higher content of limonene and carvone than oil extracted using hydrodistillation.

Table 2: Variation in chemical composition of dill seed oil with different geographic regions

Components	Concentration (%)												
	Iran		Egypt	Pakistan		Canada	India		Tzakistan	China	Uzbekistan	Thailand	
	(Kazemi *et al.* 2012, Khani and Basavand 2013) [24, 26]		Mahran *et al*. 1992 [35]	(Babri *et al.*2012, Singh *et al*. 2005) [1, 61]		Khaldi *et al*. 2015 [25]	Singh 2012, Chahal *et al*. 2016) [60, 4]		Sharopov *et al*. 2013 [57]	Ma *et al*. 2015 [31]	Yilli *et al*. 2009 [79]	Peerakam *et al*. 2014, Tanurean *et al*. 2014) [45, 68]	
α-phellandrene	18.36	6.0	1.0	-	-	3.28	-	0.8	8.0	0.51	0.03	-	
Dill ether	5.02	-	-	-	-	0.67	-	1.02	13.2	-	-	0.07	0.15
β-phellandrene	3.38	-	-	-	-	-	0.6	-	-	-	-	-	
Myristicin	3.31	-	3.2	-	-	-	-	-	-	0.40	0.04	0.08	0.22
p-Cymene	2.34	-	0.5	-	-	0.51	-	0.1	1.1	0.18	-	0.13	-
m-Cymene	-	-	-	0.3	-	-	-	-	-	-	-	0.19	-
α- pinene	1.90	-	0.7	-	-	0.54	-	1.06	0.1	-	-	-	-
β- pinene	-	-	0.5	-	-	-	-	0.29	-	-	-	-	0.10
Limonene	1.11	10.2	30.3	15.94	14.4	21.26	83.0	23.11	6.9	32.63	21.42	18.08	12.19
α- thujene	1.0	-	-	-	-	-	0.1	-	-	-	-	-	-
Apiol	0.8	6.9	-	30.8	-	32.78	-	-	-	16.79	-	-	-
Carvone	-	30.2	22	-	55.2	31.04	-	41.15	51.7	41.51	73.61	20.73	45.16
Trans dihydrocarvone	-	11.7	2.1	10.99	2.8	0.30	-	3.75	14.7	3.35	1.44	5.81	6.70
Cis-dihydrocarvone	-		1.3	-	2.6	1.18	-	-	1.6	2.56	5.87	-	4.70
Dill apiol	-	11.5	26.8	-	14.4	-	-	1.65	0.4	-	-	19.64	26.26
R-Carvone	-	-	-	38.9	-	-	-	-	-	-	-	-	-
S-carvone	-	-	-	0.06	-	-	-	-	-	-	-	-	-
Anethole	0.46	-	-		-	-	-	-	1.4	-	-	-	1.08
E, E-2,6 dimethyl-3,5octatetraene	-	-	-	0.6	-	-	-	-	-	-	-	-	-
ϒ-terpinene	-	-	-	0.2	-	-	-	-	-	0.1	-	0.06	0.21
Myrcene	-	-	0.7	-	-	0.19	-	2.36	0.1	-	-	-	-
Linaylacetate	-	-	0.4	-	-	-	-	-	-	-	-	-	-

Camphor	-	-	0.7	-	11.44	0.53	-	-	0.3	-	-	-	-
Δ^8-Dehydro-p-Cymene	-	-	0.6	-	-	-	-	-	-	-	-	-	-
Carveol	-	-	0.6	-	-	-	-	-	-	-	-	-	-
Piperitone	-	-	8.2	-	-	6.11	-	-	-	-	-	-	-
β Myrcene	-	-	-	-	-	-	0.3	-	-	-	0.07	0.07	-
Thujyl alcohol	-	-	-	-	-	-	0.7	-	-	-	-	-	-
Grandisol	-	-	-	-	-	-	7.4	-	-	-	-	-	-
neoiso-dihydrocarveol	-	-	-	-	-	-	-	-	0.1	0.33	-	0.39	0.47
Dihydrocarveol	-	-	-	-	-	-	-	-	-	0.22	0.15	0.67	0.25
cis-Carveol	-	-	-	-	-	-	-	-	-	0.24	-	-	-
Sabinene	-	-	-	-	-	0.20	-	0.68	-	-	0.02	0.09	-
2-Carene	-	-	-	-	-	0.20	-	-	-	-	-	-	-
o-Isopropenyltolune	-	-	-	-	-	0.12	-	-	-	-	-	-	-
1,2-diethoxyethane	-	-	-	-	-	-	-	-	-	-	1.43	-	-
Diplaniol	-	-	-	-	-	-	-	-	-	-	2.16	-	-
Linalool	-	-	-	-	3.7	-	-	0.49	-	-	-	-	-
Bis-1,2 Benzenedicarboxylic acid	-	-	-	-	-	-	5.7	-	-	-	-	-	-

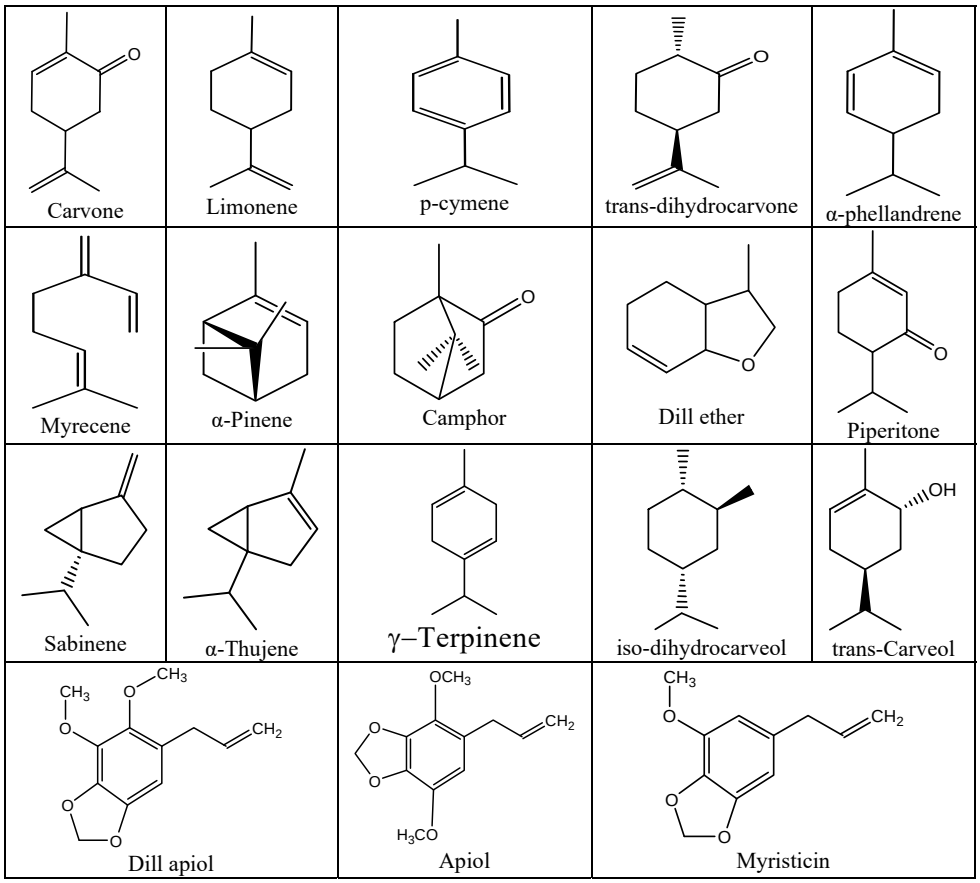

Fig 1: Structures of compounds present in dill essential oil

Some studies revealed the presence of entirely different compounds in dill plant. The principal components of essential oil from dill seed growing in China were n-pentacosane (27.96%), dioctylester of 1,2-phenyldicarboxylic acid (25.10), octacosane (13.81),tricosane (9.14), and n-nonacosane (6.85%) (Yilli *et al*. 2006) [78]. Eight pure compounds such as 8-hydroxygeraniol-D-glucopyranoside, p-menth-2-ene-1,6-diol-D-glucopyranoside, (E)-2,6-dimethyl-6-hydroxy-octa-2,7-dienoicacid, 3-hydroxy-α-ionol, 3-hydroxy-β-ionol 3-O-β-D-glucopyranoside , chlorogenic acid (10), (Z)-3-hexenyl-β-D-glucopyranoside and quercetin 3-O-β-D-glucuronide were isolated from glycosidic extract of dill herb (Bonnlander and Winterhalter 2000) [3]. A new furanocoumarin, 5-[4″-hydroxy-3″-methyl-2″-butenyloxy]-6,7-furocoumarin was isolated from the whole herb of dill plant. Other known compounds oxypeucedanin, oxypeucedanin hydrate and falcarindiol were also isolated from this plant (Stavri and Gibbons 2005) [66].

4. Biological properties

Essential oil of dill exhibited various biological activities such as antimicrobial, antifungal, antioxidant, insecticidal, anti-inflammatory, antispasmodic, antidiabetic, anticancer and anti-hypercholesterolaemic, due to the presence of biologically active compounds.

4.1 Antimicrobial activity

Dill oil was strongly effective against *Staphylococcus aureus, Escherichia coli, Yersinia enterocolitica, Geotrichum candidum* and *Rhodotorula glutinis* with inhibition zone of

36-69 mm and moderately effective against *Salmonella typhimurium* with inhibitory zone of 26 mm. Dill oil was weakly effective against *Aspergillus niger* with inhibitory zone of 12 mm, while dill oil had no inhibitory effect on growth of *Lactobacillus plantarum*, *Listeria monocytogenes* and *Pseudomonas aeruginosa* (Elgayyar *et al*. 2001) [13].

Dill seed oil showed activity with minimum inhibitory concentrations (0.47, 0.37 and 0.17% v/v) for *E. coli* (ATCC 43895), *S. aureus* (ATCC 25923) and *Saccharomyces cerevisiae* respectively, whereas no activity was observed against *S. typhimurium*, *P. fragi* DC7 and *L. monocytogenes* (LCDC 81–861) (Delaquis *et al*. 2002) [9].

The antibacterial activity of the volatile oil and acetone extract of dill was studied against *E. coli*, *S. typhi*, *P. aeruginosa*, *Bacillus cereus*, *B. subtilis* and *S. aureus* by disc diffusion and plate count methods. In disc diffusion assay volatile oil showed inhibition zone in the range of 23-100 mm at 10 µl. Complete inhibition of zone was observed against *B. subtilis* at 10 µl dose and more than 40% at 6 µl. Extracts exhibited activity in disc diffusion assay but in plate count method some activity (5.5-28.3 10^7/Units/ml) was observed but lesser than volatile oil which showed 100% activity. In comparison with two methods plate count method was the suitable method for determining antibacterial activity of essential oils (Singh *et al*. 2007) [62].

Dill essential oil exhibited antimicrobial activity against *E. coli*, *S. typhi* and *B. subtilis* with inhibition zone of 7-9 mm (Nazish *et al*. 2008) [41]. The dill seed essential oil showed antimicrobial activity against *Candida albican* and *S. aureus* with MIC at 0.00273 and 0.273 mg/ml respectively (Yili *et al*. 2009) [79].

Extracts of dill leaf and seed were studied for antimicrobial activity by agar well diffusion technique against *S. aureus, E. coli and C. albicans*. The leaf extracts showed no antibacterial activity, whereas the extract of dill seed exhibited inhibition of growth of *C. albicans* (19 mm. inhibition zone) (Rasheed *et al*. 2010) [49].

The antibacterial activity of dill seed essential oil against both Gram-positive bacteria such as, *S. aureus* MRSA, *S. aureus*, *Enterococcus* sp. and gram-negative bacteria *E. coli*, *Klebsiella pneumonia* and *P. aeruginosa* was assessed using agar well diffusion method. Dill oil showed significant to moderate antibacterial activity (10.0-15.0 mm zone inhibition) (Dahiya and Purkayastha 2012) [7].

The powdered material of fresh dill plant and seed essential oil was tested for inhibitory effect on microorganism *E. Coli*, K12-MG165 in liquid culture. The results indicated good antimicrobial activity of dill oil as well as dil powder (MIC at 0.73 mg/ml) (Isopencu and Ferdes 2012) [22].

Antimicrobial study of dill leaf essential oil and its components was studied against bacterial strains *S. aureus*, *B. cereus*, *B. megaterium*, *B. subtilis*, *Micrococcus luteus* and *Streptococcus*-β-*haemolyticus*, *S. typhi*, *Shigella dysenteriae*, *S. shiga*, *S. sonnei*, *S. boydii*, *E. coli*, *Klebsiella* sp., *P. aeruginosa* and *Proteus* sp.; human pathogenic bacteria as well as eight pathogenic fungi (*A. fumigatus*, *A. niger*, *A. flavus*, *Vasin factum*, *Mucor* sp., *C. albicans*, *Fusarium oxysporum* and *Colletotrichum falcatum*). The antibacterial assays were carried out by the disc-diffusion and micro dilution method. Dill leaf oil in the disc-diffusion method showed no bacteriostatic activity at 1 µg/disc, whereas in microdilution method dill leaf oil showed the lowest MIC (8.0-10.0 µg/ml) and MBC (7.0-12.0 µg/ml). Carvone showed the strongest antibacterial and antifungal activity with MIC at 0.5-4.0 µg/ml and MBC at 0.25-2.0 µg/ml while limonene showed MIC at 1.0-9.0 µg/ml and MBC at 2.0-10.0 µg/ml. In disc diffusion assay carvone and limonene inhibited bacterial growth of all bacteria and fungi and inhibition zones were 10.0-22.0 and 20.0-38.0 mm respectively (Kazemi *et al*. 2012) [24].

The dill oil from aerial parts was screened for antimicrobial activity against *B. cereus* (ATCC 14579), *S. aureus* (ATCC 29213), *P. aeruginosa* (ATCC 27853) and *E. coli* (ATCC 10798). The essential oil showed only marginal antimicrobial activity to *E. coli* (MIC= 625 µg/ml) (Sharopov *et al*. 2013) [57].

Dill seed essential oil was screened for antimicrobial effect using disc diffusion assay against *L.* monocytogenes (EMCC 1875), *S. aureus* (ATCC 13565), *B. cereus* (EMCC 1080), *E. coli* (ATCC 51659) and *S. typhimurium* (ATCC 25566) at four different concentrations i.e. 25, 50, 75 and 100% using two volumes 20 and 60µl. The results showed that by increasing the volume or concentrations of essential oil activity was also increased. For practical application of essential oil in cheese yoghurt**,** the minimum inhibitory concentrations (MICs) of dill seed oil was determined using 0.001 to 0.007 ml/ml concentrations and dill seed oil showed maximum MIC value 0.005 ml/ml against all the tested strains (Mohamed *et al*. 2013) [36].

Dill seed essential oil exhibited antimicrobial activity against *S. aureus* (ATCC 25923), *C. albicans* (ATCC 90028), *E. coli* (ATCC 25922) and *A. flavus* except *P. aeruginosa* (ATCC 27853) with inhibition zone of 16-30 mm in diameter. The MIC (minimum inhibitory concentration) of essential oil ranged from 5.99-59.47 µg/ml, the lowest concentration of essential oil (5.99 µg/ml) restrained *S. aureus* and *E. coli* (Peerakam *et al*. 2014) [45].

Essential oil fraction, deodorized hot water fraction and methanol fraction of dill plant were evaluated for their antibacterial activity against *E. coli, P. aeruginosa*, *E. faecalis, K. pneumoniae, S. aureus, S. epidermidis* and *S. typhi* by disc-diffusion and micro-well dilution methods. The essential oil fraction exhibited activity against five pathogenic bacteria (*E. faecalis, K. pneumoniae, S. aureus, S. epidermidis* and *S. typhi*) with inhibition zone of 7.8-11.3 mm in diameter while the deodorized hot water fraction and methanol fraction were inactive. The most sensitive strain was *S. epidermidis* with MIC= 0.25 mg/ml (Tanurean *et al*. 2014) [68]. The screening of antimicrobial activity of eighteen samples of dill essential oil from Iran were individually evaluated against *B. subtilis* (ATCC 9372), *E. faecalis* (ATCC 15753), *S. aureus* (ATCC 25923), *S. epidermidis* (ATCC 12228), *E. coli* (ATCC 25922), *P. aeruginosa* (ATCC 27852) and *K. pneumonia* (ATCC 3583). The highest activity of dill oils was observed against *B. subtilis* (inhibition zone= 27 mm; MIC= 1.87 mg/ml). However, *E. coli* was the most sensitive and *E. faecalis* was the most resistant bacteria (Salehiarjmand *et al*. 2014) [54].

Hussein *et al*. 2015 [20] reported that volatile oils obtained from vegetative herb, flowering herb and the seeds of dill completely inhibited the growth of *B. subtilis*, *S. aureus*, *A. niger*, *Trichoderma* sp and *C. albicans* at 25 µg/ml except inhibition of only 10-32 mm zone of *B. cereus*, *E. coli* and *P. aeroginosa*. Dill oil at flowering and fruiting stage showed moderate inhibition against *C. albicans* and *B. cereus.* All the tested dill oils exhibited activity against tested strains with MIC values of 5 µg/ml.

The essential oil extracted using hydrodistillation showed antibacterial activity against *E. coli* (ATCC 8739), *K. pneumonia* (ATCC 700603) and *S. typhimurium* (ATCC

14028) with MIC values of 10 mg/ml, whereas the oil extracted using steam distillation showed antibacterial activity against *S. aureus* (ATCC 25923), *S. aureus* (ATCC 29213) and *S. typhimurium* (ATCC 14028) with MIC values of 10 mg/ml. *S. aureus* (MRSA) (ATCC 43300) was the most sensitive strain to both limonene and carvone with MIC values of 0.3125 and 1.25 mg/ml, respectively and MBC values of 1.25 and 2.5 mg/ml, respectively. Strains of *S. aureus* (ATCC 25923), *S. sorbrinus* (ATCC 33478), *S. typhimurium* (ATCC 14028) were more sensitive to limonene than carvone and dill oils with the MIC values of 1.25-5.0 mg/ml and MBC values of 1.25-10.0 mg/ml, whereas, *S. aureus* (ATCC 6538), *S. aureus* (ATCC 29213) and *K. pneumonia* (ATCC 700603) showed same MIC and MBC values with range 5-10 mg/ml in both limonene and carvone. *P. aeruginosa* (ATCC 27853) and *P. aeruginosa* (ATCC 9027) were not inhibited by all tested concentrations of samples (Ruangamnart *et al*. 2015) [52].

4.2 Antifungal activity

Dill seed essential oil was tested for antifungal activity against *A. flavus, A. oryzae, A. niger* and *Alternaria alternata* (*in vitro*) by poisoned food technique. The minimum inhibitory concentration of dill seed oil against four tested fungi was found to be 2.0 ml/ml. Observations on the microstructure of *A. niger* showed degenerative alterations in the conidial heads and hyphal morphology after oil treatment that included distorted conidial heads, decreased hyphal diameters, shrivelled hyphal aggregates and swelling of the hyphal wall (Tian *et al*. 2011) [69].

Deweer *et al*. 2013 [10] examined antifungal potential of dill seed essential oil and its two major compounds carvone and limonene against two strains of *Zymoseptoria tritici*, S6 (sensitive strain) and R1187 (resistant strain) by measuring IC_{50} (half maximal inhibitory concentration) values. The essays were repeatedly carried out with dill seed essential oil crude, with Tween 80 (5% v/v) and with dimethyl sulfoxide (1% v/v). The comparison of IC_{50} values showed that the crude dill seed essential oil and dill seed oil with dimethyl sulfoxide (1%) were more efficient on S6 (350 mg/L) than on R1187 (1000 mg/L) except oil used with Tween 80 revealed the same effect on both strains (300 mg/L) whereas carvone showed the same effect on both strains for all the preparation tested. Limonene preparations were generally less efficient than carvone unless supplemented with Tween.

Eleiwa and El-diasty (2014) [12] studied the dill seed essential oil as antifungal agent (*in vivo*) by treating minced meat with essential oil at 0.5 and 2.0% concentration. The samples were packed into plastic bags and stored in refrigerator at 4 ºC. Samples were evaluated for sensorial properties and mycological counts on 0, 2, 4, 6 and 8 days of storage. The results showed that the mould and yeast counts detected in the control (non-treated) minced meat was 2.60 log cfu/g at the zero day of examination. This count increased during storage and reached to the highest level (7.80 log cfu/g) by the end of storage period. The treatment of minced meat with dill oil led to the inhibition and retardation of moulds and yeasts growth and lowered the maximum growth levels in the minced meat. The moulds and yeasts counts ranged from the beginning 4.01to 4.93 log cfu /g at the end of storage period in minced meat samples treated with dill oil at 2.0%, while in samples treated with dill oil at 0.5% the count ranged from 5.95- 8.81 log cfu /g.

The minimal inhibitory concentration of dill seed hot water extract was found to be 6 mg/ml against *Malassezia furfur*. Dill seed extract was used to treat *Tinea versicolor*(superficial fungal infection of skin caused by *M. furfur*) in human by topical application of dill seed extract (6 mg/g) twice daily in a time course of two weeks (Mahmoud *et al*. 2015) [34].

The antifungal activity of dill seed essential oil and its two main constituents namely carvone and limonene toward mycelial growth and effect on the viability of *Sclerotinia sclerotiorum* was assessed in both contact and vapor phase. Mycelial growth and sclerotial germination were thoroughly inhibited by dill seed essential oil at 1.00 µl/ml under contact condition and 0.125 µl/ml air under vapor condition. Carvone and limonene also synergistically inhibited the growth of the fungus but carvone contributed more than limonene in inhibiting the growth. *In vivo* experiments, the essential oil remarkably suppressed *S. sclerotiorum* and considerable morphological alterations were observed in the hyphae and sclerotia. Its mechanism of action was also evaluated by investigating inhibition of ergosterol synthesis, malate dehydrogenase, succinate dehydrogenase activities and external medium acidification (Ma *et al*. 2015) [31].

Antifungal activity of dill seed essential oil was also evaluated against seven fungal pathogens (*A. niger*, *A. flavus*, *A. ochraceus*, *Penicillium expansum*, *F. oxysporum* f. sp. *albedinis*, *A. alternata* and *Cladosporium species*) by measuring minimum inhibitory concentrations according to the direct contact method and evaluating inhibition of germination and sporulation of spores. The results of direct contact method for mycelia growth showed that all strains were inhibited at MIC 1/500 v/v, except *A. niger* at MIC 1/180 v/v. *A. alternata* was most sensitive, with inhibition at MIC as weak as 1/6500 v/v. However, concentration of 1/370 v/v completely inhibited the mycelia growth of all tested strains, except *A. niger* at 1/150 v/v. Dill seed essential oil also showed prompted antifungal activity against germination and sporulation of spores. All fungal strains were inhibited at concentrations as weak as 1/370 v/v. *F. oxysporum* f. sp. *albedinis*, *A. flavus* and *A. alternata* were most sensitive, being inhibited as from 1/1500 v/v (Khaldi *et al*. 2015) [25].

To elucidate the mechanism of the antifungal action of dill seed essential oil, the effect of the essential oil on the plasma membrane and mitochondria of *A. flavus* (Tian *et al*. 2011) [69] and *C. albicans* (Chen *et al*. 2013) [5] was investigated. The lesion in the plasma membrane was detected through flow cytometry and further verified through the inhibition of ergosterol synthesis. The essential oil caused morphological changes in the cells of *A. flavus* and *C. albicans* and a reduction in the ergosterol quantity. Moreover, mitochondrial membrane potential, acidification of external medium, mitochondrial ATPase and dehydrogenase activities were detected. The reactive oxygen species accumulation was also examined through fluorometric assay. Exposure to dill oil resulted in an elevation of mitochondrial membrane potential and the suppression of the glucose-induced decrease in external pH at 4 µl/ml. Decreased ATPase and dehydrogenase activities in *A. flavus* cells were also observed in a dose-dependent manner. The above dysfunctions of the mitochondria caused reactive oxygen species accumulation in *A. flavus*. A reduction in cell viability was prevented through the addition of L-cysteine, which indicated that reactive oxygen species was an important mediator of the antifungal action of dill oil.

Dill seed essential oil, its non-polar and polar fractions and its two compounds (limonene and camphor) were screened for fungicidal activity against *A. triticina* and *Bipoalris*

sorokiniana using spore germination inhibition at different concentrations 0.25-3.0 mg/ml. All the tested components showed promising activity against *A. triticina* with ED_{50} and ED_{90} values of less than 0.38 and 2.15 mg/ml respectively. ED_{50} and ED_{90} values of all the tested compounds against *B. sorokiniana* were less than 0.78 and 2.1 mg/ml respectively (Chahal *et al*. 2016) [4].

4.3 Insecticidal activity

The essential oil of dill assessed for insecticidal activity against *Callosobruchus maculates* L. adults through fumigant bioassay. The LC_{50} value of essential oil was 25.48 µl/L air (Ebadollahi *et al*. 2012) [11].

The dill seed essential oil was found to be toxic to *Periplanata americana* L., *Musca domestica* L. and *Tribolium castaneum* by continuos exposure bioassays and fumigant toxicity bioassays. The mortality against *P. americana* ranged from 25 to 100% during the first 3 hrs in contact toxicity bioassay and during the first 12 hrs in the fumigant toxicity bioassay. In case of the *M. domestica* L., mortality ranged from 33.3 to 70% during the first 3 hrs, whereas the mortality ranged from 58.3 to 100% during 24 hrs for the *T. castaneum* (Babri *et al*. 2012) [1].

Khani and Basavand (2013) [26] reported the volatile toxicity of dill seed essential oil against two stored product insects *T. confusum* and *C. maculates* by fumigant toxicity assay. *C. maculates* (LC_{50}=0.54 µl/L air) was more susceptible to the tested plant product than *T. confusum* (LC_{50}=143.8 µl/L air) based on LC_{50} values.

4.4 Antioxidant activity

Antioxidants are compounds that can delay or inhibit the oxidation of lipids or other molecules by inhibiting the initiation or propagation of oxidizing chain reactions (Velioglu *et al*. 1998) [72].

The antioxidant activity of the essential oils and acetone extracts of dill was studied by DPPH (1,1-diphenyl-2-picryl-hydrazyl), reducing power, conjugated diene and chelating effect assays. The results showed moderate to good antioxidant activity at 5-25 µl (Singh *et al*. 2007) [62].

The antioxidant activity of hexane, ethyl acetate and ethanolic extract of dill flowers, seeds and leaves was evaluated with DPPH radical scavenging, trolox equivalent antioxidant capacity, reducing power, chelating power and β-carotene bleaching assays. In all assays, the flower extract showed higher antioxidant activity than the leaf and seed extracts. Among the flower extracts ethyl acetate extract showed maximum activity followed by ethanol and hexane extract (Shyu *et al*. 2009) [59].

Antioxidant activity of aqueous and methanolic extracts of soup formulated with dill leaves was investigated by measuring total phenolic content, reducing power ability and free radical-scavenging activity. The phenolic acid profile contained tannic acid, protocatechuic, gentisic, vanillic acid and syringic acids. The reducing power ability increased by about 2.5 times in aqueous and seven times in methanolic extracts, as a result of dill leaf powder addition. Concentration-dependent scavenging activity was observed and IC_{50} values reduced from 16.5 to 3.8 µg/ml in aqueous and 9.1 to 3.9 µg/ml in methanolic extracts as a result of addition of dill leaf powder (Rekha *et al*. 2010) [51].

The antioxidant activity of water, ethanol and acetone extracts of dill leaves was investigated by ferric thiocyanate method, reducing power, DPPH, free radical scavenging, hydrogen peroxide scavenging and ferrous ions chelating activities. Among the three extracts, the water extract of dill leaf showed the most potent antioxidative capacity in each assay, showed absorbance 79.66% at 1 mg/ml in the DPPH radical scavenging activity, 63% at 800 µg/ml in the metal chelating effect, 60% at 400 µg/ml in the hydrogenperoxide scavenging activity and 0.61% at 1 mg/ml in the ferric reducing antioxidant power (Isbilir and Sagiroglu 2011) [21].

Antioxidant efficacy of ethanolic extract of dill was evaluated in carbon tetrachloride induced hepatotoxicity in albino rats. The results showed that 100 mg/Kg wt of ethanolic extract of dill restored the activity of serum enzymes and antioxidant enzymes which enhanced in experimental rats (Tamilarasi *et al*. 2012) [67].

Dichloromethane, n-hexane, ethyl acetate and ethanol extracts from dill cultivated under organic and conventional conditions was tested for antioxidant activity using DPPH, N,N-dimethyl-p phenylendiamine and nitric oxide radical scavenging assays as well as ferric ion-chelation capacity, ferric reducing antioxidant power and phosphor molybdenum-reducing antioxidant power. The ethanol extracts of both dill samples exhibited better scavenging effects and ferric reducing antioxidant power. However, these two extracts showed more remarkable radical scavenging assay against NO radical (78.49 ± 1.86% for dill cultivated under conventional conditions and 71.86 ± 5.41% for dill cultivated under organic conditions). Dichloromethane extract of dill cultivated under organic conditions exerted the highest ferric ion-chelation effect (74.34 ± 1.40%) while the dichloromethane extracts of both dill cultivated under organic and conventional conditions showed better ferric reducing antioxidant power values than rest of the extracts (Orhan *et al*. 2013) [42].

Antioxidant activity of the essential oil fraction, the hot water and the methanol fraction of dill based on free radical scavenging activity and lipid peroxidation inhibition was evaluated. The methanol fraction displayed the highest level of DPPH radical scavenging (IC_{50} 22.3 µg/ml) while the hot water fraction exhibited the highest inhibition of lipid peroxidation inhibiton (IC_{50} 4.7 µg/ml). High amounts of phenolic compounds were found in the deodorized hot water fraction (35.1 mg GAE g^{-1} extract) and the methanol fraction (22.1 mg GAE/g extract), while the essential oil fraction contained low amount (9.5 mg GAE/g extract) of phenolic compounds. Moreover, a high content of chlorogenic acid (6.04 µg/g extract) was found in the deodorized hot water fraction (Tanruean *et al*. 2014) [68].

4.5 Anti-inflamatory activity

Inflammation represents a highly coordinated sequence of cellular events where tissues respond to physical trauma, noxious chemicals and pathogens. The hydro alcoholic extract of the dill seed caused significant decrease in the inflammation and pain in rats (Valadi *et al*. 2010) [71]. Dill oil and diclofenac-gel showed a significant (p<0.001) decrease in the paw volume in rats compared to the blank group. Dill oil showed even more decrease in the paw volume compared to the diclofenac (Naseri *et al*., 2012). A single topical application of an ethanol extract of dill fruit to the inner and outer surface of the ear of mice inhibited ear inflammation induced by 12-O-etradecanoylphorbol-13 acetate by 60%. A 10% aqueous extract of the fruits and 5% aqueous solution of the essential oil showed analgesic effects in mice pain induced by hot plate and acetic acid writhing models. The effect of fruits (1.0 g/kg body weight) was comparable to 200 mg/Kg body weight of acetyl salicylic acid (Racz-Kotilla *et al*. 1995) [46].

Rezaee-Asl *et al*. (2013) [50] carried the study of hydro alcoholic extracts of dill seed and aerial parts for use as an analgesic drug on mice using formalin test and hot plate test, In formalin test, seed and crop extracts significantly decreased indications of pain. In the hot plate test, crop and seed extracts showed hyperalgesic properties. This effect was stronger in animals treated with crop extracts as compared to seed extracts.

4.6 Antidiabetic activity

Dill significantly decreased blood glucose, cholesterol, triglyceride (TG), low density lipoprotein (LDL), very low density lipoprotein (VLDL) and increased high density lipoprotein (HDL) level in alloxan induced diabetic rat model (Madani *et al*. 2005) [32]. Dill leaf extract regulates corticosteroid-induced type 2 *Diabetes mellitus* in female rats. Dill reversed the alterations made by dexamethasone in liver of female rats. Dill extracts were observed to increase serum concentration of insulin and glucose in hepatic lipid peroxidation. It also decreased the serum concentration of thyroid hormones, endogenous antioxidant enzymes (superoxide dismutase and catalase) and reduced glutathione in liver (Panda 2008) [43].

4.7 Anticancer activity

Methanol extracts of dill showed anti-proliferative activity against tumor cell lines MK-1, HeLa and B16F10 (Nakano 1998) [38]. The aqueous extracts of dill weed and seed exhibited mutagenicity to *Salmonella typhimurium*. The aqueous methanol extracts were fractionated by the mutation assay. Isorhamneticn 3-sulfate (persicarin) and quercetin 3-sulfate were characterized as the mutagenic principles. Carcinogenicity was not observed when the diets containing dill weed and seeds in 33% were administered to the inbred strain ACI rats (Fukuoka *et al*. 1980) [14]. Dill weed oil induced the detoxifying enzyme glutathione S-transferase in several mouse target tissues. α, β-unsaturated ketone system in carvone appeared to be critical for the high enzyme-inducing activity (Zheng *et al*. 1992) [82].

4.8 Antispasmodic activity

Dill fruit was reported as potent antispasmodic agent. Contraction induced by a variety of spasmogen in rat ileum was significantly relaxed by alcoholic extract of dill fruit. The precontracted ileum of male wistar rats by potassium chloride (60 mm), acetyl choline esterase (1µm) and barium chloride (4mm) were relaxed by the cumulative concentration of dill fruit hydro alcoholic extract (0.5-4.0 mg/ml). The relaxatory effect of the extract on the barium chloride -induced ileum contractions was greater than the other spasmogens. Results indicated that the α-and β-adrenoceptors, opioid receptors and NO generation were not involved in inhibitory effect of alcoholic extract of dill fruit. However, the relaxatory effect of dill fruit hydroalcoholic extract on the ileum may be due to blockage of voltage dependent calcium channels (Naseri and Heidari 2007) [39].

4.9 Adaptogenic activity

Anti-stress and cognition-improving effects of dill extract were studied in a rat model. Urinary vanillylmandelic acid (VMA) and ascorbic acid were estimated as biomarkers for evaluating antistress activity in rats. Conditioned avoidance response using Cook's pole climbing apparatus in normal and scopolamine-induced amnestic rats was used to assess cognitive-improving activities. Daily administration of dill at doses of 100, 200 and 300 mg/kg body weight 1 hr prior to induction of stress inhibited stress-induced urinary biochemical changes in a dose-dependent manner without altering the levels in normal control groups. Changes in cognition (as determined by the acquisition), retention and recovery in rats were dose-dependent (Koppula and Choi 2011) [27].

4.10 Effect on female reproductive system

Dill seed was reported for its effect on female reproductive system and estrus cycle. The effects of aqueous and ethanol extract of dill on the female reproductive system were studied in 54 Wistar female rats. The estrus cycle changes were determined by daily vaginal smear changes. Treatment with high dose of the dill extract significantly increased duration of the estrous cycle, diestrus phase and the progesterone concentration. The stereological study did not revealed any significant changes in the volumes of ovaries, primary, secondary and graafian follicles (Monsefi *et al*. 2006) [37].

Dill seed possessed contractive effects on myometer, enhanced releasing of oxytocin which is an effective hormone in uterus contractions. A dose of 6-7 gm of dill seed extract after delivery decreases postpartum hemorrhage due to its contractive characteristic. Limonene and anethole showed contractive effect on uterine myometrium (Bertram and Emertius 2001; Mahdavian *et al*. 2001; Gharibn 2005) [2, 33].

Zagamil *et al*. (2012) [80] carried out a clinical study to evaluate the effect of dill seed on uterus contractions in active phase of labor. 40 women used Dill seed infusion (one tablespoon of whole dill seed seeped in a half or whole cup boiling water for 3- 4 min before going to the hospital at the beginning of uterus contractions) and 60 women used nothing in the control group. Interpretable electronic fetal monitoring was obtained for half an hour at the beginning of the active phase. The Fall: Rise ratio was calculated by measuring the duration of time for a contraction to return to its baseline from its peak (fall) divided to the duration of its rise time to its peak (rise).The number of contractions in the treated group was significantly more than the control group. The ratio of contraction's fall time to its rise time in the treated group was shorter than the control group. The study showed that dill seed shortens duration of the first stage of labor.

4.11 Genotoxic properties

Genotoxic effect of the essential oils extracted from dill herb and seeds were studied using chromosome aberration (CA) and sister chromatid exchange (SCE) tests in human lymphocytes *in vitro*, and *Drosophila melanogaster* somatic mutation and recombination test (SMART) *in vivo*. The highest concentration tested (0.25ml/ml) induced a 16-fold (dill herb) and 19-fold (dill seeds) increase over control. Essential oil from dill seeds was slightly more clastogenic than essential oil from dill herb. Also in SCE test essential oil from dill seeds seems to be slightly more active than essential oil from dill herb, whereas essential oil from dill herb was very active in inducing somatic mutations in *D. melanogaster* than from essential oil from dill seeds (Lazukta *et al*. 2001) [29].

4.12 Anti-hypercholesterolaemic activity

Hyperlipidemia is highly prevalent disorder, a major cause of atherosclerosis which leads to ischemic heart disease (Lloyd-Jones *et al*. 2010) [30]. The effect of dill extract on serum lipoproteins(changes in serum triglyceride (TG), total cholesterol (TC), high density lipoprotein-cholesterol (HDL-

C) and low density lipoprotein-cholesterol (LDL-C) in hypercholesterolaemic rats was studied and its mechanism of action to some extent on liver hydroxy-3-methyl-glutaryl-CoA (HMG-CoA) reductase activity was also studied. Administration of dill extract to hyperlipidaemic rats significantly lowered serum TG (33.1%), TC (38.5%) and LDL-C (66.5%) levels and increased HDL-C level (24.6%). The rats treated with dill extract showed further decrease in the HMG-CoA reductase activity (Yazdanparast and Bahramikia 2008) [77].

Administration of dill leaf powder resulted in highly significant reduction of lipid profile (TC (19.9%), TG (29.5%), LDL-C (22.2%), VLDL-C (25.2%) and HDL-C (8.5%) in hyperlipidemic patients, its effect was comparable to that of standard agent lovastatin (Sahib *et al*. 2012) [53].

The effect of dill powder on blood parameters (glucose, cholesterol, triglyceride and HDL) in broiler chicken was studied by supplemented bird's diet with dill powder. All birds received a starter diet in mash form from 7 to 21 days and grower diet from 21 to 42 days. Different levels of dill powder showed no significant effect on glucose, triglyceride and HDL level in 21 day of diet. Dill powder showed no significant effect on cholesterol and triglyceride level in 42 day of diet (Mohamed *et al*. 2013). [36]

Lipid profiles of 50 hyperlipidemic patients was checked who were given dill tablet (650 mg) twice daily. Results revealed that triglyceride increased by 6.0%. Dill reduced total cholesterol by 0.4% and LDL- cholesterol by 6.3% (Kajouri *et al*. 2007) [28].

Serum triacylglycerides and total cholesterol levels in rats, with hyperlipidaemia induced by diet, were determined after oral administration of a water extract of dill leaves before and after the extraction of the furocoumarin content of the leaves. Administration of the extracts consecutively for 14 days reduced the triacylglycerides and total cholesterol levels by almost 50 and 20%, respectively. Chloroform extraction of furocoumarins from the aqueous extracts did not reduce the antihyperlipidaemic potential of the extracts to a significant degree. Oral administration of the essential oil of dill seeds, at two different doses, also reduced the triacylglyceride levels by almost 42%. The total cholesterol level was not reduced by the same doses of the essential oil (Yazdanparast and Alavi 2001) [76].

4.13 Diuretic

Volatile oil of dill fruits significantly increased excretion of Na^+ and Cl^- in urine in dogs; produced an increase in urine flow in dogs (Mahran *et al*. 1992) [35].

4.14 Antimycobacterial activity

Oxypeucedanin, oxypeucedanin hydrate and falcarinidol isolated from dill herbexhibited antibacterial activity against a panel of rapidly growing mycobacteria with minimum inhibitory concentraton (MIC) values in the range 2-128 µg/ml (Stavri and Gibbons 2005) [66].

4.15 Anti-ulcer activity and toxicological effect/ Effects on gastrointestinal system

As a folk remedy, dill seed is used for some gastrointestinal ailments. Aqueous and ethanolic extracts of dill seed showed significant mucosal protective and antisecretory effects of the gastric mucosa in mice. Gastric mucosal lesions were induced by oral administration of HCl (1 N) and absolute ethanol in mice. The acidity and total acid content of gastric juice were measured in pylorus-ligated mice. The acidity and total acid content were reduced by the orally or intraperitoneally administration of the extracts (Hosseinzadeh *et al*. 2002) [19]. Dill seed extracts exerted moderate activity against *Helicobacter pylori*. The essential oil of dill reduced contractions of rabbit intestine (Shipochliev 1968) [58]. Ethanol extract inhibited acetylcholine and histamine induced contractions of guinea-pig ileum (Dhar *et al*. 1968) [8]. The essential oil was a mild carminative and reduced foaming *in vitro* (Harries *et al*. 1978) [18].

5. Conclusions

Screening of literature on dill showed that *Anethum graveolens* is a plant with wide range of biologically active compounds. Some broad variations were observed in the relative amounts of the main components of the essential oils from different parts of dill, attributed to different geographic origins, genetic variability, growing conditions, seasonal variation and isolation procedures. The major compounds present in dill seed essential oil were carvone, limonene, dill apiol and α-phellandrene. Dill essential oil and its constituents possessed wide spectrum of biological activities such as antimicrobial, insecticidal, antioxidant, anti-inflammatory, antihyperlipedemic, diuretic etc. There is a great promise for development of novel drugs from *A. graveolens* to treat various diseases as a result of its effectiveness and safety.

6. References

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