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Plant Essential Oils from Apiaceae Family as Alternatives to Conventional Insecticides

*Asgar Ebadollahi**

Young Researchers Club, Ardabil Branch, Islamic Azad University, Ardabil, IRAN
*Corresponding author: Asgar.ebadollahi@gmail.com, Ebadollahi_2008@yahoo.com

Abstract. Main method to control insect pest is using synthetic insecticides, but the development of insect resistance to this products, the high operational cost, environmental pollution, toxicity to humans and harmful effect on non-target organisms have created the need for developing alternative approaches to control insect pest. Furthermore, the demand for organic crops, especially vegetables for the fresh market, has greatly increased worldwide. The ideal insecticide should control target pests adequately and should be target-specific, rapidly degradable, and low in toxicity to humans and other mammals. Plant essential oils could be an alternative source for insect pest control because they constitute a rich source of bioactive chemicals and are commonly used as flavoring agents in foods. These materials may be applied to food crops shortly before harvest without leaving excessive residues. Moreover, medically safe of these plant derivatives has emphasized also. For these reasons, much effort has been focused on plant essential oils or their constituents as potential sources of insect control agents. In this context, Apiaceae (Umbelliferae) family would rank among the most important families of plants. In the last few years more and more studies on the insecticidal properties of essential oils from Apiaceae family have been published and it seemed worthwhile to compile them. The focus of this review lies on the lethal (ovicidal, larvicidal, pupicidal and adulticidal) and sublethal (antifeedant, repellent, oviposition deterrent, Growth inhibitory and progeny production) activities of plant essential oils and their main components from Apiaceae family. These features indicate that pesticides based on Apiaceae essential oils could be used in a variety of ways to control a large number of pests. It can be concluded that essential oils and phytochemicals isolated from Apiaceae family may be efficacious and safe replacements for conventional synthetic insecticides.

Keywords: Apiaceae family, essential oils, phytochemicals, natural insecticides, lethal effects, sublethal effects.

Introduction

Currently different kinds of preventive and curative control measures are practiced to get protection from insect pests. Among those, synthetic pesticides such as organochlorines, organophosphates, carbamates, pyrethroids and neonicotinoids have been considered to be the most effective and easy to use tools against insect pests. Most of the farmers are not aware with the ill effect of chemical pesticides and still using most of the systemic and organic insecticides to control insect pests. Although these methods are effective, their repeated use for several decades has its consequences. It has been estimated that about 2.5 million tons of pesticides are used on crops each year and the worldwide damage caused by pesticides reaches $100 billion annually. Repeated applications of synthetic insecticides has disrupted natural enemies in the biological control system and led to

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outbreaks of insect pests, widespread development of resistance and environmental and human health concerns (BENHALIMA *et al*., 2004; BUGHIO & WILKINS, 2004; SANNA *et al*., 2004; TAPONDJOU *et al*., 2005). In this context, efforts are being made worldwide to replace these chemicals with biological alternatives (biopesticides), which are less toxic to the environment.

Plants offer an alternative source of insect-control agents because they contain a range of bioactive chemicals, many of which are selective and have little or no harmful effect on non-target organisms and the environment. Because of the multiple sites of action through which the plant materials can act, the probability of developing a resistant population is very low (ISMAN, 2006). Botanical insecticides degrade rapidly in air and moisture and are readily broken down by detoxification enzymes. This is very important because rapid breakdown means less persistence in the environment and reduced risks to nontarget organisms (ISMAN, 2008). Among natural products certain highly volatile EOs currently used in the food, perfume, cosmetic and pharmaceutical and agricultural industries show promise for controlling insect peat, particularly in confined environments such as greenhouses or granaries. Because of this, much effort has been focused on plant EOs as potential sources of commercial insect control agents. From the standpoint of pest control, one of the most valued properties of *EO*s is their fumigant activity against insects, since it may involve their successful use to control pests in storage without having to apply the compound directly to the insects. In this context, EOs have received much attention as potentially useful bioactive compounds against insects showing a broad spectrum of activity against insects, low mammalian toxicity, degrading rapidly in the environment and local availability (BAKKALI *et al*., 2008; KOUL *et al*., 2008; RAJENDRAN & SRIRANJINI, 2008). EOs are secondary metabolites that plants produce for their own needs other than for nutrition. The aromatic characteristics of *EO*s provide various functions for the plants including attracting or repelling insects, protecting themselves from heat or cold; and utilizing chemical constituents in the oil as defense materials. In general, they are complex mixtures of 20-60 organic compounds that give characteristic odour and flavour to leaves, flowers, fruits, seeds, barks and rhizomes. In industrialized countries, EOs could be useful alternatives to synthetic insecticides in organic food production, while in developing countries; they can be a means of low cost protection (Cosimi, *et al*., 2009). Bioactivity of these EO depends on its chemical composition which varies with plant part used for extraction, harvesting time, plant age, and nature of the soil and growth conditions. EOs are complex mixtures comprised of a large number of constituents in variable ratios. EOs contain natural flavors and fragrances grouped as monoterpenes (hydrocarbons and oxygenated derivatives), sesquiterpenes (hydrocarbons and oxygenated derivatives) and aliphatic compounds (alkanes, alkenes, ketones, aldehydes, acids and alcohols) that provide characteristic odors. Many EOs isolated from various plant species belonging to different genera, contain relatively high amount of monoterpenes. Jointly or independently they may contribute to the protection of plants against herbivores, although some herbivores have counter adapted to them (DEVI & MAJI, 2011; SAFAEI-KHORRAM *et al*., 2011). Plant EOs show wide and varied bioactivities against both agricultural pests and medically important insect species, ranging from toxicity with ovicidal, larvicidal, pupicidal and adulticidal activities to sublethal effects including oviposition deterrence, anti-feedant activity and repellent actions as well as they may affect on biological parameters such as growth rate, life span and reproduction (EBADOLLAHI, 2011b; ZOUBIRI & BAALIOUAMER, 2011a,b). Accordingly, the use of plant EOs can lead to the identification of new bioinsecticides.

Some of the plant families known as excellent sources of EOs with insecticidal properties that Apiaceae family is one of them. Apiaceae (Umbelliferae) is one of the best known families of flowering plants, which comprise 300–450 genus and 3000–3700 species. They are aromatic plant and have a distinctive flavor which diverse volatile compounds from the fruits and leaves. The plants of Apiaceae (Umbelliferae) family are occurring throughout the world, but it is most common in temperate regions and rare in the tropics. The most obvious distinctive feature of the family is the inflorescence, which is a simple or compound umbel. Umbelliferae refers to the characteristic umbellate inflorescence. Having bilaterally symmetric flowers towards the outside of the inflorescence tends to make the inflorescence as a whole resemble a single flower (BERENBAUM, 1990; CHRISTENSEN & BRANDT, 2006). The family includes many herbs, spices and medicines, would rank among the most important families of plant.

Although a number of review articles have appeared in the past on the various aspects of *EO*s bioactivities (ISMAN, 2000; BINDRA, *et al*., 2001; PETERSON, & COATS, 2001; BAKKALI *et al*., 2008; ISMAN *et al*., 2008: TRIPATHI, 2009: EBADOLLAHI, 2011b: ZOUBIRI & BAALIOUAMER, 2011b; REGNAULT-ROGER *et al*., 2012) but the present paper emphasizes on the potential of Apiaceae EOs in insect-pest management. In fact, the present study attempted to explain the efficiency of EOs from Apiaceae family and their components as phytochemicals with lethal and sublethal effects against insect pests.

Lethal toxicity

The insecticidal activity of many EOs from Apiaceae has been evaluated against a number of insects. The isolation and identification of the bioactive compounds and EOs from Apiaceae are of utmost importance so that their potential application in controlling insect pests can be fully exploited. Table 1 shows lethal toxicity of *EO*s isolated from Apiaceae family against different insect pests that published since 2000. EOs have several characteristics that improve their efficacy as insecticides. They are both phytochemically diverse (containing many biosynthetically different compounds) and redundant (containing many analogs of one class) (REGNAULT-ROGER *et al*., 2012). *EO* are natural products that contain natural flavors and fragrances grouped as monoterpenes (hydrocarbons and oxygenated derivatives), sesquiterpenes (hydrocarbons and oxygenated derivatives) and aliphatic compounds (alkanes, alkenes, ketones, aldehydes, acids and alcohols) that provide characteristic odors. Among components of EOs, terpenes especially monoterpenoids and sesquiterpenes have been shown to be toxic to a variety of insects (HUMMELBRUNNER & ISMAN, 2001; LEE *et al*., 2002; ERLER, 2005; STAMOPOULOS *et al*., 2007). Previous studies have also shown that the toxicity of *EO*s obtained from aromatic plants against insect pests is related to the oil's main components such as 1.8-cineole, carvacrol, eugenol, limonene, α-pinene and thymol. For example, EOs from seeds of *Coriandrum sativum*, and *Carum carvi* L. were tested in the laboratory for volatile toxicity against *Sitophilus oryzae*, *Rhyzopertha dominica* (F.) and *Cryptolestes pusillus* (Stephens). Coriander contained linalool (1617 ppm of the oil) as the main product active against the three pests. Camphor-rich fractions (over 400 ppm) were very toxic to *Rhyzopertha dominica* and *Cryptolestes pusillus*. The caraway profile included carvone, limonene and (E)-anethole as major components. Carvone was the most effective (972 ppm) monoterpenoid against *Sitophilus oryzae*. In addition, (E)-anethole at 880 ppm was toxic to *Rhyzopertha dominica* while vapors of limonene (1416 ppm) fractions killed adults of *Cryptolestes pusillus* only (LOPEZ *et al*., 2008). In the study of EVERGETIS *et al*. (2009) insecticidal properties of six different taxa of the Apiaceae family (*Heracleum sphondylium* ssp. *pyrenaicum*, *Seseli montanum* ssp. *tomasinii*, *Conopodium capillifolium* Coss., *Bupleurum fruticosum* L., *Oenanthe pimpinelloides* L. and *Eleoselinum asclepiu*m Bert.) were evaluated against *Culex pipiens* third to fourth instar larvae in order to delineate the relationship between the EOs phytochemical content and larvicidal activity. Results indicated that the oil of *Oenanthe pimpinelloides*, which contains mainly nonoxygenated monoterpenes, possesses the highest activity, displaying a

LC_{50} value of 40.26 mg/l. On the contrary, the EO of *Eleoselinum asclepium*, which is consisted of pinenes and oxygenated monoterpenes, was the less active (LC_{50} value of 96.96 mg/l). These results reveal that the nonoxygenated monoterpenes possess potent insecticidal activities against *Culex pipiens*. Our recent study showed that *Azilia eryngioides* (Pau) Hedge Et Lamond oil had a strong insecticidal activity on adult of *Sitophilus granarius* and *Tribolium castaneum*. Major components in this oil were α-pinene (63.8%) and bornyl acetate (18.9%). The 37.03 µl/l concentration and 48-h exposure time was enough to attain 100 % mortality of all the insects. The EO concentration to cause LC_{50} in *S. granarius* was 20.05 µl/l, whereas it was 46.48 µl/l in *Tribolium castaneum* after a 24-h treatment. Results revealed that the insecticidal activity of *A. eryngioides EO* could be related to these constituents (EBADOLLAHI & MAHBOUBI, 2011). Larvicidal activities of EOs isolated from fourteen different taxa of the Apiaceae family including *Angelica sylvestris* L., *Athamanta densa* Boiss. & Orph., *Chaerophyllum heldreichii* Orph. Ex Boiss., *Ferulago nodosa* (L.), *Laserpitium pseudomeum* Orph., Heldr. & Sart. Ex Boiss., *Peucedanum neumayeri* (Vis.) Reichenb, *Peucedanum officinale* L., *Pimpinella tragium* Vill., *Pimpinella peregrina* L., *Pimpinella rigidula* (Boiss. & Orph.) H. Wolf, *Scaligeria cretica* (Miller), *Seseli parnassicum* Boiss. & Heldr., *Smyrnium rotundifolium* Miller and *Thamnosciadium junceum* (Sibth. & Sm.) Hartvig against 3^{rd}-4^{th} instar larvae of *Culex pipiens* were evaluated by EVERGETIS *et al.* (2012) and their LC_{50} values calculated as >150, 10.15, 53.61, 67.39, 56.73, 47.40, 86.46, 40.13, >150, 40.31, 111.99, 122.54, 80.32 and 44.17 mg/l, respectively. The EO derived from the endemic in Greece plant *Athamanta densa* was determined as the most active since displayed the highest toxicity against mosquito larvae, with LC_{50} value 10.15 mg/l. The EO tested contains a series of compounds which were not found in the other EOs tested, such as bisabolene and the unidentified compounds $C_{14}H_{30}O$, $C_{12}H_{25}O_2N$ and $C_{13}H_{27}O_2N$, which have to study more thoroughly in order to determine their activities. The Apiaceae EOs with toxic effects against insect pests have known to contain the active terpenes such as anethole, camphor, carvone, cymene, linalool, thymol, *α*-pinene and *β*-pinene, which are common constituents of many Apiaceae Eos (Table 2). From above studies, it could be found that the efficacy of EOs varies according to the phytochemical profile of the plant oil and the entomological target. In fact, toxicity of EOs to insects was influenced by the chemical composition of the oil, which in turn depended on the source, season and ecological conditions, method of extraction, time of extraction and plant part used. Bioactivity of EOs is also affected by interactions among their structural components. Even minor compounds can have a critical function due to additive action between chemical classes and synergism or antagonism.

Table 1. Summary of reports indicating lethal toxicity of essential oils isolated from Apiaceae family.

Plant species	Insecticidal activity and tested insect	Reference
Ammi visnaga	Ovicidal activity against *Mayetiola destructor*.	LAMIRI *et al*., 2001
	Adulticidal and ovicidal activity against *Callosobruchus maculatus*.	TRIPATHI *et al*., 2001b
Anethum graveolense	Larvicidal against third instar larvae of *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*.	AMER & MEHLHORN, 2006a,b
	Adulticidal activity on *callosobrucus chinensis*	UPADHYAY *et al*., 2007
	Fumigant toxicity against *Callosobruchus chinensis*.	CHAUBEY, 2008
	Fumigant antitermitic activity against *Reticulitermes speratus*.	SEO *et al*., 2009

	Fumigant toxicity against adults of *Callosobruchus chinensis*	CHAUBEY, 2011a
	Fumigant toxicity against *Callosobruchus maculatus* adults.	EBADOLLAHI *et al*., 2012
	Contact and fumigant toxicity against adult male and female of *Blattella germanica*.	YEOM *et al*., 2012
Angelica archangelica	Fumigant toxicity against *Lycoriella mali* adults.	CHOI *et al*., 2006
Angelica dahurica	Contact and fumigant toxicity against adults of *Lasioderma serricorne*.	KIM *et al*., 2003a
	Adulticidal on *Sitophilus oryzae* and *Callosobruchus chinensis*.	KIM *et al*., 2003b
Angelica sylvestris	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Apium graveolens	Adulticidal fumigant toxicity against *Acanthoscelides obtectus*.	PAPACHRISTOS & STAMOPOULOS, 2002
	Larvicidal against *Anopheles dirus* and *Aedes aegypti*.	PITASAWAT *et al*., 2007
	Larvicidal against *Lucilia sericata*.	KHATER & KHATER, 2009
	Adulticidal and larvicidal activity against early fourth instars of *A. aegypti*.	KUMAR *et al*., 2012
Athamanta densa	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Athamanta haynaldii	Larvicidal effect against the second instar gypsy moth larvae.	KOSTIĆA *et al*., 2013
Azilia eryngioides	Fumigant toxicity on adult of *Sitophilus granarius* and *Tribolium castaneum*.	EBADOLLAHI & MAHBOUBI, 2011
Azorella cryptantha	Toxic effects on *Ceratitis capitata*.	LÓPEZ *et al*., 2012
Bifora radians	Adulticidal effect on *Lipaphis pseudobrassicae*.	SAMPSON *et al*., 2005
Bunium persicum	Fumigant toxicity against adults of *Tribolium castaneum*.	MORAVEJ *et al*., 2009
Bupleurum fruticosum	Larvicidal against *Culex pipiens* larvae	EVERGETIS *et al*., 2009
Carum carvi	Fumigant toxicity against eggs, nymphs, and adults of *Trialeurodes vaporariorum*.	CHOI *et al*., 2003
	Larvicidal against *Aedes aegypti* and *Culex quinquefasciatus*.	LEE, 2006
	Larvicidal against *Anopheles dirus* and *Aedes aegypti*.	PITASAWAT *et al*., 2007
	Adulticidal effect against *Sitophilus oryzae*, *Rhyzopertha dominica* and *Cryptolestes pusillus*.	LOPEZ *et al*., 2008
	Fumigant antitermitic activity against *Reticulitermes speratus*.	SEO *et al*., 2009
	Contact toxicity against *Sitophilus zeamais* and *Tribolium castaneum* adults.	FANG *et al*., 2010
	Adulticidal on *Meligethes aeneus*.	PAVELA, 2011
	Contact and fumigant toxicity against adult male and female of *Blattella germanica*.	YEOM *et al*., 2012
Carum copticum	Adulticidal activity against *Sitophilus oryzae* and *Tribolium castaneum*.	SAHAF *et al*., 2007
	Adulticidal activity on *callosobrucus chinensis*.	UPADHYAY *et al*., 2007
	Ovicidal, larvicidal and Adulticidal against *callosobrucus maculatus*.	SAHAF & MOHARRAMI POUR, 2008a
	Toxicity against the workers of the *Odontotermes obesus* termite.	GUPTA *et al*., 2011
	Fumigant toxicity against adults of *Tribolium confusum, Rhyzopertha dominica* and *Oryzaphilus surinamensis*.	HABASHI *et al*., 2011
Centella asiatica	Larvicidal against *Culex quinquefasciatus*.	RAJKUMAR & JEBANESAN, 2005

Chaerophyllum heldreichii	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Cnidium officinale	Contact and fumigant toxicity against adults of *Lasioderma serricorne*.	KIM *et al*., 2003a
	Adulticidal on *Sitophilus oryzae* and *Callosobruchus chinensis*.	KIM *et al*., 2003b
Conopodium capillifolium	Larvicidal against *Culex pipiens* third to fourth instar larvae.	EVERGETIS *et al*., 2009
Coriandrum sativum	Fumigant toxicity against eggs, nymphs, and adults of *Trialeurodes vaporariorum*.	CHOI *et al*., 2003
	Adulticidal effect on *Lipaphis pseudobrassicae.*	SAMPSON *et al*., 2005
	Fumigant toxicity against adults of *Sitophilus oryzae*, *Rhyzopertha dominica* and *Cryptolestes pusillus*.	LOPEZ *et al*., 2008
	Larvicidal activity against *Ochlerotatus caspius*.	KNIO *et al*., 2008
	Toxicity against *Sitophilus granarius* adults.	ZOUBIRI & BAALIOUAMER, 2010
	Larvicidal activity against *Anopheles stephensi*.	SEDAGHAT *et al*., 2011
	Adulticidal against *Tribolium confusum* and *Callosobruchus maculatus*.	KHANI & RAHDARI, 2012
	Contact toxicity on *Diaphorina citri* adults.	MANN *et al*., 2012
Cuminum cyminum	Ovicidal activity against eggs of *Tribolium confusum* and *Ephestia kuehniella*.	TUNC *et al*., 2000
	Larvicidal against *Culex quinquefasciatus*.	PRAJAPATI *et al*., 2005
	Adulticidal activity on *Callosobrucus chinensis*.	UPADHYAY *et al*., 2007
	Fumigant toxicity against *Callosobruchus chinensis*.	CHAUBEY, 2008
	Fumigant activity against *Sitophilus oryzae* adults.	CHAUBEY, 2011b
	Fumigant toxicity against *Callosobruchus maculatus* adults.	EBADOLLAHI *et al*., 2012
	Larvicidal against early fourth instar larvae of *Culex quinquefasciatus*.	RANA & RANA, 2012
	Contact and fumigant toxicity against adult male and female of *Blattella germanica*.	YEOM *et al*., 2012
Cymbocarpum erythraeum	Larvicidal effects on *Drosophila melanogaster*.	AKSAKAL *et al*., 2012.
Daucus carota	Larvicidal against *Aedes aegypti* and *Culex quinquefasciatus*.	LEE, 2006
Eleoselinum asclepium	Larvicidal against *Culex pipiens* third to fourth instar larvae.	EVERGETIS *et al*., 2009
Ferula gummosa	Larvicidal against third instar larvae of *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*.	AMER & MEHLHORN, 2006a,b
Ferulago angulata	Insecticide effects on *Tribolium castaneum*.	ATASHI *et al*., 2012
Ferulago nodosa	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Foeniculum vulare	Fumigant toxicity against adults of *Tribolium castaneum*.	LEE *et al*., 2002
	Contact and fumigant toxicity against adults of *Lasioderma serricorne*.	KIM *et al*., 2003a
	Adulticidal on *Sitophilus oryzae* and *Callosobruchus chinensis*.	KIM *et al*., 2003b
	Adulticidal effect on *Lipaphis pseudobrassicae*.	SAMPSON *et al*., 2005
	Fumigant toxicity against *Lycoriella mali* adults.	CHOI *et al*., 2006
	Larvicidal against *Anopheles dirus* and *Aedes aegypti*.	PITASAWAT *et al*., 2007
	Adulticidal activity on *callosobrucus chinensis*.	UPADHYAY *et al*., 2007
	Aphidicidial activity against *Brevicoryne brassicae.*	ISIK & GORUR, 2009
	Larvicidal activity against *Culex pipiens.*	MANOLAKOU *et al*., 2009
	Larvicidal activity against *Aedes albopictus*.	CONTI *et al*., 2010

	Fumigant activity against *Sitophilus oryzae* and *Sitophilus granarius* adults.	EBADOLLAHI, 2011c
	Adulticidal on *Meligethes aeneus*.	PAVELA, 2011
	Larvicidal activity against *Anopheles stephensi*.	SEDAGHAT *et al*., 2011
	Fumigant toxicity on *Sitophilus granaries*.	ZOUBIRI & BAALIOUAMER, 2011a
	Fumigant toxicity against *Callosobruchus maculatus* adults.	EBADOLLAHI *et al*., 2012
	Larvicidal against early fourth instar larvae of *Culex quinquefasciatus*.	RANA & RANA, 2012
	Fumigant toxicity on adults of *Callosobruchus maculatus*.	MANZOOMI *et al*., 2010
Heracleum persicum	Adulticidal against *Plodia interpunctella*.	EBADOLLAHI & ASHOURI, 2011
	Larvicidal activity against *Anopheles stephensi*.	SEDAGHAT *et al*., 2011
	Adulticidal against *Callosobruchus maculatus*.	IZAKMEHRI *et al*., 2012
Heracleum sphondylium	Larvicidal against *Culex pipiens* larvae.	EVERGETIS *et al*., 2009
Laserpitium pseudomeum	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Ligusticum hultenii	Termiticidal activity against *Coptotermes formosanus*.	MEEPAGALA *et al*., 2006
Ligusticum mutellina	Contact toxicity on third instar of *Pseudaletia unipuncta*.	PASSREITER *et al*., 2005
Oenanthe pimpinelloides	Larvicidal against *Culex pipiens* larvae.	EVERGETIS *et al*., 2009
Ostericum sieboldii	Contact and fumigant toxicity against *Tribolium castaneum* and *Sitophilus zeamais* adults.	LIU *et al*., 2011a
Petroselinum sativum	Larvicidal activity against *Ochlerotatus caspius*.	KNIO *et al*., 2008
	Larvicidal against *Culex pipiens*.	KHATER & SHALABY, 2008
	Ovicidal and larvicidal activity against *Plodia interpunctella*.	RAFIEI-KARAHROODI *et al*., 2011
Peucedanum neumayeri	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Peucedanum officinale	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Pimpinella anisum	Ovicidal activity against eggs of *Tribolium confusum* and *Ephestia kuehniella*.	TUNC *et al*., 2000
	Fumigant toxicity against adults of *Tribolium castaneum*.	LEE *et al*., 2002
	Larvicidal, Adulticidal and ovicidal activities towards *Anopheles stephensi*, *Aedes aegypti* and *Culex quinquefasciatus*.	PRAJAPATI *et al*., 2005
	Adulticidal effect on *Lipaphis pseudobrassicae*.	SAMPSON *et al*., 2005
	Fumigant toxicity against Lycoriella ingénue.	PARK *et al*., 2006
	Larvicidal activity against *Ochlerotatus caspius*.	KNIO *et al*., 2008
	Fumigant toxicity on *Pediculus humanus capitis* adults.	TOLOZA *et al*., 2010
Pimpinella peregrina	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Pimpinella rigidula	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Pimpinella tragium	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012
Polylophium Involvucratum	Larvicidal against *Anopheles stephensi* and *Culex pipiens*	VERDIAN-RIZI & HADJIAKHOONDI, 2007
Prangos acaulis	Adulticidal and larvicidal against *Callosobruchus maculatus*.	TAGHIZADEH-SARIKOLAEI & MOHARAMIPOUR, 2010
Scaligeria cretica	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al*., 2012

Seseli montanum	Larvicidal against *Culex pipiens* third to fourth instar larvae.	EVERGETIS *et al.*, 2009
Seseli parnassicum	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al.*, 2012
Smyrnium rotundifolium	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al.*, 2012
Thamnosciadium junceum	Larvicidal against third to fourth instar larvae of *Culex pipiens*.	EVERGETIS *et al.*, 2012
Trachyspermum ammi	Fumigant toxicity against *Anopheles stephensi*.	PANDEY *et al.*, 2009
	Fumigant antitermitic activity against *Reticulitermes speratus*.	SEO *et al.*, 2009
	Contact and fumigant toxicity against adult male and female of *Blattella germanica*.	YEOM *et al.*, 2012
	Fumigant toxicity against adults of *Callosobruchus chinensis*.	CHAUBEY, 2011a

Table 2. Summary of reports on main components in the introduced Apiaceae essential oils as insecticides.

Plant species	Main constituents	Reference
Ammi visnaga	Isobutyrate (14.0%), 2,2-dimethylbutanoic acid (30.1%), croweacin (12.2%) and linalool (12.1%).	KHALFALLAH *et al.*, 2011
Anethum graveolense	Carvone (57.3%) and Limonene (33.2%).	SEFIDKON, 2001
Angelica archangelica	α-Pinene (19.1%), δ-3-carene (16.0%), β-limonene (8.0%) and osthol (3.6%).	NIVINSKIENCE *et al.*, 2003
Angelica dahurica	3-Carene (12.7%), beta-elemene (6.2%), beta-terpinene (3.5%) and beta-myrcene (1.9%).	ZHAO *et al.*, 2011
Angelica sylvestris	β-Phellandrene (42.9%), α-pinene (24.6%), myrcene (4.7%) and germacrene D (4.4%).	EVERGETIS *et al.*, 2012
Apium graveolens	(Z)-3-Butylidenephthalide (27.8%), 3-butyl-4,5-dihydrophthalide (34.2%) and α-thujene (7.9%).	SELLAMIA *et al.*, 2012
Athamanta densa	β-Bisabolene (12.7%), β-pinene (8.8%), trans-ocimene (5.1%) and Myrcene (4.3%).	EVERGETIS *et al.*, 2012
Azilia eryngioides	α-Pinene (63.8%), bornyl acetate (18.9%), β-pinene (2.6%) and linalool (2.1%).	EBADOLLAHI & MAHBOUBI, 2011
Azorella cryptantha	α-pinene, α-thujene, sabinene and δ-cadinene.	LÓPEZ *et al.*, 2012
Bifora radians	(E)-2-tridecenal (47.2%) and (E)-2-tetradecenal (23.4%).	BASERA *et al.*, 1998
Bunium persicum	ρ-Cuminaldehyde (16.9%), γ-terpinen-7-al (10.5), ρ-cymene (8%) and γ-terpinene (4.2%).	AZIZI *et al.*, 2009
Bupleurum fruticosum	α-Pinene (37.8%), β-pinene (28.5%), β-phellandrene (21.6%) and cis-ocimene (5.4%).	EVERGETIS *et al.*, 2009
Carum carvi	(R)-Carvone (37.9%), D-limonene (26.5%), α-pinene (5.2%) and cis-carveol (5.0%).	FANG *et al.*, 2010
Carum copticum	Thymol (41.3%), α-terpinolene (17.4%) and ρ-cymene (11.7%).	SAHAF *et al.*, 2007
Centella asiatica	α-Humulene (21.0%), β-caryophyllene (19.0%), bicyclogermacrene (11.2%) and germacrene B (6.2%).	OYEDEJI & AFOLAYAN, 2005
Chaerophyllum heldreichii	Sabinene (71.76%), β-Phellandrene (10.86%), α-terpineol (3.35%) and γ-terpinene (2.54%).	EVERGETIS *et al.*, 2012
Cnidium officinale	cis-Butylidene phthalide (33.2%), 3-butyl phthalide (21.1%), cis-3-isobutylidene phthalide (10.1%) and terpinen-4-ol (8.5%).	CHOI *et al.*, 2002
Conopodium capillifolium	α-Pinene (37.8%), Sabinene (29.1%), p-Cymene (4.6%) and Limonene (4.1%).	EVERGETIS *et al.*, 2009
Coriandrum sativum	Linalool (57.1%), trans-anethol (19.8%), c-terpinene (3.8%) and geranyl acetate (3.2%).	KNIO *et al.*, 2008
Cuminum cyminum	Caryophyllene oxide (6.1%), α-pinene (4.8%), geranyl acetate (4.1%) and âcaryophyllene (3.4%).	ROMEILAH *et al.*, 2010

Cymbocarpum erythraeum	(E)-2-Decenal (52.2%), (2E)-dodecenal (15.7%), 8S.14-cedranediol (8.5%) and ntetradecenal (5.5%).	AksakAl *et al.*, 2012.
Daucus carota	Carotol (66.7%), daucene (8.7%), (Z,Z)-α farnesene (5.8%) and germacrene D (2.3%).	ÖZCAN & CHALCHAT, 2007
Eleoselinum asclepium	Sabinene (35.3%), α-Pinene (27.4%), Myrcene (5.9%) and β-Pinene (5.2%).	EVERGETIS *et al.*, 2009
Ferula gummosa	Sabinene (40.1%), α-pinene (14.3%), β-pinene (14.1%) and p-cymene (8.46%).	ABEDI *et al.*, 2008
Ferulago angulate	α-Pinene (27٪), cis-ocimene (22٪), and bornyl acetate (8.5٪) and trans-verbenol (5.8%).	GHASEMPOUR *et al.*, 2007
Ferulago nodosa	α-Pinene (30.8٪), β-Phellandrene (10.2%), myrcene (6.6%) and camphene (4.3%).	EVERGETIS *et al.*, 2012
Foeniculum vulare	Methyl clavicol (43.5%), α-phellandrene (16.0%) and fenchone (11.8%) .	CONTI *et al.*, 2010
Heracleum persicum	(E)-Anethole (47.0%), terpinolene (20.0%), γ-terpinene (11.6%) and Limonene (11.5%).	SEFIDKON *et al.*, 2004
Heracleum sphondylium	Octyl acetate (17.4%), limonene (13.1%), trans-β-farnesene (6.3%) and germacrene-D (5.0%).	EVERGETIS *et al.*, 2009
Laserpitium pseudomeum	α-Pinene (49.5%), sabinene (24.7%), β-pinene (8.5%) and α-Phellandrene (6.7%).	EVERGETIS *et al.*, 2012
Ligusticum mutellina	Myristicin (39.3%) and alpha-phellandrene (23.4%).	BRANDT & SCHULTZE, 1995
Oenanthe pimpinelloides	γ-Terpinene (43.2%), o-Cymene (14.4%), β-Sesquiphellandrene (8.2%) and β-Pinene (6.7%).	EVERGETIS *et al.*, 2009
Ostericum sieboldii	Myristicin (30.3%), α-terpineol (9.9%), α-cadinol (7.2%) and β-farnesene (6.2%).	LIU *et al.*, 2011a
Petroselinum sativum	Apiol (18.2%), α-pinene (16.1%) and β-pinene (11.1%).	ROMEILAH *et al.*, 2010
Peucedanum neumayeri	γ-Terpinene (32.2%), α-pinene (21.2%), β-phellandrene (12.7%) and cis-ocimene (4.7%).	EVERGETIS *et al.*, 2012
Peucedanum officinale	1-Bornyl acetate (81.1%), 2,3,4-trimethyl bezaldehyde (4.6%) and liminene (2.7%).	EVERGETIS *et al.*, 2012
Pimpinella anisum	trans-Anethol (76.7%), anisalacetone (7.1%), estragol (6.1%) and anisaldehyd (1.5%).	KNIO *et al.*, 2008
Pimpinella peregrina	α-Brgamontene (62.1%), aristolene (19.9%), β-selinene (3.7%) and calaren (3.4%).	EVERGETIS *et al.*, 2012
Pimpinella rigidula	β-Selinene (23.2%), trans-isomiristicin (7.7%), α-zingiberene (7.7%) and miristicin (6.7%).	EVERGETIS *et al.*, 2012
Pimpinella tragium	Germacrene (23.3%), germacrene B (19.2%), geigerene (10.2%) and pregeigerene (5.1%).	EVERGETIS *et al.*, 2012
Polylophium Involvucratum	Limonene (60.3%), perillaldehyde (25.8%), α-pinene (7.1%) and perillalcohol (6.6%).	VERDIAN-RIZI & HADJIAKHOONDI, 2007
Prangos acaulis	δ-3-Carene (25.5%), α-terpinolene (14.7%), α-pinene (13.%) and limonene (12.9%).	MESHKATALSADAT *et al.*, 2010
Scaligeria cretica	β-Farnesene (29.2%), germacrene D (28.3%), sabinene (13.7%) and α-pinene (8.7%).	EVERGETIS *et al.*, 2012
Seseli montanum	α-Pinene (32.2%), Sabinene (16.9%), β-Phellandrene (19.0%) and Myrcene (4.9%).	EVERGETIS *et al.*, 2009
Seseli parnassicum	β-Sesquiphellandrene (30.3%), germacrene D (13.0%), germacrene B (10.6%) and β-elemene (10.8%).	EVERGETIS *et al.*, 2012
Smyrnium rotundifolium	Myrcene (11.2%), furanodiene (11.8%), germacrone (5.6%) and α-selinene (5.2%).	EVERGETIS *et al.*, 2012
Thamnosciadium junceum	Limonene (40.7%), cis-ocimene (18.5%), terpinolene (12.9 %), trans-isomirticisin (10.1%).	EVERGETIS *et al.*, 2012
Trachyspermum ammi	Thymol (41.7%), γ-terpinene (27.7%), *p*-cymene (24.40%) and β-pinene (1.4%).	PARK *et al.*, 2007

Sublethal toxicity

Investigations in several countries confirm that some plant *EO*s not only have lethal toxicity, but possess repellency against insect pests as well as exhibited feeding inhibition or harmful effects on the reproductive system and growth of insects. In the following, repellent, Antifeedant, oviposition deterrent, growth inhibition and progeny production effects of some EOs from Apiaceae family that recently published will be discussed as sublethal toxicityies;

a- Repellent: The repellents are desirable chemicals as they offer protection with minimal impact on the ecosystem, as they drive away the insect pest from the treated materials by stimulating olfactory or other receptors. Concern over health implications from the use of residual and broad insecticidal spray treatments has been impetus for research on alternative methods. Repellents from plant origins are considered safe in pest control for minimize pesticide residue; ensure safety of the people, and environment. Repellents may play a very important role in some situations or in some special space where the insecticides are not able to use. Many plant EOs and their components have been shown to have good repellent activity against insect pests. Insect repellent activity of some EOs from Apiaceae family summarized in Tables 3. The major promising uses for EOs in the human health are for repelling biting flies. The anti-mosquito activities of some of *EO*s from Apiaceae plants are shown in table 1 (lethal toxicity) and table 3 (repellency). In 2007 RAJKUMAR & JEBANESAN, investigated the repellent effect of *Centella asiatica* (L.) Urb. EO against the malaria fever mosquito *Anopheles stephensi* Liston in mosquito cages. The oil was tested at three concentrations: 2, 4 and 6%. In general, a dose-dependent effect was noticed. The highest concentration (6%) led to the highest repellency effect. The results showed repellency effect at the highest concentration (6%) lasted up to 150 min whereas ethanol (as a control) showed only 8 min repellency. The effect of thymol from the EO of *Tachyspermum ammi* against *Anopheles stephensi* was investigated by PANDEY *et al*. (2009). The larvicidal, oviposition deterrent, vapour toxicity and repellent activity against the malarial vector were evaluated. Thymol (major component in *Trachyspermum ammi* oil) showed an LD_{50} value of 48.88 mg/ml toward fourth-instar larvae of *A. stephensi*. So it was 1.6-fold more toxic than the oil, which showed an LD_{50} value of 80.77 mg/ml. After treatment with vapours of thymol the egg laying by female adults of this fly was significantly more reduced compared to the treatment with the EO. The evaluation of the egg hatching and larval survival showed similar results. The vapour toxicity assay exhibited an LC_{50} value of 185.4 mg/mat for the crude oil against adults of *A. stephensi*, whereas thymol showed an LC_{50} value of 79.5 mg/mat. After 1 h, the treatment of adult flies with 25.0 mg/mat of thymol demonstrated complete repellency. The same degree of repellency was obtained by the oil of *Trachyspermum ammi* at the dose of 55.0 mg/mat. This indicates that thymol possesses two-fold activity. Moreover, the repellency of *a*-pinene, myrcene, carvacrol, thymol and caryophyllene oxide was found 2, 4, 6, and 24 h after treatment against *Tribolium castaneum* adults. In addition, caryophyllene oxide and *a*-pinene gave 85 and 82% at 0.001 mg/cm^2, respectively and hydrogenated monoterpenoids such as thymol, carvacrol, and myrcene also showed more than 77% at 0.03 and 0.006 mg/cm^2 repellent activity (KIM *et al*., 2012). These monoterpenoids are major constituents in the many Apiaceae EOs. Results emphasize the performance of EOs and components isolated from Apiaceae family as repellents. The repellent properties of the tested EOs are not unexpected given that EO products are generally considered broad spectrum because of multiple active ingredients and modes of action. In conclusion, the identification of these potential repellent plants from the local flora will generate local employment and stimulate local efforts to enhance public health.

Table 3. Summary of reports indicating repellent of essential oils isolated from Apiaceae family.

Plant species	Tested insect	Reference
Anethum graveolens	*Aedes aegypti, Anopheles stephensi, Culex quinquefasciatus*	AMER & MEHLHORN, 2006c
	Adults of *Tribolium castaneum*	CHAUBEY, 2007
	Adults of *Plodia Interpunctella*	RAFIEI-KARAHROODI *et al.*, 2009b
Angelica sinensis	*Blattella germanica*	LIU *et al.*, 2011b
Apium graveolens	Adults of *Acanthoscelides obtectus*	PAPACHRISTOS & STAMOPOULOS, 2002
	Aedes aegypti	KUMAR *et al.*, 2012
Carum carvi	female *Culex pipiens* adults	KANG *et al.*, 2009
	Adults of *Plodia Interpunctella*	RAFIEI-KARAHROODI *et al.*, 2009b
	Blattella germanica, *Periplaneta americana* and *Periplaneta fuliginosa*	YOON *et al.*, 2009
	Adults of *Meligethes aeneus*.	PAVELA, 2011
Centella asiatica	*Anopheles stephensi*	RAJKUMAR & JEBANESAN, 2007
Coriandrum sativum	*Tribolium castaneum*	ISLAM *et al.*, 2009
	female *Culex pipiens* adults	KANG *et al.*, 2009
	Blattella germanica, *Periplaneta americana* and *Periplaneta fuliginosa*	YOON *et al.*, 2009
	Sitophilous oryzae and *Tribolium castaneum*	MISHRA & TRIPATHI, 2011
Cuminum cyminum	Adults of *Diaphorina citri*	MANN *et al.*, 2012
	Sitophilus oryzae adults	CHAUBEY, 2011b
Foeniculum vulgare	Adults of *Sitophilous zeamais*, *Cryptolestes ferrugineus* and larvae of *Tenebrio molitor*	COSIMI *et al.*, 2009
	female *Culex pipiens* adults	KANG *et al.*, 2009
	Adults of *Plodia Interpunctella*	RAFIEI-KARAHROODI *et al.*, 2009b
	Adults of *Meligethes aeneus*.	PAVELA, 2011
Ferula assa-foetida	Adults of *Ectomyelois ceratoniae*	PEYROVI *et al.*, 2011
Ferula galbaniflua	*Aedes aegypti, Anopheles stephensi, Culex quinquefasciatus*	AMER & MEHLHORN, 2006c
Petroselinum sativum	Adults of *Plodia Interpunctella*	RAFIEI-KARAHROODI *et al.*, 2009b
Pimpinella anisum	*Anopheles stephensi*, *Aedes aegypti* and *Culex quinquefasciatus*	PRAJAPATI *et al.*, 2005
	Culex pipiens	ERLER *et al.*, 2006
Pturanths tortosus	larvae and moths of *Phthorimaea operculella*	SHARABY *et al.*, 2009
Tachyspermum ammi	Adults of *Tribolium castaneum*	CHAUBEY, 2007
	Anopheles stephensi	PANDEY *et al.*, 2009

b- Antifeedant: Feeding deterrents or antifeedants are materials that inhibit feeding but do not kill the insect directly. However, the insect may remain close to the plant but will die from starvation or dehydration rather than feeding from it. Such deterrents can be found among all of the major classes of secondary metabolites. Many *EO*s and their components have been known to exhibit antifeedant properties against insects (HUMMELBRUNNER & ISMAN, 2001; TRIPATHI *et al.*, 2001a; KIRAN *et al.*, 2007; BENZI *et al.*, 2009; EBADOLLAHI, 2011a; AKHTAR *et al.*, 2012). In the following, antifeedant activity of some EOs from Apiaceae family that recently published will be discussed. The effect of *Petroselinum sativum*, *Foeniculum vulgare*, *Carum carvi* and

*Anethum graveolens EO*s on nutritional indices of 15 days old larvae of *Plodia interpunctella* demonstrated by RAFIEI-KARAHROODI *et al*. (2009a). In other study, the EO extracted from *Carum copticum* was tested against *Tribolium castaneum*, for antifeedant activity (SAHAF & MOHARAMIPOUR, 2009). In this study, several experiments were designed to measure the nutritional indices such as relative growth rate (RGR), relative consumption rate (RCR), efficiency of conversion of ingested food (ECI) and feeding deterrence index (FDI). Results indicated that nutritional indices were significantly varied as EO concentrations increased and *Carum copticum* decreased RGR, RCR and ECI significantly. *Carum copticum EO* increased FDI as the oil concentration was increased, showing high feeding deterrence activity against *Tribolium castaneum*. In the study of KOSTIĆA *et al*. (2013) ethanol solutions of EO obtained from *Athamanta haynaldii* (Borbás & Uechtr.) Tutin. was tested for their toxicity and antifeedant activity against the second instar gypsy moth larvae. Tested oil showed low to moderate larvicidal effect in both residual toxicity test and in chronic larval mortality bioassay. However, antifeedant index achieved by application of tested solutions in feeding choice assay was significantly higher in comparison to control. They stated that low toxic and high antifeedant properties (antifeedant index 85-90%) make these EOs suitable for integrated pest management programs. Accordingly, exploration of the influence of chemical complexity of EOs on feeding behavior of insects can assist in the development of new crop protection products for use in integrated pest management systems. Understanding the role of each constituent in the efficacy of the oil renders an opportunity to create artificial blends of different constituents on the basis of their activity and efficacy against different pests. Feeding inhibitors have several advantages in plant protection, compared to traditional chemical methods. The host choice of generalists and specialists may be modified when inhibitors are used. If an insect species can feed on other plants than its targeted host, it can be easier to direct away than if it is highly specialized in one host. The range of insect species targeted may be chosen by either the chemical structure of the inhibitor or by the composition of a mixture of inhibitors, if different inhibitors are active against different species within the range. The practice of using feeding inhibition allows us to develop and exploit naturally occurring plant defense mechanisms, thereby reducing the use of traditional pest management chemicals.

c- Oviposition deterrent, growth inhibition and progeny production effects: Many Apiaceae EOs and their constituents were evaluated against insect pests for their efficiency on oviposition, egg hatching, growth inhibition and fecundity and progeny production. In the following, these effects from recent studies will be discussed. PAPACHRISTOS & STAMOPOULOS (2002) revealed that along with Adulticidal fumigant toxicity and repellent effect of *Apium graveolens*, this oil had a reduce fecundity, decrease egg hatchability, increase neonate larval mortality and adversely influence offspring emergence. Toxic and developmental inhibitory activity of the EOs from *Anethum graveolens* and *Trachyspermum ammi* against *Tribolium castaneum* were tested. The EOs reduced the oviposition potential and increased the developmental period of the insect. Fumigation of these EOs inhibited development of larvae to pupae and the pupae to adults and also resulted in the deformities in the different developmental stages of the insect (CHAUBEY, 2007). In similar study, along with insecticidal and oviposition effects, egg hatching and developmental inhibitory activities of *Anethum graveolens*, *Cuminum cyminum* and *Trachyspermum ammi* were determined against *Callosobruchus chinensis*. These EOs reduced the oviposition potential, egg hatching rate, pupal formation and emergence of adults of F1 progeny on the insect with fumigated by sublethal doses. Furthermore, these oils caused chronic toxicity as the fumigated insects caused less damage to the grains (CHAUBEY, 2008). Most of the EOs tested seem to have no effect upon the eggs hatchability, but increase the first instar larval mortality before penetration into the seeds. Those results must be due either to direct toxicity towards larvae or to an indirect effect such as repellency and/or antifeedant activity. Oviposition deterrence of EOs from dry seeds of *Carum copticum* with six concentrations (0.02-0.5l oil per one gram seed) was determined against *Callosobruchus maculatus* by SAHAF & MOHARAMIPOUR, 2008b. At the highest concentration (0.5 l per one gram seed) oviposition deterrence was reached to 100%. ISIK & GORUR (2009) studied the aphidicidial activity of *Foeniculum vulgare EO* against cabbage aphid, *Brevicoryne brassicae* L., under laboratory conditions. Applications of *Foeniculum vulgare EO* significantly reduced the reproduction potential of the cabbage aphid and resulted in higher mortality. The biological activity of EO extracted from *Coriandrum sativum* against eggs, larvae and adults of *Tribolium castaneum* was reported by ISLAM *et al*. (2009). On the developmental inhibition, individuals fumigated at the larval stage confirmed that the percentage of larvae reaching to pupal stage and pupae to adult stage, decreased significantly ($P < 0.001$) with increasing dosage concentration. Effect of the EO from *Ferula assa-foetida* was investigated on some reproductive behaviors of *Ectoyelois ceratoniae* (Zeller) under field and laboratory conditions. The EO can prevent pheromone release in the females and/or disrupt male searching behavior. Preliminary results from laboratorial data showed interference in pheromone production in females. Time period and number of pheromone production was decreased in the presence of the EO (KAMELSHAHI *et al*., 2010**)**. In the other study, fumigation of *Tribolium castaneum* adults with two sublethal concentrations of α-pinene, β-caryophyllene, main component of several members of Apiaceae family, and its binary combination reduced oviposition potential of insect. Oviposition was reduced to 71.91% and 58.54%, and 68.20% and 48.09% of the control when *Tribolium castaneum* adults were fumigated with 40 and 80% of 24-h LC_{50} of α-pinene and β-caryophyllene alone. Similarly, oviposition was reduced to 56.4% and 36.52% of control when *T. castaneum* adults were fumigated with 40 and 80% of 24-h LC_{50} of α-pinene and β-caryophyllene binary combination. The percentage of larvae transformed into the pupae and percentage of pupae transformed into adult were decreased when fumigated with two sublethal concentrations of α-pinene and β-caryophyllene alone or in binary combination. Pupation in treated larvae was reduced to 70.8% and 55%, 85% and 64.2%, and 64.2% and 34.2% of control when *Tribolium castaneum* larvae were fumigated with 40 and 80% of 24-h LC_{50} of α-pinene and β-caryophyllene alone or in binary combination respectively. Adult emergence was reduced to 50.8% and 39.2%, 66.7% and 45.8%, and 47.5% and 15.8% of control when *Tribolium castaneum* larvae were fumigated with 40 and 80% of 24-h LC_{50} of α-pinene and β-caryophyllene alone or in binary combination respectively (CHAUBEY, 2012). In the study of IZAKMEHRI *et al*. (2012), lethal and sublethal effects of EO from *Heracleum persicum* were evaluated on the adults of *Callosobruchus maculates*. The LC_{50} value of *Heracleum persicum* in fumigant toxicity was 136.36 µl/l air after 24 hours. The results showed that sublethal concentration of EO (78.78 µl/l air) negatively affected the longevity and fecundity of female adults. The sex ratio of *Callosobruchus maculatus* offspring was not significantly affected by EO. Inhabitation of egg hatching or ovicidal effect of EO extracted from seed of Parsley, *Petroselinum sativum*, on the eggs of *Ephestia kuehniella* was studied by SALAHI *et al*. (2012). The LC_{50} value of this oil for ovicidal effect on eggs of *Ephestia kuehniella* was assessed as 860 µl/l air. In another study, the EO and extracts obtained from the seeds of *Angelica archangelica* were used to determine the efficacy in terms of antifeedancy and growth inhibition of *Spodoptera littoralis* Boisd. larvae. Significant acute toxicity was caused only by the EO (LD_{50} 96 µg/larva). Significantly higher chronic toxicity was found for the extracts obtained using organic solvents (LD_{50} was estimated at 0.32, 0.82 and 0.52 mg/g for benzene, acetone and methanol, respectively), compared to the EO (LD_{50} = 7.53 mg/g). All the tested extracts and the EO caused growth inhibition. The highest larval growth inhibition was caused by the benzene extract, with ED_{50} estimated at 2.4 µg/g. All extracts and the EO also showed antifeedant activity. However, the benzene extract showed the highest efficacy (ED_{50} = 0.31 µg/cm^2), while the least efficacy was shown by the water extract (ED_{50} = 1.92 µg/cm) (PAVELA & VRCHOTOVÁ, 2013). EOs have been reported to have low vapour density than fatty oils. Hence, they are readily volatilized. This could be the reason why most of the eggs that might have hatched could not survive. These studies revealed good results for utilizing sublethal doses of EOs and its constituents (as antifeedant, repellent, reduction of egg laying, and hatching, progeny production and growth inhibitors) along with lethal dose for insect pest management.

Conclusion

The most attractive aspect of using EOs and/or their constituents for pest control is their favorable mammalian toxicity because many EOs and their constituents are commonly used as culinary herbs and spices and as medicines. It is found that the use of biopesticides will help in preventing the discarding of thousands of tons of pesticides on the earth and provide the residue free food and a safe environment to live (DEVI & MAJI, 2011). The present review shows a range of EOs and phytochemicals from Apiaceae family that exhibit interesting insecticidal properties against several inst pests.

Elucidation of the mode of action of oils and their constituents is of practical importance for insect control because it may give useful information on the most appropriate formulation and delivery means. Volatile oil can disrupt communication in mating behavior of insect by blocking the function of antennal sensilla and unsuccessful mating could lead to a lower fecundity and ultimately lower the population of insect pest (AHMED *et al*., 2001). Rapid action of EOs or its constituents against insect pests is an indicative of neurotoxic actions. Treatments the insects with natural compounds such as *EO*s or pure compounds may cause symptoms that indicate neurotoxic activity including hyperactivity, seizures, and tremors followed by paralysis (knock down), which are very similar to those produced by the insecticides pyrethroids. ENAN (2001) suggested that toxicity of constituents of EO is related to the octopaminergic nervous system of insects. Relatively few studies have been done on insecticidal activity or fumigant toxicity of caryophyllene oxide. Its high toxicity may result from the inhibition of the mitochondrial electron transport system because changes in the concentration of oxygen or carbon dioxide may affect respiration rate of insect, thus eliciting fumigant toxicity effects (EMEKCI *et al*., 2004). Several reports indicate that EOs and monoterpenoids cause insect mortality by inhibiting acetylcholinesterase enzyme (AChE) activity. Effects of furanocoumarins and pthalides isolated from *Angelica acutiloba* Kitagawa var. *sugiyame* Hikino against *Droshophila melanogaster* revealed the hypothesis that the insecticidal properties of the plant extracts are connected with the AChE (Acetylcholinesterase) inhibition (MIYAZAWA *et al*., 2004). Thymol binds to GABA receptors associated with chloride channels located on the membrane of postsynaptic neurons and disrupts the functioning of GABA synapses (PRIESTLEY *et al*., 2003).Further studies on cultured cells of *Periplaneta americana* (L.) and brains of *Drosophila melanogaster* demonstrated that eugenol mimics the action of octopamine and increases intracellular calcium levels (Enan, 2005). Ethanolic extract from the fruits of *Pimpinella anisoides* V Brig. exhibited activity against AChE and BChE (Butyrylcholinesterase), with IC_{50} values of 227.5 and 362.1 µg/ml, respectively. The most abundant constituents of the extract were *trans*-anethole that exhibited the high activity against AChE and BChE with IC_{50} values of 134.7 and 209.6 µg/ml, respectively (Menichini *et al*., 2009). It is confirmed that the insecticidal activity of *EO*s and/or monoterpenes is due to several mechanisms that affect multiple targets.

The physiological pattern of plants varies with the seasons and that within the same plant species different varieties may produce different chemical types having different effects on insects. From this point of view, it is very difficult to establish a clear relation between botanicals and insects because different varieties or even different parts of the same plant species give different effects. Accordingly, analytical studies should be carried out to determine the exact chemical structure of the extracted EOs and to clarify how each of their constituents influences insect physiology and behaviour. Moreover, EOs are complex mixtures of various molecules. Their biological effects might be either the result of a synergism of all molecules or could reflect only those of the main molecules. Almost literature cases analyses only the main constituents of EOs. In that sense, for biological purposes, it could be more informative to study the entire oil rather than some of its components because the concept of synergism seems to be important.

In conclusion, the development of natural or biological insecticides will help to decrease the negative effects of synthetic chemicals. Negative effects refer to residues in products and insect resistance. I believe that the present study with the utility of Apiaceae EOs and phytochemicals together with the previous studies on others support the biopesticidal nature of the plant derived EOs. These oils can be used as a cheap, safe and efficient alternative as well as a supplement, in the developing countries to protect the crops against the various plant pathogens. For all these reasons, we can infer that the EOs could be considered as a natural alternative in the control insects. However, for the practical application of the EOs as novel insecticides, further studies on the safety of the oils to humans and on development of formulations are necessary to improve the efficacy and stability and to reduce cost.

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