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Iranian Plant Essential Oils as Sources of Natural Insecticide Agents

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ABSTRACT

Stored cereals, oilseeds, pulses, spices, dried fruits, tree nuts and their processed foods which are important for food and trade purposes, suffer economic and quality losses due to insect pest attack. Chemical insecticides play major role in insect pest elimination from stored products. Increase of problems concerning use of synthetic chemical insecticides, such as persistence of residues, resistance and damage to the environment as well as human health has generated interest in naturally occurring products. Essential oils may have attractive or repellent effects and insecticidal action against certain insect pests. It was found that these bioactive compounds are potentially toxic to insects but relatively safe to human. In recent years, several studies were reported on toxicity of Iranian plant essential oils from different families such as Alliaceae, Apiaceae, Asteraceae, Cupressaceae, Graminaceae, Lamiaceae, Lauraceae, Myrtaceae, Pedaliaceae, Rutaceae, Scrophulariaceae, Verbenaceae and Zingiberaceae against various insect species. Previous studies have also shown that toxicity of essential oils is related to the oil's main components such as 1,8-cineole, thymol, eugenol, terpinene, limonene, α-pinene, carvacrol. Some of these oils and their constituent are widely used as flavoring agents in foods or considered as medicinal products. These advantages combined with wide availability of essential oils from flavor and fragrance industries have made it possible to commercialize of essential oil-based insecticides. Reports have indicated that isolated essential oils from Iranian plants and their major constituents are potential for utilization in insect pest management programs due to their availability, efficiency and safety to environment and non-target organisms.

Key words: Iranian plants, essential oils, chemical constituents, natural insecticides

INTRODUCTION

In recent years, scientists have focused on food protection to meet the demands of the rapidly expanding world population. One of the most important constraints of having every day sufficient food is the post harvest preservation of its quality and quantity. During storage, foods are currently destroyed by insect pests. Insects cause severe damage to the commodity resulting in losses in weight, seed viability and nutritive quality of foodstuffs. Stored products of agricultural and animal origin are attacked by more than 600 species of beetle pests and 70 species of moths causing quantitative and qualitative losses (Rajendran, 2002).

Fumigants and synthetic chemical protectants have played important and beneficial roles in the control of agricultural insect pests and the reduction of insect-borne diseases (Huang and Subramanyam, 2005). Fumigants such as phosphine and methyl bromide are mostly used against stored grain insect pests, not only because of their broad spectrum of activity but also their penetrating power and result in minimal residues on the treated products. Recently, other fumigants such as sulphuryl fluoride (Bell and Savvidou, 1999), carbonyl sulphide (Ren *et al.*,

2008) and ethyl formate (Haritos *et al.*, 2006) have also been investigated to control insect pests. Although these materials are effective, their repeated use for several decades has had its consequences. These insecticides are often associated with residues that are dangerous for the consumer and the environment and the low doses of many insecticides are toxic to humans and other animals and some insecticides are suspected to be carcinogens (Lamiri *et al.*, 2001; Passino *et al.*, 2004; Tapondjou *et al.*, 2005; Ali and Rizvi, 2008). The number of confirmed insect species with resistance against synthetic pesticides has continued to rise, apart from risks associated with the use of these chemicals (Aslan *et al.*, 2004; Bugiho and Wilkin, 2004). In fact, combating of environmental pollution and its ill-effects on the life and life-support systems is one of the most serious challenges before the present day world. It has been estimated that about 2.5 million t of pesticides are used on crops each year and the worldwide damage caused by pesticides reaches $100 billion annually (Koul *et al.*, 2008). As a result, many researchers, farmers and homeowners are seeking less hazardous alternatives to conventional synthetic insecticides. 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 (able to kill the pest insect but not other insects or animals), rapidly degradable and low in toxicity to humans and other mammals. The use of plant materials as traditional protectants of stored products is an old practice used all over the world. Plant derivatives have advantages and disadvantages as insecticides. Botanical pesticides have the advantage of providing novel modes of action against insects that can reduce the risk of cross-resistance as well as offering new leads for design of target-specific molecules (Isman, 2006, 2008). Botanicals insecticides degrade rapidly in sunlight, 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, 2006; Rajendran and Sriranjini, 2008; Betancur *et al.*, 2010). Many botanicals may be applied to food crops shortly before harvest without leaving excessive residues (Isman, 2000; Rajendran and Sriranjini, 2008). Moreover, medically safe of these plant derivatives has emphasized also (Pavela, 2007; Dayan *et al.*, 2009). Some disadvantages are high costs, low availability, as well as scarce data of effective results (Cloyd, 2004). Therefore, in recent years many scientists have switched to use of botanicals instead of chemical insecticides for the control of insect pest of agricultural importance. Approximately >350 pesticides derived from plants are insecticidal and more than 900 isolates are feeding deterrents alone (Koul, 2005). Botanicals used as insecticides presently constitute 1% of the world insecticide market (Rozman *et al.*, 2007). Because of the multiple sites of action through which the plant materials can act, the probability of developing a resistant population is very low (Sampson *et al.*, 2005). In addition, these substances can be toxic via penetration of the insect cuticle (contact effect), via respiratory system (fumigant effect) and via the digestive apparatus (ingestion effect) (Prates *et al.*, 1998).

In Iran, aromatic plants are widely distributed and there is a very rich and diversified flora, famous for their nutritional and medicinal characteristics. They are used for the production of cosmetics, perfumes, as well as in pharmacology and food flavouring (Zargari, 1991; Naghibi *et al.*, 2005). Present review examines the work conducted and addresses the prospects of the use of Iranian plant essential oils and their major components as insecticides.

Plant essential oils and their bio-efficiency: The interaction between plants and insects is chemically mediated by secondary metabolites. Because of the intensity of plant-insect interactions, the plants there have well-developed defense mechanisms against pests and are excellent sources of new insecticidal substances (Prakash and Rao, 1997). Presence of volatile monoterpenes or essential oils in the plants provides an important defense strategy to the plants, particularly against herbivorous insect pests and pathogenic fungi (Langenheim, 1994). These volatile terpenoids also play a vital role in plant-plant interactions and serve as attractants for pollinators (Tholl, 2006). They act as signaling molecules and depict evolutionary relationship with their functional roles (Theis and Lerdau, 2003). Essential oils are found in glandular hairs or secretary cavities of plant-cell wall and are present as droplets of fluid in the leaves, stems, bark, flowers, roots and/or fruits in different plants. Essential oils are defined as any volatile oil(s) that have strong aromatic components and that give distinctive odour, flavor or scent to a plant. Plant essential oils are obtained from non-woody parts of the plant, particularly foliage, through steam or hydrodistillation (Koul *et al.*, 2008). The interest in essential oils has regained momentum during the last decade, primarily due to their fumigant and contact insecticidal activities and the less stringent regulatory approval mechanisms for their exploration due to long history of use (Isman, 2006). It is primarily because essential oils are easily extractable, ecofriendly being biodegradable and get easily catabolized in the environment (Zygadlo and Grosso, 1995), do not persist in soil and water (Misra and Pavlostathis, 1997; Isman, 2000) and play an important role in plant protection against pests (Isman, 2006; Bakkali *et al.*, 2008). All these benign properties of essential oils permit their use even in sensitive areas such as schools, restaurants, hospitals and homes. These compounds are volatile and can act like fumigants offering the prospect for use in stored-product protection (Shaaya *et al.*, 1997; Papachristos and Stamopoulos, 2004). In stored-product insect pest control, essential oils may have numerous types of effect: they may have a fumigant activity (Ogendo *et al.*, 2008; Haouel *et al.*, 2010; Chen *et al.*, 2011), they may penetrate inside the insect body as contact insecticides (Stefanazzi *et al.*, 2011), they may act as repellents (Ibrahim, 2001; Yaghoobi-Ershadi *et al.*, 2006) or as antifeedants (Benzil *et al.*, 2009; Stefanazzi *et al.*, 2011) or they may affect some biological parameters such as growth rate and oviposition (Betancur *et al.*, 2010; Denloye *et al.*, 2011). In recent years, several studies were reported on the toxicity of essential oils against various insect species in Iran. Essential oils from different families such as Alliaceae, Apiaceae (Umbelliferae), Asteraceae (Compositae), Cupressaceae, Graminaceae, Lamiaceae (Labiatae), Lauraceae, Myrtaceae, Pedaliaceae, Rutaceae, Scrophulariaceae, Verbenaceae and Zingiberaceae have been studied for insecticidal toxicity (Table 1). On the other hand, essential oils isolated from *Achillea millefolium* L., *Achillea wilhelmsii* C. Koch, *Agastache foeniculum* Kuntze, *Allium sativum* L., *Anethum graveolens* L., *Artemisia aucheri* Boiss, *Artemisia dracunculus* L., *Artemisia haussknechtii* Boiss., *Artemisia scoparia* Waldst et Kit, *Artemisia sieberi* Besser, *Artemisia unnua* L., *Azilia eryngioides* Hedge et Lamond, *Bunium persicum* Boiss, *Carthamus tinctorius* L., *Carum copticum* C. B. Clarke, *Carum carvi* L., *Cinnamomum zelanicum* Blume, *Cinnamomum camphora* (L.), *Citrus aurantium* Risso, *Citrus limon* (L.), *Citrus paradisi* Macf, *Citrus sinensis* (L.), *Cominum cyminum* L., *Coriandrum sativum* L., *Cupressus arizonica* E.L. Greene, *Cymbopogon olivieri* bar, *Elletaria cardamomum* Maton., *Eucalyptus camaldulensis* Denhardt, *Eucalyptus globulus* Labill, *Ferula gummosa* Boiss., *Foeniculum vulgare* Mill, *Heracleum persicum* Desf., *Helianthus annuus* L., *Juniperus Sabina* L., *Laurus nobilis* L., *Lavandula angustifolia* Mill., *Lavandula stoechas* L., *Lippia citrodora* Kunth, *Melissa officinalis* L., *Mentha longifolia* (L.), *Mentha piperita* L., *Mentha pulegium* L., *Mentha spicata* L., *Nepeta cataria* L., *Perovskia atriplicifolia* (Benth), *Prangos acaulis* Bornm, *Pulicaria gnaphalodes* Boiss, *Rosmarinus officinalis* L., *Salvia bracteata*

Table 1: Summary of reports indicating insecticidal effects of Iranian plant essential oils

Essential oil source -- Species	Family	Insecticide effect	References
Achillea millefolium	(Asteraceae)	Feeding deterrence activity on larvae of *Plodia interpunctella*	Rafiei-Karahroodi *et al.* (2009b)
Achillea wilhelmsii	(Asteraceae)	Fumigant toxicity against 1-7 days old adults of *Tribolium* castaneum and *Callosobruchus maculatus.*	Asghari *et al.* (2010a)
Agastache foeniculum	(Lamiaceae)	Adulticidal against *Oryzaephilus surinamensis* and *Lasioderma serricorne*	Ebadollahi *et al.* (2010d)
		Fumigant toxicity on adults of *P. interpunctella.*	Ebadollahi *et al.* (2010e)
		Fumigant toxicity on adults of *T. castaneum* and *Rhyzopertha dominica*	Ebadollahi (2011b)
Allium sativum	(Alliaceae)	Fumigant toxicity on adults of *Sitophilus granarius*	Majd *et al.* (2010)
Anethum graveolens	(Asteraceae)	Repellent Effect on the adults of *P. interpunctella*	Rafiei-Karahroodi *et al.* (2009a)
Artemisia aucheri	(Asteraceae)	Larvicidal, ovicidal and oviposition deterrence on *C. maculatus*	Shakarami *et al.* (2004b)
		Fumigation toxicity and repellency on *C. maculatus, T. castaneum, Sitophilus oryzae* and *S. granarius*	Shakarami *et al.* (2004a)
Artemisia dracunculus	(Asteraceae)	Fumigant toxicity, repellency and oviposition deterrent activity on *C. maculates* and *T. castaneum*	Mirkazemi *et al.* (2010)
		Ovicidal, larvicidal and oviposition deterrence on *P. interpunctella*	Rafiei-Karahroodi *et al.* (2011)
Artemisia haussknechtii	(Asteraceae)	Fumigant toxicity against adults of *C. maculates*	Gavadi-Elmi *et al.* (2007)
Artemisia scoparia	(Asteraceae)	Antifeedant activity and growth inhibitory toward *T. castaneum*	Negahban and Moharamipour (2007a)
		Larvicidal, oviposition deterrence and egg hatching inhibitory in *C. maculatus*	Negahban and Moharamipour (2007b)
Artemisia sieberi	(Asteraceae)	Fumigant toxicity and repellency on *C. maculatus, S. oryzae* and *T. Castaneum*	Negahban and Moharamipour (2006)
		Antifeedant activity and growth inhibitory toward *T. castaneum*	Negahban and Moharamipour (2007a)
		Larvicidal, oviposition deterrence and egg hatching inhibitory in *C. maculatus*	Negahban and Moharamipour (2007b)
Artemisia unnua	(Asteraceae)	Fumigant toxicity on adults of *C. maculatus.*	Hosseinpour *et al.* (2009)
Azilia eryngioides	(Apiaceae)	Fumigant toxicity against 1-7 day old adults of *S. granarius* and *T. castaneum*	Ebadollahi and Mahboubi (2011)
Bunium persicum	(Asteraceae)	Toxicity against adults of *T. castaneum*	Moravej *et al.* (2009)
Carthamus tinctorius	(Asteraceae)	Progeny proution deterrency on *T. castaneum*	Khashaveh *et al.* (2009)
Carum copticum	(Apiaceae)	Fumigant toxicity against adults of *S. oryzae* and *T. castaneum*	Sahaf *et al.* (2007)
		Fumigant toxicity against growth stages of *P. interpunctella*	Shojaaddini *et al.* (2008)
		Ovicidal, larvicidal and adulticidal against *C. maculatus*	Sahaf and Moharamipour (2008a)
		Oviposition deterrence in *C. maculatus*	Sahaf and Moharamipour (2008b)
		Antifeedant activity against *T. castaneum*	Sahaf and Moharamipour (2009)
		Toxicity against adults of *Tribolium confusum, R. dominica* and *O. surinamensis*	Shokri-Habashi *et al.* (2011)
Carum carvi	(Apiaceae)	Repellent effect on the adults of *P. interpunctella*	Rafiei-Karahroodi *et al.* (2009a)
Cinnamomum zelanicum	(Lauraceae)	Feeding deterrence activity on larvae *P. interpunctella*	Rafiei-Karahroodi *et al.* (2009b)
Cinnamomum camphora	(Lauraceae)	Repellent on *Sitotroga cerealella* oliv. and *Ephestia kuehniella* zeller 5th instar larvae	Allahvaisi *et al.* (2011)
Citrus aurantium	(Rutaceae)	Fumigant toxicity on adults of *C. maculatus*	Moravvej and Abbar (2008)
Citrus limon	(Rutaceae)	Repellency on *Anopheles stephensi* Liston	Oshaghi *et al.* (2003)

Table 1: Continued

Essential oil source			
Species	Familly	Insecticide effect	References
Citrus paradise	(Rutaceae)	Fumigant toxicity on adults of *C. maculatus*	Moravvej and Abbar (2008)
Citrus sinensis	(Rutaceae)	Fumigant toxicity on adults of *T. castaneum, S. granarius, C. maculatus P. interpunctella*	Mahmoudvand *et al.* (2011b)
Cominum cyminum	(Apiaceae)	Toxic effect against adults of *C. maculatus*	Fallahzadeh and Kamjoo (2010)
		Toxic effect against adults of *E. kuehniella*	Khodadoust and Moharramipour (2010)
Coriandrum sativum	(Apiaceae)	Fumigant toxicity on adults of *S. granarius*	Majd *et al.* (2010)
Cupressus arizonica	(Cupressaceae)	Larvicidal activity against *A. stephensi*	Sedaghat *et al.* (2011)
Cymbopogon olivieri	(Poaceae)	Larvicidal activity against *A. stephensi.*	Hadji-Akhoondi *et al.* (2003)
Elletaria cardamomum	(Zingiberaceae)	Fumigant toxicity against adults of *T. castaneum, C. maculates* and *E. kuehniella*	Abbasipour *et al.* (2010)
Eucalyptus camaldulensis	(Myrtaceae)	Larvicidal and repellent property on *Trogoderma granarium* Everts and *Tribolium* spp.	Modarres-Najafabadi *et al.* (2006)
		Fumigant toxicity on adults of *T. castaneum* and *C. maculatus*	Abbasipour *et al.* (2009)
		Larvicidal activity against *A. stephensi*	Sedaghat *et al.* (2010)
Eucalyptus globules	(Myrtaceae)	Fumigant toxicity on adults of *L. serricorne* and *R. domonica*	Ebadollahi *et al.* (2010a)
		Ovicidal, larvicidal and adulticidal effects on *T. castaneum*	Ebadollahi *et al.* (2010b)
		Contact and fumigant toxicity against adult of *L. serricorne*	Ebadollahi *et al.* (2010c)
		Antifeedant effect on adults of *T. castaneum*	Ebadollahi (2011a)
Ferula gummosa	Apiaceae)	Ovicidal effect on *E. kuehniella*	Seyedi *et al.* (2010)
Foeniculum vulgare	(Apiaceae)	Fumigant toxicity, repellency and oviposition deterrent effect on *C. maculates* and *T. castaneum*	Mirkazemi *et al.* (2010)
Heracleum persicum	(Apiaceae)	Toxicity against *C. maculatus* adults	Manzoomi *et al.* (2010)
		Fumigant toxicity toward *S. granarius*	Majd *et al.* (2010)
Helianthus annuus	(Asteraceae)	Progeny production deterrency on *T. castaneum*	Khashaveh *et al.* (2009)
Juniperus Sabina	(Cupressaceae)	Adulticidal on *C. maculatus*	Mahmoudvand *et al.* (2011a)
Laurus nobilis	(Lamiaceae)	Larvicidal effects against *A. stephensi* and *Culex pipiens.*	Verdian-Rizi (2009)
Lavandula angustifolia	(Lamiaceae)	Ovicidal, larvicidal and oviposition deterrence on *P. interpunctella*	Rafiei-Karahroodi *et al.* (2011)
Lavandula stoechas	(Lamiaceae)	Fumigant toxicity on adults of *L. serricorne* and *R. domonica*	Ebadollahi *et al.* (2010a)
		Ovicidal, larvicidal and adulticidal effects on *T. castaneum*	Ebadollahi *et al.* (2010b)
		Contact and fumigant toxicity against adult of *L. serricorne*	Ebadollahi *et al.* (2010c)
		Antifeedant effect on adults of *T. castaneum*	Ebadollahi (2011a)
Lippia citrodora	(Verbenaceæ)	Adulticidal on *C. maculatus*	Mahmoudvand *et al.* (2011a)
Melissa officinalis	(Lamiaceae)	Repellent Effect on *A. stephensi*	Oshaghi *et al.* (2003)
		Feeding deterrence activity on larvae *P. interpunctella*	Rafiei-Karahroodi *et al.* (2009b)
		Ovicidal, larvicidal and oviposition deterrence on *P. interpunctella.*	Rafiei-Karahroodi *et al.* (2011)
Mentha longifolia	(Lamiaceae)	Fumigant toxicity against *C. maculates*	Gavadi-Elmi *et al.* (2007)
Mentha piperita	(Lamiaceae)	Feeding deterrence effect against larvae *P. interpunctella*	Rafiei-Karahroodi *et al.* (2009b)
		Adulticidal on *C. maculatus*	Mahmoudvand *et al.* (2011a)
		Ovicidal, larvicidal and oviposition deterrence on *P. interpunctella*	Rafiei-Karahroodi *et al.* (2011)
Mentha pulegium	(Lamiaceae)	Fumigant toxicity on adults of *T. castaneum, S. granarius, C. maculatus P. interpunctella*	Mahmoudvand *et al.* (2011b)
Mentha spicata	(Lamiaceae)	Larvicidal effects against *A. stephensi*	Hadji-Akhoondi *et al.* (2000)
Nepeta cataria	(Lamiaceae)	Larvicidal, ovicidal and oviposition deterrence on *C. maculatus*	Shakarami *et al.* (2004b)

Table 1: Continued

Essential oil source			
Species	Familly	Insecticide effect	References
Perovskia atriplicifolia	(Lamiaceae)	Toxicity against *T. castaneum* adults	Ahmadi *et al.* (2009)
Prangos acaulis	(Apiaceae)	Adulticidal, larvicidal and egg hatching inhibitor against *C. maculatus*	Taghizadeh-Sarikolaei and Moharamipour (2010)
Pulicaria gnaphalodes	(Asteraceae)	Fumigation toxicity against 1-7 days old adults of *T. castaneum* and *C. maculatus*	Asghari *et al.* (2010b)
Rosmarinus officinalis	(Lamiaceae)	Repellent Effect on *P. interpunctella* adults	Rafiei-Karahroodi *et al.* (2009a)
		Fumigant toxicity on adults of *T. castaneum, S. granarius, C. maculatus P. interpunctella*	Mahmoudvand *et al.* (2011b)
		Fumigant toxicity, repellency and oviposition deterrent activity on *C. maculates* and *T. castaneum*	Mirkazemi *et al.* (2010)
Salvia bracteata	(Lamiaceae)	Larvicidal, ovicidal and oviposition deterrence on *C. maculatus*	Shakarami *et al.* (2004b)
		Fumigation toxicity and repellency against *C. maculatus, T. castaneum, S. oryzae* and *S. granarius*	Shakarami *et al.* (2005)
Salvia multicaulis	(Lamiaceae)	Feeding deterrence activity on larvae *P. interpunctella*	Rafiei-Karahroodi *et al.* (2009b)
Salvia sclarea	(Lamiaceae)	Repellent effect on 3-5 days adults of *C. maculatus*	Nabavi *et al.* (2010a)
		Larvicidal effect against 3th instar larvae of *Musca domestica*	Nabavi *et al.* (2010b)
Satureja hortensis	(Lamiaceae)	Fumigant toxicity, repellency and oviposition deterrent activity on *C. maculates* and *T. castaneum*	Mirkazemi *et al.* (2010)
		Fumigant toxicity against 12-14 day old *P. interpunctella* larvae	Mollai *et al.* (2010)
Sesamum indicum	(Pedaliaceae)	Progeny production deterrency on *T. castaneum*	Khashaveh *et al.* (2009)
Syzygium aromaticum	(Myrtaceæ)	Repellent on *S. cerealella* and *E. kuehniella* 5th instar larvae	Allahvaisi *et al.* (2011)
Tagetes minuta	(Asteraceae)	Toxicity on *A. stephensi* larvae	Hadji-Akhoondi *et al.* (2008)
Thymus daenensis	(Lamiaceae)	Fumigant toxicity against *C. maculates*	Gavadi-Elmi *et al.* (2007)
		Toxicity on 10 days old adults of *T. confusum*	Aliakbari *et al.* (2010)
Thymus persicus	(Lamiaceae)	Adulticidal, larvicidal and egg hatching inhibitor against *C. maculatus*	Taghizadeh-Sarikolaei and Moharamipour (2010)
		Fumigant toxicity against adults of *T. castaneum* and *S. oryzae*	Taghizadeh-Sarikolaei *et al.* (2010)
Thymus vulgaris	(Lamiaceae)	Repellent Effect on the adults of *P. interpunctella*	Rafiei-Karahroodi *et al.* (2009a)
		Ovicidal, larvicidal and oviposition deterrency effects against *C. maculatus*	Dezfouli *et al.* (2010)
Verbascum cheiranthifolium	(Scrophulariaceae)	Toxicity and progeny production deterrency on *R. dominica*	Khoshnoud *et al.* (2008a)
		Toxicity and progeny production deterrency on *S. oryzae*	Khoshnoud *et al.* (2008b)
Verbascum	(Scrophulariaceae)	Toxicity and progeny production deterrency on *S. oryzae*	Khoshnoud *et al.* (2008b)
Vitex pseudo-negundo	(Verbenaceae)	Adulticidal on *T. castaneum* and *S. oryzae*	Sahaf *et al.* (2008)
		Ovicidal, larvicidal and adulticidal against *C. maculatus*	Sahaf and Moharamipour (2008a)
		Oviposition deterrence in *C. maculatus*	Sahaf and Moharamipour (2008b)
		Antifeedant activity against *T. castaneum*	Sahaf and Moharamipour (2009)
Zataria multiflora	(Lamiaceae)	Fumigant toxicity on adults of *T. castaneum, S. granarius, C. maculatus* and *P. interpunctella*	Mahmoudvand *et al.* (2011b)
Zingiber officinale	(Zingiberaceae)	Fumigant toxicity against 12-14 day old *P. interpunctella* larvae	Mollai *et al.* (2010)
Zhumeria majdae	(Lamiaceae)	Oviposition deterrency on *C. maculatus*	Nikooei *et al.* (2010a)
		Adulticidal effect against *C. maculatus*	Nikooei *et al.* (2010b)

Banks and Soland, *Salvia multicaulis* Vahl, *Salvia sclarea* L., *Satureja hortensis* L., *Sesamum indicum* L., *Syzygium aromaticum* (L.), *Tagetes minuta* L., *Thymus daenensis* Celak, *Thymus persicus* (Roniger ex Reach F.), *Thymus vulgaris* L., *Verbascum cheiranthifolium* Bioss, *Verbascum speciosum* Schard, *Vitex pseudo-negundo* (Hausskn), *Zataria multiflora* Boiss, *Zingiber officinale* Rosci and *Zhumeria majdae* Rech F. and Wendelbo were introduced as insecticides from Iran (Table 1).

Essential oil constituents and their bio-efficiency: Essential oil 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 (Mahdi *et al.*, 2011). Essential oil components and quality vary with geographical distribution, harvesting time, growing conditions and method of extraction (Yang *et al.*, 2005). Among the essential oil components, the monoterpenoids have drawn the greatest attention for insecticidal activity against stored-product insects. Many essential oils isolated from various plant species belonging to different genera, contain relatively high amount of monoterpenes (Ogendo *et al.*, 2008). Monoterpenes are volatile and responsible for the characteristic odours of many plants. Their volatility which made them easy to discover in fragrant plant material and at the same time readily obtainable by simple distillation of plant parts, lent to them the essential oil (Ibrahim, 2001). These are easily degradable in soil and water (Misra and Pavlostathis, 1997).

Previous studies have shown that the toxicity of essential oils obtained from aromatic plants against storage pests is related to the oil's main components (Isman *et al.*, 2001; Lee *et al.*, 2003) such as 1.8 Cineole, Carvacrol, Thymol, Eugenol, Terpinene, Limonene, α-Pinene, among others. The essential oil of a plant may contain hundreds of different constituents but certain components will be present in larger quantities. For example, 1,8-cineole was predominant in the essential oils of *Achillea millefolium* (22%), *Artemisia aucheri* (22.8%), *Eucalyptus camaldulensis* (69.46%), *Eucalyptus globulus* (31.42%), *Lavandula stoechas* (48.5%), *Laurus nobilis* (4.02) and *Perovskia atriplicifolia* (20.74) (Table 2). In recent years, several studies were reported on the toxicity of some essential oil constituents against various insect species. For example, Obeng-Ofori *et al.* (1997) found 1,8-cineole to be highly repellent and toxic to *Sitophilus granarius* L., *S. zeamais, Tribolium confusum* du Val and *Prostephanus truncatus* (Horn). Antifeedant activity of 1,8-Cineole has been demonstrated against *T. castaneum* (Tripathi *et al.*, 2001). Application of 1, 8-Cineole reduced oviposition rate by 30-50% at concentration of 1.0%, as compared to untreated controls (Koschier and Sedy, 2001). Lee *et al.* (2002) reported that 1,8-cineole was the most toxic fumigant constituent against the adults of *Tribolium castaneum* Herbst. (LD_{50} = 7.4 μl L^{-1} air) followed by Menthone (LD_{50} = 8.5 μl L^{-1} air) and p-cymene (LD_{50} = 11.4 μl L^{-1} air). Yang *et al.* (2004) reported that 1,8-cineole showed toxicity against human head lice, *Pediculus humanus* capitis. The pediculicidal activity of 1,8-Cineole was more than that of commercially used pediculides, delta-phenothrin or pyrethrum. Limonene was found in a huge range of plants including *Anethum graveolens* (33.2%), *Artemisia scoparia* (9.19%) *Carum carvi* (23.8%), *Citrus paradisi* (91.5%), *Citrus sinensis* (94.3%) and *Cupressus arizonica* (14.44%). *Heracleum persicum* (11.5%) and *Mentha longifolia* (13.7%) (Table 2). Similarly, Limonene has exhibited significant insect control properties. According to Raina *et al.* (2007), orange oil extracted from citrus peel (containing ~92% d-Limonene) caused 96 and 68% mortality to

Table 2: Summary of reports on major components in the introduced Iranian plant essential oils as insecticides

Species	Main components	References
Achillea millefolium	1,8-cineole (22%), Camphor (21%), Borneol (7,6%) and β-pinene (5.3%)	Haziri *et al.* (2010)
Achillea wilhelmsii	Carvacrol (25.1%), Linalool (11.0%), 1,8-cineol (10.3%), E-nerolidol (9.0%) and Borneol (6.4%)	Javidnia *et al.* (2004)
Agastache foeniculum	Estragole (94.003%) and 1,8-cineole (3.334%)	Ebadollahi (2011b)
Allium sativum	Trisulfide-di-2-propenyl (49.6%), Disulfide, di-2-propenyl (37.2%) and Trisulfide-methyl-2-propenyl (5.6%)	Dieumou *et al.* (2009)
Anethum graveolens	Carvone (57.3%) and Limonene (33.2%)	Sefidkon (2001)
Artemisia aucheri	1,8-Cineol (22.8%), Chrysanthenone (18.16%), α-pinene (8.33%) and Mesitylene (7.41%)	Hashemi *et al.* (2007)
Artemisia dracunculus	(Z)-anethole (51.72%), (Z)-α-ocimene (8.32%), Methyl eugenol (8.06%), Limonene (4.94%) and Linalool (4.41%)	Ayoughi *et al.* (2011)
Artemisia haussknechtii	Camphor (12.4%), α-terpineol (9.93%), Davana ether (6/24%) and Bornyl acetate (3.77%)	Khanahmadi *et al.* (2009)
Artemisia scoparia	Capillene (48.5%), β-pinene (9.84%), Camphor (6.94) and 1,8-Cineole+Limonene (9.19)	Rabie *et al.* (2003)
Artemisia sieberi	Camphor (54.7%), Camphene (11.7%), 1,8-cineol (9.9%), Thujone (5.6%) and α-pinene (2.5%)	Negahban *et al.* (2007)
Artemisia annua	*Artemisia* ketone (14.3 %), 1,8-cineol (9.78%), Pinocarvone (9.07%) and camphor (8.11%)	Rabie *et al.* (2003)
Azilia eryngioides	α-pinene (63.8%) and Bornyl acetate (18.9%), β-pinene (2.6%), Linalool (2.1%) and Z- citral (1.3%)	Ebadollahi and Mahboubi (2011)
Bunium persicum	γ-terpinen-7-al (26.91%), Cumin aldehyde (23.29%), γ-terpinene (22.02%) and ρ-cymene (7.32%)	Moghtader *et al.* (2009)
Carthamus tinctorius	1-pentadecene (19.31%), b-caryophyllene (8.74%), terpinolene (6.23%), Methyl eugenol (4.21%) and Linalool (3.52%)	Harrathi *et al.* (2011)
Carum capticum	Thymol (43%), γ-terpinene (15.85%) and β-cymene (21.67%)	Shokri-Habashi *et al.* (2011)
Carum carvi	Carvone (73.8%0 and Limonene (23.8%).	Ahmadi (2001)
Cinnamomum zelanicum	3-caryophyllene (15.5%), Linalool (15%), Cinnamyl acetate (14.8%), Eugenol acetate (6.2%) and Cymene (6%)	Elumalai *et al.* (2011)
Cinnamomum camphora	Fenchone (34.82%), Camphene (23.77%), α-thujene (17.45%), L-limolene (7.54%) and Cis-p-menthane (5.81%)	Srivastava *et al.* (2008)
Citrus aurantium	Geraniol (26.6%), α-terpineol (20.7%), Linalool (15.4%) and Benzene acetaldehyde (5.5%)	Monsef-Esfahani *et al.* (2004)
Citrus limon	Geranial (31.45%), Neral (23.16%), α-pinene (22.39%) and Limonene (6.7%)	Mosadegh *et al.* (2004)
Citrus paradisi	Limonene (91.5%), β-pinene (0.8%), Linalool (1.1%) and α-terpinene (0.7%)	Uysal *et al.* (2011)
Citrus sinensis	Limonene (94.3%), Myrcene (1.5%) and Linalool (0.9%)	Mirza and Bahernik (2006)
Cominum cyminum	p-mentha-1,4-dien-7-al (23.69%), Cuminaldehyde (20%), γ-terpinene (15.71%) and β-pinene (12.22%)	Kizil *et al.* (2008)
Coriandrum sativum	Linalool (40.9?79.9%), Neryl acetate (2.3?14.2%), γ-terpinene (0.1-13.6%) and α-pinene (1.2-7.1%)	Ebrahimi *et al.* (2010)
Cupressus arizonica	Limonene (14.44%), Umbellulone (13.25%) and α-pinene (11%)	Sedaghat *et al.* (2011)
Cymbopogon olivieri	Piperitone (48.9%), α-terpinene (13.8%), Limonene (6.3%) and Elemol (3.8%)	Sonboli *et al.* (2006)
Elletaria cardamomum	4-terpineol (30.26%), 1,8-cineol (25.7%), α-terpinolene (9.8%), ρ-cymene (5.3%), α-terpinene (4.6%) and α -terpineol (3.4%)	Mahmud (2008)
Eucalyptus camaldulensis	1,8-cineole (69.46%), γ-Terpinene (15.10%), α-Pinene (5.47%) and Globulol (2%)	Sedaghat *et al.* (2010)
Eucalyptus globulus	1,8-cineole (31.42%), trans-3(10)-Caren-2-ol (10.10%) and 3,7-dimethyl-2-Octen-1-ol (9.37%)	Ebadollahi *et al.* (2010a)
Ferula gummosa	β-pinene (58.8%), δ-3-carene (12.1%) and Myrcene (4.6%)	Ghannadi and Amree (2002)
Foeniculum vulgare	Trans-anethole (56.6%), β-thujone (13.2%), p-anisaldehyde (8.7%) and Fenchone (7.42%)	Mahboubi *et al.* (2011)
Heracleum persicum	(E)-anethole (47.0%), Terpinolene (20.0%), γ-terpinene (11.6%) and Limonene (11.5%)	Sefidkon *et al.* (2004)
Helianthus annuus	α-pinene (72.6%) and Sabinene (12.8%)	Cecarini *et al.* (2004)
Juniperus Sabina	Sabinene (48.6%), Myrcene (10.8%) and α-pinene (8.1%)	Asili *et al.* (2010)
Laurus nobilis	1,8-cineole (48.5%), α-terpinenyl acetate (12.5%), Sabinene (9.5%) α-pinene (3.3%) and β-pinene (3.2%)	Barazandeh (2001)

Table 2: Countinued

Species	Main components	References
Lavandula angustifolia	Linalool (36.9%), 1,8-cineole (16%), Orneol (11.5%), Camphor (4.2%) and Terpinene-4-ol (4.19%)	Rasouli and Rezaei (2000)
Lavandula stoechas	1,8-cineole (7.02%), γ-cadinene (5.33%), T-cadinol (5.07%) and p-mentha-1-en-8-ol (5.02%)	Ebadollahi *et al.* (2010a)
Lippia citrodora	Geraniol (20.9%), Nerol (13.8%), Neral (12.7%), Geranial (12.1%) and Limonene+1,8-cineole (9.3%)	Mojab *et al.* (2002)
Melissa officinalis	Citronellal (25.4%), 13- caryophyllene (11.3%), Thymol (10.5%), Globolol (6.1%) and Geraniol (5.7%)	Asgari and Sefidkon (2004).
Mentha longifolia	Piperitone (43.9%), Limonene (13.7%) and Trans-piperitol (12.9%)	Rasouli and Rezaei (2002)
Mentha piperita	Neo-menthol (42.62%), 1, 8-Cineole (16.S1%) and Piperitone (12.25%)	Jaymand *et al.* (2000)
Mentha pulegium	Pulegone (54.6 %) and Menthone (15.1 %)	Semnani *et al.* (2011)
Mentha spicata	Carvone (22.40%), Linalool (11.25%) and Limonene (10.80%)	Hadji-Akhoondi *et al.* (2000)
Nepeta cataria	α-citral (51.95%), Nerol (32.24%), β- citronellol (9.03%) and Geraniol (4.31%)	Saeidnia *et al.* (2008)
Perovskia atriplicifolia	1,8-cineole (20.74%), Camphor (14.52%), Limonene (8.58%), β-caryophyllene (7.91%) and α-pinene (7.77%)	Dabiri and Sefidkon (2001)
Prangos acaulis	Cis-sescuisabinene hydrate (25.6%) and α-Pinene (12.5%)	Rustaiyan *et al.* (2006)
Pulicaria gnaphalodes	α-pinene (34.1%), 1,8-cineol (11.9%) Cadina-1(10) and 4-dien-8α-ol (11.0%)	Weyerstahl *et al.* (1999)
Rosmarinus officinalis	α-pinene (21.5%) and 1,8-cineole (15.2%), Verbenone (8.6%), Camphor (6.8%) and Camphene (6.3%)	Mahboubi *et al.* (2011)
Salvia bracteata	β-caryophyllene (41.6%) and χ-muurolene (22.8%)	Houshidari *et al.* (2006)
Salvia multicaulis	Benzyl benzoate (60.3 %), n-hexyl benzoate (16.7 %), Amyl benzoate (5.2 %) and 2- octyl benzoate (4.2 %)	Taran *et al.* (2011)
Salvia sclarea	Germacrene D (12.67%), Trans-caryophyllene (7.66%), Linalool L (7. 41%) and (+) Spathulenol (6.94%)	Salimpour *et al.* (2011)
Satureja hortensis	Carvacrol (54.14%), Terpinolene (20.59%), α-phellandrene (5.31%) and ρ-cymene (3.56%)	Abdolahi *et al.* (2010)
Sesamum indicum	γ-tocopherol (77.0%), Sesamin (3.02%), δ-tocopherol (1.66%) and α-tocopherol (0.19%)	Williamson *et al.* (2008)
Syzygium aromaticum	Eugenol (52.11%), Cyperen (23.76%) and Eugenol acetate (6.77%)	Rahnama *et al.* (2011)
Tagetes minuta	Trans-Ocimenone (19.89%), Cis-Ocimene (17.67%), Dihydrotagetone (5.56%) and Cis-Tagetone (5.03%)	Hadji-Akhoondi *et al.* (2008)
Thymus daenensis	Thymol (51.3%), p-cymene (2.7%), γ-terpinene (2.7%), Carvacrol (2.0%) and β-caryophyllene (2.4%)	Barazandeh and Bagherzadeh (2007)
Thymus persicus	Carvacrol (44.69%) and Thymol (11.05%)	Taghizadeh-Sarikolaei *et al.* (2010)
Thymus vulgaris	Thymol (43.8%), ρ-cymene (15.2%), Germacrene-D (11.7%), Terpinolene (3.4%) and Carvacrol (3.2%)	Asbaghian *et al.* (2001)
Vitex pseudo-negundo	α-guaiene (14.2%), Germacrene D (11/6%), 1,8-Cineole (10.9%), α-pinene (10.3%) and α-Cadinol (10%)	Abbas-Azimi *et al.* (2006)
Zataria multiflora	Carvacrol (37%), p-cymene (15%) and Dodecane (9%)	Rasouli and Rezaei (2002)
Zingiber officinale	Zingiberene (14%), Sabinene (12%), Camphene (11.9%), Geranial, z-citral (8.2%) and 1,8-cineole (5.3%)	Dieumou, *et al.* (2009)
Zhumeria majdae	Linalool (64.4%), Camphor (26.5%) and Borneol (2.1%)	Soltanipour *et al.* (2007)

Coptotermes formosanus Shiraki within 5 days and there was significant reduction in feeding as compared to controls at 5 ppm concentration (v/v), also the termites did not tunnel through glass tubes fitted with sand treated with 0.2-0.4% orange oil extract. d- Limonene, linalool, α-myrcene and α-terpineol significantly increased the nymphal duration in German cockroach, *Blattella germanica* (L.) when fed through artificial diet (Karr and Coats, 1992). Prates *et al.* (1998) also showed fumigant activity of Limonene against *T. confusum*. Limonene has also shown insecticidal properties against human blood-sucking insects when tested against early 4th instar larvae of the mosquito *Culex quinquefasciatus* (Say). The LC_{50} was 53.80 ppm after 24 h and 32.52 ppm after 48 h. Limonene-treated water was less favourable than untreated water for oviposition by females of the mosquito (Kassir *et al.*, 1989). Carvacrol in the essential oils isolated from *Achillea wilhelmsii* (25.1%), *Satureja hortensis* (54.14%), *Thymus persicus* (44.7%) and *Zataria multiflora* (37%), Citronellal in *Melissa officinalis* essential oil and Thymol in the essential oils of *Carum capticum* (43%), *Melissa officinalis* (10.5%), *Thymus daenensis* (51.3%), *Thymus persicus* (11.05%) and *Thymus vulgaris* (43.8%) were major components (Table 2). Thymol and Carvacrol are very effective in inhibiting *Acanthosceides obtectus* (Say) reproduction (Regnault-Roger and Hamraoui, 1995). These compounds are also effective against *Oryzaephilus surinamensis* (L.) (Shaaya *et al.*, 1991). Carvacrol was highly toxic to nymphs of the termite *Reticulitermes speratus*, adults of the rice weevil *Sitophilus oryzae* L., the pulse beetle *Callosobruchus chinensis* (L.), the cigarette beetle *Lasioderma serricorne* F. (Ahn *et al.*, 1998) and the mite, *Tetranychus urticae* Koch (Isman, 2000). Thymol was also found to repel mosquitoes (Chokechaijaroenporn *et al.*, 1994). Lee *et al.* (1997) evaluated acute toxicity of 34 naturally occurring monoterpenoids against three insect species. They reported that Citronellic acid and Thymol were the most toxic against house fly while Citronellol and Thujone were most effective against the western corn root worm. Waliwitiya *et al.* (2005) evaluated the insecticidal effects of Thymol, Citronellal and Eugenol on the late instar larvae of *Agriotes obscurus* (L.) (Coleoptera: Elateridae). They found that Thymol had the greatest contact toxicity (LD_{50} = 196.0 μg L^{-1} arva), whereas citronellal and Eugenol were less toxic (LD_{50} = 404.9 and 516.5 μg L^{-1} arva, respectively). In terms of volatile toxicity, citronellal was the most toxic to wireworm larvae (LC_{50} = 6.3 μg cm^3) followed by Thymol (LC_{50} = 17.1 μg cm^3) and Eugenol (LC_{50} = 20.9 μg cm^3). Eugenol and its derivatives were main constituents in the essential oils isolated from *Artemisia dracunculus* (8.06%), *Carthamus tinctorius* (4.21%), *Cinnamomum zelanicum* (6.2%) and *Syzygium aromaticum* (52.11%+6.77%) (Table 2). Eugenol was reported as toxic to *Drosophila melanogaster* Meigen and *Spodoptera litura* F. (Lee *et al.*, 1997; Hummelbrunner and Isman, 2001). Both contact and fumigant toxicities of Eugenol and methyl Eugenol were demonstrated on the American cockroach, *Periplaneta americana* (L.) (Ngoh *et al.*, 1998). Ogendo *et al.* (2008) studied the fumigant and repellent effects of Eugenol against adults of *S. oryzae*, *T. castaneum*, *O. surinamensis*, *Rhyzopertha dominica* (F.) and *C. chinensis*. Except for *T. castaneum* which was more tolerant, LC_{50} values for tested insects ranged from 0.01 to 17 μl L^{-1} air 24 h after treatment. At 1 μl L^{-1} air, Eugenol caused 79, 61 and 100% mortality of *R. dominica*, *O. surinamensis* and *C. chinensis*, respectively, 24 h after treatment. All test insects had Percentage Repellence (PR) values which ranged from 45 to 100% for Eugenol. Camphor was determined as major component in the essential oil from *Achillea millefolium*, *Artemisia*, *haussknechtii*, *Artemisia sieberi*, *Perovskia atriplicifolia* and *Zhumeria majdae* (Table 2). In the Kordali *et al.* (2006) study, Camphor, 1,8-cineole, Terpinen-4-ol, Borneol, Bornyl acetate and α-terpineol tested for their toxicity against *S. granarius*. While all compounds were found to be toxic against *S. granarius*, 1,8-cineole and terpinen-4-ol were more toxic among the tested compounds. 1,8-cineole and terpinen-4-ol showed 100% mortality at all doses after 12 h of exposure. In the Mahdi *et al.* (2011) study, 12 pure oxygenated monoterpenes were tested for their toxicity against second and third instar larvae and adults of three different populations of Colorado potato beetle (*Leptinotarsa decemlineata* Say). In general, Fenchone, Linalool, Citronella and Menthone showed a strong toxicity against the tested developmental stages; Camphor, Carvone and Linalyl acetate showed moderate toxicity against larvae and adults of Colorado potato beetle and some compounds like Fenchol, Isomenthol, Menthol, Nerol and Neryl acetate showed the least or no toxicity against the tested developmental stages of *L. decemlineata*. Terpinene and its derivatives found in a huge range of plants including *Bunium persicum, Carum capticum, Citrus aurantium, Cominum cyminum, Coriandrum sativum, Cymbopogon olivieri, Elletaria cardamomum, Eucalyptus camaldulensis, Heracleum persicum, Laurus nobilis, Lavandula angustifolia, Pulicaria gnaphalodes, Satureja hortensis, Thymus daenensis* and *Thymus vulgaris* (Table 2). The most repellent compound in *Baccharis salicifolia* (Ruiz and Pav.) Pers. essential oil against *T. confusum* was α-terpineol (Garcia *et al*., 2005). Lee *et al*. (2001) demonstrated that 1,8-cineole (LD_{50} = 23.5 µl L^{-1} air), ρ-cymene (LD_{50} = 25.0 µl L^{-1} air), Terpine-4-ol (LD_{50} = 25.6 µl L^{-1} air), Linalool (LD_{50} = 39.2 µl L^{-1} air), Eugenol (LD_{50} = 50.7 µl L^{-1} air), α-pinene (LD_{50} = 54.9 µl L^{-1} air), Limonene (LD_{50} = 61.5 µl L^{-1} air), α-terpineol (LD_{50} = 69.1 µl L^{-1} air), Thymol (LD_{50} = 69.7 µl L^{-1} air), α-terpinene (LD_{50} = 71.2 µl L^{-1} air) and Carvacrol (LD_{50} = 79.7 µl L^{-1} air) had the possible fumigant toxicity to *S. oryzae*. Erler (2005) reported the fumigant activity of Carvacrol, 1,8-cineole, Menthol, γ-terpinene, Terpinen-4-ol and Thymol against adults and eggs of *T. confusum* and larvae and eggs of *Ephestia kuehniella* Zeller. The most active constituent was Carvacrol and achieved >90% mortality against all test insects at 46.2 mg L^{-1} air and an exposure of 24-96 h except for *E. kuehniella* larvae which required a higher dose, 184.8 mg L^{-1}. γ-terpinene caused 99% mortality in all test insects after 26.4-57.5 h. This was followed by Thymol and terpinen-4-ol which achieved the same mortality against only one insect species and stage in a dose range of 46.2-184.8 mg L^{-1}. The constituents 1,8-cineole and menthol achieved less than 99% mortality against any insect species tested at doses and exposure periods used. Stamopoulos *et al*. (2007) found that Terpinen-4-ol, 1,8-cineole, Linalool, R-(+)-limonene and Geraniol had toxic effects against different stages of *T. confusum*. Terpinen-4-ol (with LC_{50} values ranging between 1.1 and 109.4 µl L^{-1} air), (R)-(+)-Limonene (with LC_{50} values ranging between 4 and 278 µl L^{-1} air) and 1,8-cineole (with LC_{50} values ranging between 3.5 and 466 µl L^{-1} air) were the most toxic to all stages tested, followed by linalool (with LC_{50} values ranging between 8.6 and 183.5 µl L^{-1} air) while the least toxic monoterpenoid tested was geraniol with LC_{50} values ranging between 607 and 1627 µl L^{-1} air. In all cases, except for geraniol, third-instar larvae were the most susceptible stage and 3-day-old eggs most tolerant. Apart from the observed direct toxicity, exposure of females to the vapours led in some cases to lower fecundity and egg hatchability. Findings of many studies indicated that α-pinene (main component in the essential oils from *Azilia eryngioides, Citrus limon, Cupressus arizonica, Helianthus annuus, Prangos acaulis, Pulicaria gnaphalodes, Rosmarinus officinalis* and *Vitex pseudo-negundo*) and β-pinene (main component in the essential oils from *Achillea millefolium, Artemisia scoparia, Cominum cyminum* and *Ferula gummosa*) had numerous insecticide effects. For example, Ojimelukwe and Adler (1999) found α-pinene to possess potent repellent and toxic effects to *T. confusum*. In the Kouninki *et al*. (2007) study, β-pinene showed toxicity against *Sitophilus zeamais* adults. Choi *et al*. (2006) showed that α-pinene was the most toxic fumigant compound in thyme essential oil (LD_{50} = 9.85 µl L^{-1} air) followed by β-pinene (LD_{50} = 11.85 µl L^{-1} air) and Linalool (LD_{50} = 21.15 µl L^{-1} air) against *Lycoriella mali* adults. The mixture of α-and β-pinene exhibited stronger fumigant toxicity than α- or β-pinene itself. Linalool in the essential oils from *Cinnamomum zelanicum* (15%), *Citrus aurantium* (15.4%), *Coriandrum sativum* (40.9%), *Lavandula angustifolia* (36.9%), *Mentha spicata* (11.25%) and Zhumeria *majdae* (64.4%) introduced as main constituents (Table 2). Rozman *et al*. (2007) illustrated the fumigant toxicity of Linalool, Eugenol, 1,8-cineole, Carvacrol, Camphor, Borneol and Thymol against adults of *S. oryzae, R. dominica* and *T. castaneum*. The most sensitive species was

S. oryzae, followed by *R. dominica*. *T. castaneum* was highly tolerant of the tested compounds. 1, 8-cineole, Borneol and Thymol were highly effective against *S. oryzae* when applied for 24 h at the lowest dose (0.1 μL 720 mL^{-1} volume). For *R. dominica* Camphor and Linalool were highly effective and produced 100% mortality in the same conditions. Against *T. castaneum* no oil compounds achieved more than 20% mortality after exposure for 24 h, even with the highest dose (100 μL 720 mL^{-1} volume). However, after 7 days exposure 1,8-cineole produced 92.5% mortality, followed by camphor (77.5%) and linalool (70.0%). Carvone is major constituent in the essential oils isolated from *Anethum graveolens* (57.3%), *Carum carvi* (73.8%) and *Mentha spicata* (22.4%) (Table 2). Lichtenstein *et al.* (1997) have reported that Carvone isolated from aerial parts of dill plants (*Anethum graveolus* L.) was insecticidal to *Drosophilla* and *Aedes* spp. l-carvone has been reported to cause 24 times more fumigant toxicity than its contact toxicity to lesser grain borer, *Rhyzopertha dominica*. l-carvone also completely suppresses the egg hatching of *T. castaneum* at 7.22 mg cm^2 surface treatment (Tripathi *et al.*, 2003). Ho *et al.* (1997) indicated that Anethole (main component in the *Heracleum persicum, Foeniculum vulgare* and *Artemisia dracunculus* essential oil) was toxic on adults of *T. castaneum* and *S. zeamais*. It was found that *T. castaneum* adults were more susceptible to both the fumigant and the contact action of anethole than *Sitophilus zeamais*. The synergism among monoterpenes is found in many essential oils and this effect was studied by Hummelbrunner and Isman (2001), who stood out that (E)-Anethole acts synergistically with Thymol, citronellal and α-terpineol against the caterpillars *Spodoptera litura* (F.) (Lepidoptera: Noctuidae). Anethole has shown significant effect on *T. castaneum* from 20 μl L^{-1} concentration (66% reduction in population) which touched to 98% at 80 μl L^{-1} level and beyond this there was absolute control of population generation. For improving the mortality effect of anethole, minimum heat treatment (45°C) device was used that enhanced the toxicity of adults by 2-fold at 50.0 μl L^{-1} and 100.0 μl 5 L^{-1} treatment, respectively Among various combinations of compounds used anethole combined with 1,8-Cineole (1:1) was the best. This combination reduced the population by 100% at 50 μl L^{-1} concentration and at the same time was toxic to adults as well (Koul *et al.*, 2007).

Maintained Iranian plant essential oils are rich in 1,8-cineole, Limonene, Carvacrol, Citronellal, Thymol, Eugenol, Camphor, Terpinene, α-pinene, β-pinene, Linalool, Carvone and Anethole which are known compounds to show effects against various insect species and fumigant activity in above cases could be attributed to them in the respective essential oils.

Mode of action of essential oils and their components: The mechanisms of toxicity of essential oils have not been fully identified. However, regardless of the method of administration (e.g., oral, topical, or inhalation), insects acutely poisoned by certain essential oils display symptoms similar to toxins with a neurotoxic mode of action (Coats *et al.*, 1991; Isman, 1999), including agitation, hyperactivity, paralysis and quick knockdown. Ryan and Byrne (1988) suggested that the toxic effect may be attributed to reversible competitive inhibition of acetylcholinesterase by occupation of the hydrophobic site of the enzyme's active centre. Several reports indicate that monoterpenoids cause insect mortality by inhibiting Acetylcholinesterase Enzyme (AChE) activity (Houghton *et al.*, 2006). According to Lee *et al.* (2003), the monoterpenes that may be volatiles and lipophylic, can penetrate through breathing and quickly intervene in physiological functions of insect. These compounds can also act directly as neurotoxic compounds, affecting acetylcholinesterase activity or octopamine receptors (Isman, 2000). In a comparative study on the fumigant action of terpenes (ZP51 and SEM76) from Labiatae plants and (+)-Limonene, a component of plant essential oil, on AChE activity as well as octopamine systems in *R. dominica* adults, Kostyukovsky *et al.* (2002) noted that AChE inhibition was highest (65%) for highly toxic ZP51 but moderate for SEM76 (27%) and it was very low for (+)-Limonene (2%) that was least toxic. Essential oils, SEM76 and ZP51 caused a significant increase in cyclic AMP levels even at low concentrations indicating possible activation of octopamine. It was also observed that the AChE inhibition was not necessarily related to insect mortality levels. Bhatnagar-Thomas and Pal, 1974 reported in vivo and in vitro inhibition of AChE activity in *Trogoderma granarium* Everts adults by *Allium sativum* L. essential oil that has fumigant action. Enan (2001) suggested that toxicity of constituents of essential oil is related to the octopaminergic nervous system of insects. There is another suggestion that some monoterpenes may inhibit cytochrome P450-dependent monooxygenases (De-Oliveira *et al.*, 1997). Safrole and isosafrole, the main constituents of the essential oils of *Sassafras albidum* (Nutt.) and *Canangium odoratum* (Lam.) Baill. ex King, respectively, inhibited a-amylase enzyme activity in *T. castaneum in vitro* (Huang *et al.*, 1999) but the significance of the inhibition in causing insect mortality is not known. These suggest that the target sites of mode of action of monoterpenes are various.

CONCLUSIONS

In pest management strategies, aromatic plants with long lasting insecticidal efficiency should be considered. These considerations must take into account the pest species or the type of stored products. Large quantities of plant material would need to be processed to gain enough essential oil for commercial-scale tests. However, certain compounds in the oils exhibit much stronger activity than others. Plant varieties should be sought that produce these compounds in larger quantities, or synthetic production methods should be explored as an option to gain enough material for full-scale use. From the above discussion, it is clear that Iranian essential oils possess a wide spectrum of biological activity against insects and provides a simple and environment friendly (non-polluting and lesser or no toxicological concerns) alternative pest control. Since essential oils have strong toxicity in the vapour form against a wide range of insects, they could be commercially exploited as a fumigant for stored products and also impregnated into packaging thus preventing the insect infestation. However, the effects on other non-target microorganisms including pollinators, honeybees and natural predators/enemies have not been yet evaluated. If the problem of cost-effective commercial production can be solved, some of the essential oils and their compounds could be find a place in IPM strategies, especially where the emphasis is on environmental and food safety and on replacing the more dangerous and toxic fumigants and insecticides.

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