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Review article

The İmportance of Plant Essential Oils in The Fight Against Warehouse Pests [a]

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ABSTRACT

The need for food in the world is increasing every year. Due to the increasing need for food, producers produce more agricultural products every year and store the harvested products from the field in large warehouses or silos before they are delivered to the end consumer. However, one of the most important problems is the healthy preservation of these products in warehouses or silos. Harvested products field are vulnerable to many species and microorganisms, such as warehouse pests, in warehouses. Before the discovery of insecticides, the use of plant-derived insecticides in pest control was quite common. With the development of technology, the discovery of synthetic insecticides has increased our success in figthing these pests. However, since these chemicals are harmful to the environment and organisms health, the interest in alternative control methods has been increasing in recent years. One of the alternative methods in the fight against harmful insects is the figth with plant essential oils. Essential oils are organic. For this reason, they are likely to be one of the alternative control methods in the future, since they only affect the target pest in the fight against pests. According to the literature, it is understood that the extracts obtained from the leaves, stems, roots and fruits of various plants that are accessible in nature have been tested on different insects and positive results have been obtained. The aim of this review is to emphasize that it is possible to use plant essential oils instead of pesticides used in the fight against storage pests..

Keywords: Agriculture, Alternative Control Methods, Pesticide, Plant Extract

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Derleme makale

Depo Zararlıları ile Mücadelede Bitkisel Uçucu Yağların Önemi

ÖZ

Dünyada gıdaya olan ihtiyaç her geçen yıl artmaktadır. Artan gıda ihtiyacı nedeniyle üreticiler her yıl daha fazla tarımsal ürün üretmekte ve tarladan hasat edilen ürünleri son tüketiciye ulaşmadan önce büyük depolarda veya silolarda muhafaza edilmektedir. Depolama sırasındaki sorunlardan biri, bu ürünlerin depolarda veya silolarda sağlıklı bir şekilde muhafaza edilmesidir. Hasat edilen ürünler, depolarda depo zararlıları gibi birçok tür ve mikroorganizmaya karşı savunmasızdır. İnsektisitlerin keşfinden önce, ürün zararlılarının kontrolünde bitki kökenli insektisitlerin kullanımı oldukça yaygındı. Teknolojinin gelişmesiyle birlikte sentetik insektisitlerin keşfi bu zararlılarla mücadeledeki başarımızı yükseltmiştir. Ancak bu kimyasalların çevre ve organizma sağlığına zararlı olması nedeniyle son yıllarda alternatif kontrol yöntemlerine ilgi artmıştır. Zararlı böceklerle mücadelede alternatif yöntemlerden biri de bitkisel uçucu yağlar ile mücadeledir. Uçucu yağlar organiktir. Bu nedenle, zararlılarla mücadelede sadece hedef zararlıyaetki ettikleri için gelecekte alternatif mücadele yöntemlerinden biri olma ihtimalleri vardır. Yapılan çalışmalar sonucunda doğada bulunan çeşitli bitkilerin yaprak, gövde, kök ve meyvelerinden elde edilen ekstraktların farklı böcekler üzerinde denendiği ve olumlu sonuçlar alındığı anlaşılmıştır. Bu derleme çalışmasının amacı, depo zararlıları ile mücadelede kullanılan pestisitlerin yerine bitkisel uçucu yağların kullanılmasının mümkün olduğunu vurgulamaktır.

Anahtar Kelimeler: Tarım, Alternatif Mücadele Yöntemleri, Pestisit, Bitki Ekstraktı.

Introduction

The systematic increase in population brings along the food problem, which has become one of the ecological problems of humankind. There are many innovations in the field of agriculture every day in order to meet the increasing need for food. Another of the most important problems is to ensure that the products harvested from the field are preserved in warehouses or silos and reach the end consumer in a healthy way. Harvested products are very vulnerable to damage caused by many living organisms such as harmful insects, fungi, pests, rodents in warehouses (Hill, 2002). It has been reported that the damage caused by insects is around 10-40% in some years, and it can reach up to 100% in our country (Çam et al. 2012; Yıldırım et al. 2014). Warehouse pests damage products directly or indirectly. These insects lay their eggs on or inside the seeds. The larva, which feeds by eating the seed, causes both the weight loss of the seed, the decrease in the nutritional quality, the decrease in the germination feature and the contamination of the seeds with their feces (Durna and Kayahan, 2022). In order to reduce these damages caused by insects, producers widely use organic-phosphorus and pyrethroid group insecticides and fumigants to figth them. However, in recent years, the use of these synthetic chemicals has had many negative effects on humans, mammals and other living organisms, and

the residues left on the products have become the problems of humanity. Due to many reasons such as environmental pollution of synthetic pesticides, their effects on non-target organisms other than pests, the resistance of insects to these insecticides, the extinction of some beneficial plant and insect species, as well as their undesirable effects on other living organisms and humans, researchers have turned their attention to alternative methods of pest control (Tiryaki et al. 2010). Recently, studies on monoterpenes, which are the raw material of herbal extracts and essential oils, have been increasing rapidly. Plant essential oils are obtained from various parts of plants and are natural extracts (Cellat, 2011; Erol and Birgücü, 2020). It has been reported in many studies that plant essential oils can be used instead of synthetic pesticides (Altundağ and Aslım, 2005; Karakoç et al. 2006; Selimoğlu et al. 2015; Akkuş et al. 2021). Especially essential oils and their components stand out as potential alternative sources for insecticides and fumigants used in pest control (Rajendran and Sriranjini, 2008). Medicinal and aromatic plants grow naturally in nature and generally, plant essential oils and extracts are obtained from them. These essential oils have been preferred by researchers in recent years because they are not toxic to nature, are generally harmless to mammals and other living organisms, do not leave any residue except carvacrol (Çam et al. 2012), and have a high lethal effect on storage pests (Kılınçer et al. 2010; Nohutçu et al. 2021).

The Importance of Plant Essential Oils in Pest Control

Medicinal and aromatic plants are also known as natural bio-agents due to the phenolic compounds and essential oils they contain (Shanker and Solanki, 2004). They have been used for centuries against various pests or in alternative medicine (Rajendran and Sriranjini, 2008; Bozhüyük et al. 2019). It has been reported that approximately 200 out of 200000 plant species in the world have pesticide effects, but only 1% of this is utilized (Isman, 1995). Plant essential oils are obtained from various parts of plants such as roots, stems, tubers, leaves, seeds and flowers by different extraction methods. Plant-derived essential oils have insecticidal, antifeedant, growth inhibitory, ovicidal, attractant and repellent effects on pests. In addition, it has been reported to have effects on organisms such as mites, nematodes, bacteria, fungi and viruses (Bozhüyük et al. 2019; Nohutçu et al. 2021). Plants actually synthesize these chemicals in order to protect themselves from external factors and other harmful organisms and to survive. These chemicals are called secondary metabolites and are also used as raw materials in many sectors (Bourgaud et al. 2001; Aydın and Mammadov, 2017). Since they are of plant origin, they mostly do not have any negative side effects on living physiology and metabolism. They are also used as pharmaceutical raw materials (Bakla, 2010). It has been reported that there are various compounds effective against insects in plant essential oils (Bourgaud et al. 2001; Aydın and Mammadov, 2017; Akkuş et al. 2021; Sağlam-Altınköy and Bilginoğlu, 2022). Plant essential oils are shown as an alternative to pesticides because they contain bioactive components such as terpenoids (monoterpene, sesquiterpene and diterpene), alkaloids and flavonoids (Varma and Dubey, 1999; Croteau et al. 2000; Karakoç et al. 2006; 2013). It may also contain aliphatic and benzoic compounds. Toxic effects in insects are generally occur by contact, ingestion and inhalation (Rajendran and Sriranjini, 2008).

Some plants can be used as insecticides

Neem tree (Azadirachta indica, A. Juss.)

Neem tree (*Azadirachta indica*), which is from the Meliaceae family, is also known as "Indian Lilac". It is known to originate from North India and China. It is about 8-12 meters tall and sheds its leaves in winter (Özger et al. 2013). Neem tree can be grown in all soils with good drainage. It is also planted for decorative purposes in our country, and it has been planted as a culture tree in the streets of many cities, usually in the Aegean and Mediterranean regions (Kısmalı and Madanlar, 1988). Since its fruits are like beads, it is known as the Tespih Tree in our language. Its leaves, roots and bark are highly toxic and contain potent compounds such as phenols, terpenoids and alkaloids. These compounds can affect the development, reproduction and life cycle of harmful insects. It has been determined that the most important substance obtained from the *A. indica* tree is azadirachtin. It has been reported that azadirachtin, which has negative effects on insects, has effects such as repellant, egg laying, antifeedant, and deformed individual (Özger et al. 2013). Azadirachtin is used commercially in the world and in our country very effectively against pests (Schmutterer, 1990).

Rosemary (Rosmarinus officinalis, Linnaeus)

Rosemary (*Rosmarinus officinalis*), a member of the Lamiaceae family, is an important medicinal and aromatic plant species. Rosemary, 1-2 meters high, bushy in appearance, white, light blue/blue perennial, does not shed its leaves in winter (Arslan et al. 2022). In our country, it spreads as a culture plant in almost every region or in forests and on the edges of fields. Its scent is quite strong. The taste of its leaves is bitter and the essential oil obtained from the leaves is used in alternative medicine and in many fields (Malayoğlu, 2010). Besides, it also shows antioxidant properties because it contains carnosol, carnosic and rosmarinic acid. It has been reported carnosic acid is three times more than carnosol and seven times more than butylate hydroxytoluene (BHT) and butylate hydroxyanisole (BHA) (Tisserand and Young, 2014).

Oregano (Thymus spp., Linnaeus)

Thyme plant, which is from the Lamiaceae family, is seen on ant nests in meadows, grassy fields and forest edges. It likes rocky and hot soil areas of mountains. Thyme plant has been used by people for centuries because of its scent (Altundağ and Aslım, 2005). It was used as incense in temples in ancient times, and its anti-irritant, germicidal and insect repellent properties were used in alternative medicine (Bozdemir, 2019). There are more than 10 species of the thyme genus, which grows in almost every region in our country. Carvacrol and thymol, the main components of the essential oils obtained from the thyme plant, ensure the widespread use and trade of it. These phenolic compounds provide thyme-specific odor and antioxidant properties. These compounds constitute 78-82% of essential oils (Botsoglou et al. 2003; Tisserand and Young, 2014).

Eucalyptus (Eucalyptus globulus, Labill.)

Australia is the homeland of eucalyptus and its from the Myrtaceae family. Eucalyptus, which has close to 700 species, grows very easily and its height reaches 70 meters. These fast growing

trees do not shed their leaves. Flowers of eucalyptus are yellow, white or red. It can be grown easily wherever the Mediterranean climate (Ebadollahi et al. 2022). The eucalyptus tree releases an average of 250 tons of water into the air per year and draws up to 300 kilograms of water from the soil. Because of these properties, eucalyptus trees are used to drain swamp. Essential oils are obtained from the leaves of *Eucalyptus globulus*. The main components of the essential oil are 1,8-cineol (eucalyptol, maximum 70%), limonene, αpinene and β-pinene (Porta et al. 1999; Tisserand and Young, 2014). The essential oil of the eucalyptus plant has been used as an insect repellent since ancient times. Today, it has an important place in alternative control methods for storage pests (Ebadollahi et al. 2022).

Laurel (Laurus nobilis, Linnaeus)

Laurel is a tree belonging to the Lauraceae family. It can reach a height of 3-10 meters and is an evergreen forest tree. Laurel is seen in regions with Mediterranean climate. Fresh leaves are thin, light green veined, reddish yellow, later light green, with little aromatic odor. 35 different compounds were detected in essential oils obtained from leaves (Özer et al. 2019). These compounds constitute 90-94% of the plant essential oil obtained from the laurel leaves. 1,8-cineol has been noted to be the main compound in essential oils (Tisserand and Young, 2014).

Garlic (Allium sativum, Linnaeus)

Garlic, a genus of Allium, belongs to the Amaryllidaceae family (Choi and Oh, 2011). Its height is 25-100 cm, its color is purplish or pink. The garlic bulb consists of a small number of shallots, which are white or pinkish in color. It is known for its strong odor and burning taste (Arslan et al. 2022). The fact that it contains bioactive components such as sulphurous compounds allows it to be shown as a health source plant. Phenolic compounds are abundant in garlic (Lanzotti, 2006). Compounds with high sulfur atoms such as diallyl trisulfide (DATS), diallyl tetrasulfide (DATTS), diallyl pentasulfite (DAPS) and diallyl hexasulfide (DAHS), which are the main components of garlic essential oil, have high antimicrobial activity (Kozan, 2012). Sulfur-containing thiosulfinates are responsible for the antimicrobial properties of garlic. Allicin is the most important of these compounds and it gives garlic its typical odour and taste (Tisserand and Young, 2014).

Cumin (Cuminum cyminum, Linnaeus)

Cumin is from the Apiacea family. There are 300 genus and 3000 species in this family. Most plants in the family contain essential oils. These plants are annual, biennial or perennial herbaceous plants. ϒ-terpinene ratio is high especially in those grown in India. *Bunium persicum* (Boiss) B. Fedsch fruits contain 3-7% essential oil. In the composition of this oil; ϒterpinene-7-al (29%), ϒ-terpinene (26%), β-pinene (26%), and cumin aldehyde (12%) (Başer, 2014). *Laser trilobum* is known as "Kefe Kimyonu" in Türkiye and the fruits of this plant are similar to cumin in smell and taste. Limonene (41-71%) and perilaldehyde (4-33%) constitute the main compounds of essential oils obtained from this plant as 4-6% (Başer, 2014).

St. John's Wort (Hypericum perforatum, Linnaeus)

St. John's Wort (*Hypericum perforatum*) is a perennial, yellow-flowered plant in the Hypericaceae family. It can bloom from June to September. This plant, which grows in areas from sea level to 2500 m, shows a wide distribution throughout the temperate and tropical regions of the world (Çırak and Kurt, 2014). It is seen in almost every region of our country. It has been reported that the extracts of the aerial parts of the plant contain many compounds such as proanthocyanidins, phloroglucinols, naphthodiantron, flavonoids, phenylpropanes, biflavones (Çırak and Kurt, 2014; Altan et al. 2015). Also present are tannins, xanthone, essential oils and amino acids.

Patchouli [Pogostemon cablin, (Blanco) Benth.)]

Patchouli plant is a perennial, branched, aromatic plant with fragrant leaves from the Lamiaceae family. It grows wild in Malaysia, Indonesia and Singapore. Patchouli was first grown as a cultivar in India in 1941 (Yoshihiro et al. 1992). It is still cultivated in coastal areas of Southern India, West Bengal, Assam, Karnataka, Madhya Pradesh and Guverat (Ramya et al. 2013). Patchouli oil is an important ingredient in exotic perfumes as it has a rich and spicy scent. They prefer warm and humid climates and altitudes above 800-100 meters (Buré and Sellier, 2004; Ramya et al. 2013). Leaves collected and dried in the shade contain 2.5-3.5% oil (Buré and Sellier, 2004). Due to this oil content, it is among the preferred oils in soap, cosmetics, incense production and and the other many products. The composition of patchouli oil has a mixed content as in other plant oils. It is unique because it contains 24 different sesquiterpenes and sesqui and di-terpene compounds (Dung et al. 1990; Buré and Sellier, 2004). Sesquiterpenes are the main and primary component of patchouli oil (Deguerry et al. 2006; Tisserand and Young, 2014). Patchouli plant draws attention with its insect repellent, antibacterial and antifungal properties as well as being used in medical and cosmetic fields.

Tobacco plant (Nicotiana tabacum ve Nicotiana rustica, Linnaeus)

Tobacco plant belongs to the Solanaceae family. The leaves are used to make pleasant substances such as cigarettes. Its seeds are rich in oil, and its leaves are rich in gum, alkaloid, resin, starch and gum (Schmeltz, 1971). It has been reported that the oil rate in tobacco grown in Türkiye is 35-45%. Although tobacco cultivation has decreased relatively recently, it is still cultivated in the Aegean, Black Sea, Thrace, Marmara, Eastern Anatolia and Southeastern Anatolia regions (Şahin and Taşlıgil, 2014). Extracts obtained from tobacco leaves have been used as an insecticide against insects with a sucking type mouth structure for a long time. Especially the fact that the leaves are rich in alkaloids nornicotine and anabasin facilitates the fight against insects (Ujvary, 1999). Nicotine enters the insect body via the trachea system and binds to acetylcholine receptors by competing with acetylcholine, which provides transmission in the nervous system (Ujvary, 1999). The function of the receptors in the nervous system of the insect, whose cation channels are opened, is impaired. This causes the insect to first paralyzed and then die (Wang and Wang, 2003; Aydın and Mammadov, 2017; Karakaş, 2018).

The Role of Essential Oils in the Fight Against Storage Pests

For centuries, humanity has found different solutions to prevent damage to crops by harmful insects. Especially in the second half of the 20th century and with the developments in

technology, insecticides were discovered and the damage to the products in the warehouses was minimized. However, in recent years, when the harms of pesticides and insecticides to human and other living organisms have emerged, producers and researchers have turned their attention to alternative control methods. One of these control methods is essential oils obtained from medicinal and aromatic plants, as they cause minimal damage to living health (Sönmez, 2022). As it is known, medicinal and aromatic plants are well known all over the world. Because, in fact, humanity has already been using these plant species for their different needs for centuries. Especially Asia is known as the "land of aromatic plants". Asia has favorable climatic conditions for the growth and development of aromatic plants. Especially in China, 400 kinds of aromatic plants are grown for both commercial and domestic use, and essential oils are produced from more than 120 plant species (Ramya et al. 2013). Essential oils are complex compounds consisting of terpenes and their oxygenated derivatives. They have characteristic taste and odor. Plant essential oils have intense fragrant and volatile substances obtained from different parts of the plant by different methods (Rajendran and Sriranjini, 2008; Tisserand and Young, 2014). Essential oils are obtained from many plant species belonging to the Lamiaceae, Asteraceae, Apiaceae family and these oils are used in many sectors such as spices, plant-derived medicines, botanical pesticides, insect repellents, cosmetics, pharmaceutical raw materials and herbal health drinks (Ramya et al. 2013). In recent years, it has been determined that plant essential oils have insecticidal, insect repellent, development and egg laying inhibitory effects against pests (Ebadollahi et al. 2022). For example, Yang and Wan (2011) observed a positive correlation between increasing dose of essential oils and mortality rate in the contact and repellent effect trials of essential oils obtained from *Thymus vulgaris* L. (Lamiaceae), *Pogostemon cablin* (Blanco) Benth. (Lamiaceae) and *Corymbia citriodora* (Hook.) K.D. Hill &L.A.S. Johnson (Myrtaceae) plants with *Bemisia tabaci* Gennadius, 1889 (Hemiptera: Aleyrodidae) (biotipe B). According to the results of the study, the highest toxicity against *B. tabaci* was obtained in *T. vulgaris*, and the strongest repellent effect was obtained in *P. cablin*. Therefore, they reported that these two essential oils can be used as effective and environmentally sustainable bio-insecticides for the control of *B. tabaci*. Çam et al. (2012) in a study investigating the fumigant effects of essential oils obtained from clones of *Mentha spicata* L. (Lamiaceae), *Mentha villoso-nervata* Opiz. (Lamiaceae) and *Mentha piperita* L. (Lamiaceae) on the wheat weevil *Sitophilus granarius* L. 1758 (Coleoptera: Curculionidae), the highest mortality rate was found in *M. villoso-nervata* with 90%. Among the main components of essential oils, menthone, limonene, menthol and carvone, the highest mortality rate was detected in carvone. Similarly, in a study by Karakoç et al. (2013), in contact effect studies with essential oils and extracts obtained from *Salvia tchihatcheffii* (Fisch. & C.A.Mey.) Boiss. (Lamiaceae) and *Salvia cryptantha* Greuter and Burdet(1985) (Lamiaceae) plants on two important storage pests [*S. granarius*, *Sitophilus oryzae* L., 1763, (Coleoptera: Curculionidae)], the highest activity among the extracts was *S. tchihatcheffii* with a mortality rate of 87% obtained from stem extracts.

It is known that more than 2000 plant species can be used as insecticides in the world (Öncüer, 1995). *Foeniculum vulgare* Mill., Gard. Dict. (Apiaceae), *Lavandula stoechas* L. (Lamiaceae), *Thymbra spicata* L. (Lamiaceae), *Teucrium polium* L. (Lamiaceae), *Heracleum platytaenium* Boiss (Apiaceae) is another study reported to show high toxicity on *Acanthoscelides obtectus*

Say, 1831 (Coleoptera: Chrysomelidae) of essential oil obtained from *F. vulgare*(Selimoğlu et al. 2015). It has been reported that essential oils obtained from *Hypericum perforatum* L. (Hypericaceae) increase the mortality rate of *Tenebrio molitor* L. 1758 (Coleoptera: Tenebrionidae) in parallel with the increase in the exposed essential oil concentration, and it has an important potential in the fight against this insect (Baş and Ersoy, 2020). Alkan et al. (2018) reported that the essential oil of *Salvia officinalis* L. (Lamiaceae) has significant toxicity on adult individuals of *Rhyzoperta dominica*Fabricius (Coleoptera: Bostrichidae), which is promising for future studies.

The toxic properties of essential oils of plant origin on storage pests are generally high. In addition to these, the effect of repellent and antifeedant also has an important place (Adamski et al. 2016; Çetin and Elma, 2017). Adamski et al. (2016) investigated the effects of *Solanum tuberosum* L. (Solanaceae) and *Lycopersicon esculentum* L. (Solanaceae) leaf extracts on *T. molitor* and *Harmonia axyridis* Pallas, 1773 (Coleoptera: Coccinellidae), and found that different concentrations had no toxicity on these insects. On the other hand, it has been stated that these essential oils can be repellent or attractive. Çetin and Elma (2017) determined that extracts obtained from *Cinnamomum cassia* L. (cinnamon) (Lauraceae), *Laurus nobilis* L. (laurel) (Lauraceae), *Syzygium aromaticum* L. (clove) (Myrtaceae) and *Rosmarinus officinalis*, Spenn., (rosemary) (Lamiaceae) plants increased the rate of mortality and egg laying inhibition with concentration in contact effect trials against *Callosobruchus maculatus* adultsFabricius, 1775 (Coleoptera: Chrysomelidae). Many more studies highlight the methods of plant extracts and essential oils that can be alternatives to chemical insecticides used in pest control. Yaman and Şimşek (2019) determined that the highest toxicity of rosemary essential oil on *S. oryzae* was demonstrated by extracts dissolved in ethanol within a 24-hour period. They suggested that the presence of 1,8 cineole, α-pinene and βcaryophyllene in essential oils obtained from rosemary increased the toxic effect. Other studies reported that essential oils obtained from *Artemisia dracunculus* L. (Asteraceae), *Ocimum basilicum* L. (Lamiaceae) and *R. officinalis* plants had significant insecticidal effects on adults of *A. obtectus* and *Tribolium confusum* (Bozhüyük et al. 2019). Essential oils obtained from *Mentha longifolia* subsp. *longifolia* L. (Lamiaceae) plant causes the most mortality on *R. dominica*, *Oryzaephilus surinamensis*Kirby, 1837 (Coleoptera: Silvanidae), and *T. confusum* storage pests (Akkuş et al. 2021).

Neem tree seeds are very effective as insecticide because of the salannin and azadiractin. Monoterpene esters also make the Chrysanthemum plant effective (Banken and Stark, 1997). *Melia volkensii* (Gürke) (Meliaceae) plant, which has a toxic effect against some pests of the Diptera, Lepidoptera and Coleoptera orders, contains limonoids.

Plants of the Apiaceae family contain furanocoumarins, which have toxic effects against insects (Kaval and Tonçer, 2020). Trans-anethole, a phenylpropanoid, obtained from *Pimpinella anisum* L. (Apiaceae) (Anise), has been shown to be toxic to many harmful species from Coleoptera, Hymenoptera and Lepidoptera orders (Kelm et al. 1997).

Alkan et al. (2015) investigated the repellent effects of stem and flower extracts of *Tanacetum abrotanifolium* L. Druce (Asteraceae) against two important storage pests: Wheat weevil (*S. granarius*) and Rice weevil (*S. oryzae*). The highest repellent effect was found in the flower

hexane extract at the end of 48th hour for rice weevil, and the highest repellent effect was determined in the stem ethyl acetate extract at the end of 48th hour with 71.40% for wheat weevil. The results of the study revealed that *T. abrotanifolium* has the potential to be used in the fight against *S. granarius* and *S. oryzae*.In another study, *Origanum onites* L. and *Origanum vulgare* L. var. hirtum essential oils have been reported to cause 100% mortality in adults of *R. dominica* and *T. confusum* (Alkan, 2020).

Plant essential oils are composed of compounds such as terpenoids, alkaloids and flavonoids. They are generally effective on pests by inhalation. In contact action applications, essential oils are made by spraying the harmful insect or dipping it into the oil for a few seconds, and taking the essential oil into its body from the cuticle. In repellant trials, the insect takes the essential oil through respiration and moves away from the environment (Sönmez, 2022). This effect may continue until the oil completely evaporates from the environment, depending on the components it contains.

Although there are many studies on the insecticidal and repellent effects of plant-derived essential oils, studies on antifeedant and egg laying inhibitory are much more recent. Elma and Çetin (2022) in a study in which they examined the toxic and egg laying inhibitory effect of rosemary essential oil on adults of *C. maculatus*, observed that females laid less eggs as the concentration increased.

The physiological effect of plant extracts that inhibit egg laying is important in terms of reducing the destructive effect of subsequent F1 progeny. Teke and Mutlu (2020) found that *R. officinalis*, *L. nobilis*, *Echinacea purpurea* L. (Asteraceae), *Origanum majorana* L. (Lamiaceae), *O. basilicum* and *F. vulgare* essential oils showed lethal and repellent effects against *S. granarius* and *T. castaneum*, and there was a significant decrease in F1 generation compared to control groups. The main compounds of the laurel plant are eucalyptol and terpinyl acetate. It has been reported that *J. regia* has lethal, repellent and adult emergence inhibitory effects (respectivley 4.1%, 12%, 41.6%) on *A. obtectus* (Jovanovic et al. 2007).

Plant essential oils and extracts have many compounds such as monoterpenoid, sesquiterpene, diterpenoid. While these compounds have a direct toxic effect on some insect species, they may not kill some insect species. However, the fact that these compounds do not kill insects does not mean that they are not effective. While they can affect their reproductive performance, they can also cause developmental disorders. The egg-killing effect of monoterpenoids occurs only when the nervous system begins to develop, and they are neurotoxins (Wang and Wang, 2003; Campolo et al. 2018).Plant-derived essential oils can change the permeability of the vitelline membrane during embryogenesis. This may affect the physiological and biochemical processes of the egg by facilitating the diffusion of essential oils into the eggs. Besides, it is still controversial that essential oils affect mating behaviors during gametogenesis and have effects on egg formation and ovulation (Campolo et al. 2018).

Sönmez (2022) determined that eucalyptus, thyme, laurel and walnut extracts were toxic in contact and repellent effect trials against *A. obtectus* and *C. maculatus* adults. In addition, it was determined that especially walnut, laurel and thyme had an inhibitory effect on egg laying, and the number of adults hatching from these eggs was much lower than the control group.

In another study, they found that the mixture of *E. globulus* + *A. sativum* had lethal effects on *A. obtectus*, inhibiting the emergence of offspring and inhibiting egg laying. Papachristos and Stamopoulos (2002), Papachristos et al. (2004) studied the effects of thirteen essential oils, including *E. globulus* and *L. nobilis*, against *A. obtectus*. They found that especially these two plant essential oils reduce fecundity, adult emergence, inhibited egg hatching and the mortality rate of the hatched larvae increased. Lazarevi´c et al. (2020) reported that thyme reduces female egg laying and adult emergence on *A. obtectus*, Taş et al. (2015) reported that anise has an effect on egg hatching of *C. maculatus*.

Conclusion

Because of the essential oils are organic extracts, they only affect insects in the fight against pests, and their damage to non-target organisms is minimal, it has the potential to be an alternative control method in the future. Plant extracts and essential oils obtained from certain parts of plants are ecofriendly because they are naturally found in wild. The gradual removal of pesticides from human life depends on the positive results of studies with plant essential oils. Increasing interest in plant essential oils will lead to improvement of production methods and decrease in cost. In order to the effects of essential oils to be long-lasting, storage conditions and which natural ingredients will prolong the life of these essential oils should be investigated. If the benchlife of plant essential oils is extended, their application is facilitated and the cost is reduced, essential oils can be replaced by pesticides. Another problem with the active application of essential oils in pest control is the difficulty of applying these substances in warehouses and other environments. With the development of technology, this problem can be solved by taking essential oils into slow-release capsules and making them easier to apply in warehouses.

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Conflict of Interest

No known or potential conflict of interest exist for any author.

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