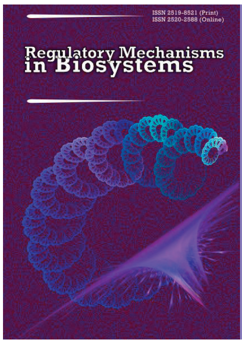

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Impact of essential oil from plants on migratory activity of *Sitophilus granarius* and *Tenebrio molitor*

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Measures against pests should be performed in the context of integrated management of agricultural crops and complex control of pests. Therefore, use of ecologically safe approaches is the best option. Essential oils of plants can make an impact on the main metabolic, biochemical, physiological and behavioural functions of insects. We evaluated the effect of 18 essential oils and 18 dried plants on migratory activity of *Sitophilus granarius* (Linnaeus, 1758) and *Tenebrio molitor* Linnaeus, 1758 in conditions of laboratory experiment. Notable repellent activity against *S. granarius* was exhibited by *Citrus sinensis* and *Picea abies*. Repellent action against *T. molitor* was displayed by dried and cut leaves of *Origanum vulgare* and *Eucalyptus globulus*, and also essential oils from *Juniperus communis*, *P. abies*, *Pterocarpus santalinus*, *C. sinensis* and *C. aurantiifolia*. Therefore, out of 18 studied essential oils, only two samples had a notable biological effect on migratory activity of *S. granarius* and five samples – on *T. molitor*. These data indicate a possibility of using essential oils or their main components as ecologically safe natural repellents against pests of stored wheat and products of its processing.

Keywords: pest control; biopesticides; plant protection; repellent; attractant.

Introduction

Measures against pests should be performed in the context of integrated management of agricultural crops and complex control of pests, and also should be ecologically-based. Therefore, use of ecologically safe approaches is the most promising variant (Koul & Walia, 2009). Over the recent 50 years, control of pests in agriculture has been based on use of synthetic chemical insecticides in field agrocenoses and conditions of greenhouse cultivation. However, synthetic insecticides are toxic, they cause a non-favourable impact on the environment, polluting soil, water and air, and also their large scale use leads to development of resistance in the target species and significant damage to populations of non-target species of invertebrates (Benhalima et al., 2004; Pimentel et al., 2009; Boyko & Brygadyrenko, 2017; Martynov & Brygadyrenko, 2017, 2018; Martynov et al., 2019). Strict measures of ecological regulation of use of pesticides have led to growth of a number of studies on use of natural plant extracts as an alternative to synthetic preparations (Isman, 2004; Pérez et al., 2010).

There are 17,500 species of aromatic plants and around 300 essential oils, which have commercial importance for cosmetics, pharmaceutics and the food industry (Bakkali et al., 2008; Pushpanathan et al., 2008; Ebadollahi et al., 2015). Over 2,000 species of plants have insecticidal activity (Klocke, 1989). Many commercial essential oils are included in the list Generally Recognized as Safe, fully recognized by the Environmental Protection Agency and Food and Drug Administration of the USA (Burt, 2004).

Essential oils are secondary metabolites and are complex substances which contain many different components that determine the properties of these compounds. Among the constituents of the essential oils, terpenes, aromatic and aliphatic compounds are distinguished. The main terpenes are monoterpenes and sesquiterpenes (Bakkali et al., 2008; Koul et al., 2008). Monoterpenes form up to 90% of essential oils and are represented by compounds different in structure: acyclic (geraniol) and cyclic (terpeniol) spirits, phenols (thymol), ketones (thujone), aldehydes (citronellal), acids (chrysanthemic acid) and oxides (1,8-cineole). Aromatic compounds, such as cinnamaldehyde, chavicol, anethole, safrole and apiole (derivatives from phenylpropane) are present in smaller amount (Isman, 2006; Tripathi et al., 2009).

Essential oils affect the main metabolic, biochemical, physiological and behavioural functions of insects (Mann & Kaufman, 2012), and can also block airways, leading to asphyxiation and death of pests (Kaufmann & Briegel, 2004; Rotimi et al., 2011). They can exert toxic, fumigative, repellent, antifeedant, ovicidal, attractant and other actions (Werdin-González et al., 2008). A number of researchers (Isman, 2000; Gutiérrez et al., 2009) report neurotoxic, cytotoxic, phototoxic and mutagenic effects of essential oils on insects. Botanical insecticides have a number of advantages: they do not persist in the environment, they pose relatively low risk for non-target organisms (useful predators and parasites) and are relatively non-toxic for mammals (Weinzierl, 1998; Scott et al., 2003). They usually quickly decompose in the environment and are easely metabolized by the animals that receive sublethal doses (Grdiša & Gršić, 2013). Reasons for limited commercial use of biological insecticides are their relatively slow action, variable efficiency, absence of stability and non-constant availability compared to synthetic analogues (Isman, 2008). Other obstacles to commercializing botanical insecticides are deficiency of natural resources, difficulties of standardization, control of quality and registration (Isman, 1997).

Sitophilus granarius (Linnaeus, 1758) is one the most harmful and common pests of grain. When feeding, an adult beetle damages different grains and products of its processing. Larvae can develop in grain of wheat, rye, barley, oat, rice, maize, buckwheat, panicgrass, and sometimes live in macaroni products and congealed flour. Another common pest of grain storages is *Tenebrio molitor* Linnaeus, 1758, which can damage different fractured grains of maize, wheat, soybean and other crops (Punzo & Mutchmor, 1980; Fazolin et al., 2007; Cosimi et al., 2009). Presence of *T. molitor* in stored grain leads to its contamination with enzymes of the body and products of vital activity of the insect, and also contributes to development of saprophytic microflora, reducing the quality of the product (Loudon, 1988; Schroeckenstein et al., 1990; Barnes & Siva-Jothy, 2000). This insect causes loss of up to 15% of grain and flour products throughout the world (Dunkel, 1992; Flinn et al., 2003; Neethirajan et al., 2007).

The objective of this article was to evaluate the impact of different essential oils on migratory activity of *S. granarius* and *T. molitor* in the conditions of laboratory experiment.

Materials and methods

The study on the impact of plant essential oils was conducted in a series of three experiments on two species of insects: *S. granarius* and *T. molitor*. In the first experiment, we used imagoes of *S. granarius*. Before the beginning of the experiment, the animals were kept in a common container with grain of wheat. Insects for the experiment were selected randomly. The experiment was undertaken in polyethylene tubes of 105 cm length and 2.5 cm diameter with marks each 10 cm. The tubes were filled with grain of wheat. At one end of the tube, 40 individuals of *S. granarius* and a cotton disk of 0.4 cm in diameter, saturated with 0.06 mL of essential oil – 0.48 mL/cm^2 concentration were placed (Table 1). The tubes were closed with a plug at both ends and put randomly on the tables of the laboratory with same illuminance and temperature, out of reach of direct sunlight. After two days, each 10 cm of the tube with grain were sieved through a laboratory sieve with diameter of cell of 2 mm for count of weevils in each part of the tube. Each variant of the experiment was performed in five replications. In all variants of the experiment, 1,800 individuals of *S. granarius* were used. The results were statistically analyzed in Statistica 8.0 (Statsoft Inc., USA) software pack using χ^2 criterion.

Table 1
Essential oils used in the experiment
on determining migratory activity of *Sitophilus granarius*

Substance	Plant	Chemical composition		ISO	References
		compounds	concentration, %		
Tea tree oil	*Melaleuca alternifolia* (Maiden & Betche) Cheel, 1925	α-pinene	2.1	4730	Cox et al., 2001
		α-terpinene	8.3		
		p-cymene	2.3		
		limonene	1.1		
		1,8-cineole	4.5		
		γ-terpinene	17.8		
		α-terpinolene	3.3		
		terpinen-4-ol	39.8		
		α-terpineol	3.4		
		aromadendrene	1.2		
		viridiforene	1.2		
		δ-cadinene	1.5		
Eucalyptus oil	*Eucalyptus globulus* Labillardière, 1861	α-pinene	5.65	770	Abdossi et al., 2015
		β-pinene	0.31		
		sabinene	0.65		
		limonene	0.84		
		1,8-cineole	76.65		
		γ-terpinene	0.63		
		terpien-4-ol	0.37		
		α-terpineol	1.96		
		α-terpineol acetate	4.85		
		isoledene	0.54		
		α-gurjunene	0.85		
		β-gurjunene	0.36		
		alloaromadendrene	3.98		
		aromadendrene	0.51		
Lavender oil	*Lavandula angustifolia* Miller, 1768	camphene	1.37	3515	Jianu et al., 2013
		β-myrcene	2.03		
		D-limonene	2.10		
		β-phellandrene	16.00		
		1,8-cineole	15.69		
		terpinen-4-ol	9.57		
		borneol	5.07		
		α-terpineol	6.00		
		santalene	4.50		
		caryophyllene	24.12		
Melissa oil	*Melissa officinalis* Linnaeus, 1753	α-pinene	0.05	–	Shabby et al., 1995
		β-pinene	0.09		
		camphene	0.12		
		myrcene	0.15		
		limonene	0.74		
		γ-terpinene	0.40		
		p-cymene	0.83		
		octanal	0.12		
		6-methyl-5-hepten-2-ol	3.79		
		linalool	0.25		
		terpinen-1-o1	0.25		
		citronellal	13.32		
		β-caryophyllene	4.95		
		neral	19.75		
		α-terpineol	1.44		
		geranial	26.80		
		geranyl acetate	1.76		
		neryl acetate	1.45		
		geraniol	4.23		
		nerol	0.64		
		caryophyllene oxide	9.99		
Bergamot oil	*Citrus bergamia* Risso & Poiteau, (1819)	α-thujene	0.27	9800	Costa et al., 2010
		α-pinene	1.04		
		sabinene	0.89		
		β-pinene	5.59		
		myrcene	0.91		
		α-terpinene	0.11		
		p-cymene	0.37		
		limonene	42.80		
		(Z)-β-ocimene	0.17		
		γ-terpinene	6.19		
		terpinolene	0.24		
		linalool	5.55		
		octyl acetate	0.10		
		neral	0.16		
		linalyl acetate	27.14		
		geranial	0.24		
		α-terpinyl acetate	0.14		
		neryl acetate	0.30		
		geranyl acetate	0.31		
		(*E*)-caryophyllene	0.25		
		trans-α-bergamotene	0.25		
		β-bisabolene	0.36		
Orange oil	*Citrus sinensis* (Linnaeus) Osbeck (pro. sp.)	α-pinene	0.36	3140	Singh et al., 2010
		sabinine	0.37		
		β-myrcene	1.71		
		octanal	0.43		
		limonene	90.66		
		linalylacetate	2.80		
		t-sabinine hydrate	0.42		
		laevo-β-pinene	0.46		
		geranyl formate	0.65		
Grapefruit oil	*Citrus paradisi* Macfadyen, 1830	α-pinene	0.4	3053	Uysal et al., 2011
		sabinene	0.3		
		β-pinene	0.8		
		β-myrcene	0.7		
		α-terpinene	0.7		
		limonene	91.5		
		linalool	1.1		
		trans-limonene oxide	0.9		
		citronellal	0.4		
		α-terpineol	0.3		
		nerol	0.3		
		neral	0.4		
		geraniol	0.3		
		geranial	0.4		
Spruce oil	*Picea abies* (Linnaeus) H. Karsten., 1881	santene	2.27	–	Radulescu et al., 2011
		α-thujene	0.74		
		α-pinene	5.40		
		camphene	7.55		
		β-pinene	0.52		

Substance	Plant	Chemical composition: compounds	concentration, %	ISO	References
		β-myrcene	0.75		
		limonene	9.29		
		1,8-cineole	0.45		
		camphor	0.40		
		borneol	1.11		
		bornyl acetate	11.78		
		α-humulene	0.60		
		γ-muurolene	0.46		
		β-selinene	0.42		
		α-muurolene	1.61		
		γ-cadinene	1.54		
		δ-cadinene	9.49		
		nerolidol	1.01		
		1-*epi*-cubenol	0.52		
		α-muurolol	11.01		
		δ-cadinol	1.48		
		α-cadinol	21.39		
		manool	3.58		

Note: * – number of ISO standard.

In the second and the third experiments, we used third age larvae of *T. molitor*. For one month before the beginning of the experiments, they were kept in a general container and fed with a single component diet (dry rolled oats). Larvae for experiments were selected randomly. The second experiment was undertaken in polyethylene tubes of 4 cm diameter and 105 cm length with marks each 10 cm. In one part of the tube, 400 g of wheat grain with cut up plants was placed (Table 2), and 400 g of grain with no additions was put in the other part. At 10 cm intervals along the tube, 5 larvae of *T. molitor* were placed. The tubes were put randomly on the tables in the laboratory with same illuminance and temperature, out of reach of direct sunlight. After two days, from each 10 cm of the tube, grain was extracted and sieved through a laboratory sieve with cells of 2 mm in diameter for detecting and counting larvae of *T. molitor* in each section of the tube. Each variant of the experiment was performed in ten replications. In all variants of the experiment, 9,500 individuals of *T. molitor* (9,000 in 18 variants of the experiment and 500 in the control) were used.

Table 2
Plants used in the experiment
on determining migratory activity of *T. molitor*

Common name	Latin name	Content of essential oils, %	Chemical composition: substances	concentration, %	References
Tasmanian bluegum	*Eucalyptus globulus* Labillardière, 1861	1.6–3.0	α-pinene	5.65	Chalchat et al., 1995; Abdossi et al., 2015
			β-pinene	0.31	
			sabinene	0.65	
			limonene	0.84	
			1,8-cineole	76.65	
			cis-β-ocimene	0.15	
			γ-terpinene	0.63	
			terpien-4-ol	0.37	
			α-terpineol	1.96	
			α-terpineol acetate	4.85	
			isoledene	0.54	
			α-gurjunene	0.85	
			β-gurjunene	0.36	
			alloaromadendrene	3.98	
			aromadendrene	0.51	
Lavender	*Lavandula angustifolia* Miller, 1768	1.13–2.75	α-thujene	0.40	Jianu et al., 2013
			α-pinene	0.78	
			camphene	1.37	
			sabinene	0.31	
			β-pinene	0.94	
			β-myrcene	2.03	
			carene	0.76	
			D-limonene	2.10	
			β-phellandrene	16.00	
			1,8-cineole	15.69	
			γ-terpinene	0.48	
			terpinen-4-ol	9.57	
			borneol	5.07	
			α-terpineol	6.00	
			santalene	4.50	
			caryophyllene	24.12	
			β-sesquiphellandrene	0.39	
Lemon balm	*Melissa officinalis* Linnaeus, 1753	2.36	propanoic acid	1.93	Pereira et al., 2014
			propanoic acid 2-hydroxy butyl ester	1.98	
			2,5-pyrrolidinedione	1.04	
			ethyl hydrogen succinate	3.88	
			conhydrin	1.62	
			ethyl *iso*-allocholate	5.06	
			heptatriacotonol	1.33	
			gallic acid	9.54	
			hexadecanoic acid	1.97	
			hexadecanoic acid methyl ester	1.09	
			β-sitosterol	45.59	
			octadecatrienoic acid methyl ester	2.11	
			chlorogenic acid	1.81	
			linoleic acid ethyl ester	0.99	
			hexadecanoic acid butyl ester	2.97	
			lupeol	0.98	
			caffeic acid	3.07	
			caffeine	1.26	
			octanal	2.10	
Peppermint	*Mentha piperita* Linnaeus, 1753	2.50	α-pinene	0.32	Andoğan et al., 2002; Saharkhiz et al., 2012
			sabinene	0.26	
			β-pinene	0.58	
			1,8-cineole	6.69	
			cis-sabinene hydrate	0.50	
			menthone	2.45	
			menthofuran	11.18	
			neomenthol	2.79	
			menthol	53.28	
			neomenthyl acetate	0.65	
			menthyl acetate	15.10	
			isomenthyl acetate	0.61	
			β-bourbonene	0.37	
			(*Z*)-caryophyllene	2.06	
			E-β-farnesene	0.30	
			germacrene D	2.01	
			bicyclogermacrene	0.22	
Absinthium	*Artemisia absinthium* Linnaeus, 1753	1.30	sabinene	1.6	Rezaeinodehi & Khangholi, 2008; Lopes-Lutz et al., 2008
			myrcene	10.8	
			α-phellandrene	0.8	
			para-cymene	1.2	
			1,8-cineole	1.0	
			(*Z*)-β-ocimene	1.5	
			(*E*)-β-ocimene	0.5	
			linalool	4.6	
			cis-thujone	0.5	
			trans-thujone	10.1	
			(*Z*)-myroxide	2.4	
			terpinen-4-ol	1.7	
			trans-sabinyl acetate	26.4	
			β-caryophyllene	0.9	
			neryl isovalerate	1.8	
Bay tree	*Laurus nobilis* Linnaeus, 1753	1.86	α-pinene	6.1	Dadalioğlu & Evrendilek, 2004; Derwich et al., 2009
			sabinene	12.1	
			β-terpinene	0.1	
			1,8-cineole	60.7	
			γ-terpinene	1.0	
			linalool	0.7	
			terpinen-4-ol	3.3	
			α-terpineol	2.0	
			α-terpinene	12.5	
			eugenol	0.5	
			β-caryophyllene	0.4	
			methyl eugenol	0.7	
Breckland thyme	*Thymus serpyllum* Linnaeus, 1753	1.05	α-thujene	1.1	Lee et al., 2005; Nikolić et al., 2014
			α-pinene	2.0	
			camphene	2.4	
			sabinene	0.8	

Common name	Latin name	Content of essential oils, %	Chemical composition: substances	Chemical composition: concentration, %	References
			β-myrcene	1.3	
			α-terpinene	1.1	
			p-cymene	8.9	
			limonene	0.6	
			γ-terpinene	7.2	
			cis-sabinene hydrate	0.5	
			linalool	2.4	
			camphor	0.7	
			borneol	6.0	
			terpinene-4-ol	0.7	
			thymol methyl ether	3.8	
			bornyl acetate	7.0	
			thymol	38.5	
			carvacrol	4.7	
			thymol acetate	2.8	
			β-caryophyllene	1.3	
			β-bisabolene	1.0	
			eudesm-3-en-6-ol	0.6	
Rosemary	*Rosmarinus officinalis* Linnaeus, 1753	1.90	α-pinene	14.90	Özcan & Chalchat, 2008; Gachkar et al., 2007
			camphene	3.33	
			β-octanone	1.61	
			sabinene	0.56	
			myrcene	2.07	
			O-cymene	0.71	
			1,8-cineole	7.43	
			linalool	14.90	
			myrcenol	0.75	
			camphor	4.97	
			borneol	3.68	
			terpinen-4-ol	1.70	
			α-terpineol	0.83	
			verbinone	1.94	
			piperitone	23.70	
			bornyl acetate	3.08	
			β-caryophyllene	2.68	
			cis-β-farnesene	1.26	
			germacrene D	0.52	
			α-bisabolol	1.01	
Cloves	*Syzygium aromaticum* (Linnaeus) Merrill et Perry, 1989	3.00	p-cymene	0.90	Nassar et al., 2007; Lee et al., 2009
			5-hexene-2-one	0.67	
			thymol	0.87	
			eugenol	71.56	
			eugenyl acetate	8.99	
			caryophyllene oxide	1.67	
			guaiol	0.90	
			nootkatin	1.05	
			isolongifolanone	0.86	
			hexadecanoic acid	0.50	
			9,17-octadecadienal	0.24	
			octadecanoic acid butyl ester	0.33	
			vitamin E acetate	0.43	
Yarrow	*Achillea millefolium* Linnaeus, 1753	0.13–0.34	thymol	0.5	Pino et al., 1998; Rohloff et al., 2000
			ethyl nonanoate	2.6	
			sabinene	5.4	
			β-caryophyllene	5.2	
			ethyl hexanoate	0.6	
			α-humulene	0.7	
			p-cymene	0.6	
			1,8-cineole	5.7	
			germacrene D	0.8	
			viridiflorene	0.8	
			linalool	1.0	
			camphor	1.2	
			humulene epoxide II	3.2	
			borneol	9.8	
			14-hydroxy-α-muurolene	0.8	
			terpinen-4-ol	2.8	
			α-terpineol	2.0	
			methyl hexadecanoate	0.8	
			caryophyllene oxide	20.0	
			(*E*)-isoeugenyl acetate	1.1	
			ethyl octanoate	1.5	
			hexadecanoic acid	1.1	
			pulegone	2.4	
			bornyl acetate	1.9	
Tansy	*Tanacetum vulgare* Linnaeus, 1753	0.22	tricyclene	0.1	Schearer, 1984
			α-pinene	0.4	
			camphene	2.5	
			sabinene	6.0	
			α-terpinene	0.1	
			1,8-cineole	5.1	
			γ-terpinene	0.5	
			ρ-cymene	1.0	
			sabinol acetate	0.2	
			camphor	29.6	
			terpinen-4-ol	1.5	
			umbellulone	24.7	
			borneol	0.8	
			carvone	8.3	
			valeranone	6.8	
			thymol	10.3	
Immortelle	*Helichrysum arenarium* Moench, 1794	0.09	linalool	1.7	Czinner et al., 2000
			α-terpineol	1.8	
			octanoic acid	6.0	
			carvone	1.1	
			anethole	3.2	
			nonanoic acid	6.9	
			β-caryophyllene	0.6	
			thymol	0.6	
			carvacrol	3.6	
			α-humulene	0.5	
			eugenol	0.4	
			decanoic acid	9.8	
			δ-cadinene	0.7	
			butylhydroxyanisole	0.6	
			dodecanoic acid	11.9	
			α-muurolol	1.3	
			β-asarone	1.5	
			globulol	1.4	
			methyl palmitate	28.5	
Sage	*Salvia officinalis* Linnaeus, 1753	1.11	α-pinene	2.6	Perry et al., 1999
			camphene	2.1	
			β-pinene	6.0	
			myrcene	0.9	
			1,8-cineole	9.2	
			(*Z*)-ocimene	0.4	
			α-thujone	34.6	
			β-thujone	5.0	
			camphor	6.5	
			borneol	2.4	
			bornyl acetate	0.4	
			β-caryophyllene	4.5	
			aromadendrene	0.5	
			α-humulene	6.2	
			germacrene D	0.3	
			δ-cadinene	0.4	
			caryophyllene oxide	0.7	
			viridiflorol	4.5	
			α-humulene oxide	0.9	
			manool	1.1	
Oregano	*Origanum vulgare* Linnaeus, 1753	2.50	α-thujene	2.2	Mechergui et al., 2010; Teixeira et al., 2013
			α-pinene	0.7	
			sabinene	1.0	
			β-myrcene	1.3	
			α-terpinene	3.7	
			β-phellandrene	0.9	
			cis-β-ocimene	1.6	
			trans-β-ocimene	1.5	
			γ-terpinene	11.6	
			α-terpinolene	0.9	
			β-bisabolene	2.1	
			linalool	2.6	
			menthone	0.7	
			δ-terpineol	7.5	
			β-fenchyl alcohol	12.8	
			pulegone	1.0	
			carvacrol	14.5	
			spathulenol	0.5	

Common name	Latin name	Content of essential oils, %	Chemical composition		References
			substances	concen-tration, %	
			caryophyllene oxide	0.6	
			thymol	12.6	
Wild rosemary	*Rhododendron tomentosum* Harmaja (1990)	0.14–0.87	α-pinene	0.7	Raal et al., 2014
			β-pinene	0.5	
			β-myrcene	1.3	
			ρ-cymene	12.5	
			ρ-cymenene	0.5	
			(*E*)-pinocarveol	0.7	
			lepalin	0.7	
			pinocarvone	0.8	
			α-thujenal	0.4	
			p-cymen-8-ol	0.7	
			myrtenal	0.8	
			γ-terpineol	31.2	
			piperitone	0.7	
			lepalone	1.3	
			isopiperitenone	0.4	
			lepalol	2.6	
			isoascaridol	2.7	
			alloaromadendrene	0.6	
			ledene	0.4	
			palustrol	15.9	
			epiglobulol	0.7	
			ledol	11.8	
			β-oplopenone	0.4	
			(*Z*)-nerolidol acetate	2.1	
			cyclocolorenone	1.6	
European birthwort	*Aristolochia clematitis* Linnaeus, 1753	1.10	2-hexanone	1.6	Dhouioui et al., 2016
			propyl-2-valerate	6.3	
			butyl isobutyrate	8.0	
			1,8-cineole	1.2	
			artemisia ketone	2.0	
			phenyl ethyl alcohol	1.5	
			linalool	1.0	
			camphor	2.2	
			trans-pinocarveol	1.4	
			cis-verbenol	1.1	
			trans-verbenol	2.2	
			terpinen-4-ol	2.7	
			terpineol	1.5	
			verbenone	2.1	
			bornyl acetate	1.2	
			methyl myrtenate	2.5	
			β-elemene	4.7	
			trans-β-caryophyllene	4.4	
			valerena 4,7(11)-diene	3.5	
			allo-aromadendrene	1.3	
			bicyclosesquiphellandrene	1.5	
			valencene	1.5	
			paciforgiol	3.2	
			α-elemol	3.1	
			epi-globulol	10.0	
			calarene oxide	4.9	
			maaliol	1.2	
			caryophyllene-oxide	4.6	
			β-funebrene epoxide	4.4	
			aromadendrene oxide	14.0	
			β-atlantol	5.7	
			aromadendreneoxide	3.2	
			isospathulenol	1.8	
			T-cadinol	2.1	
			agarospirol	1.6	
			τ-muurolol	1.5	
			bisabolone-oxide A	2.9	
			β-elemene dioxide	2.2	
			eremophilone cyclocolo-	8.4	
			renone	3.6	
			14-oxy-α-muurolene	1.3	
			α-vetivone	1.4	
Basil	*Ocimum basilicum* Linnaeus, 1753	0.5–0.8	*cis*-β-ocimene	0.6	Hussain et al., 2008
			1,8-cineole	1.1	
			fenchone	0.9	
			linalool oxide	1.0	
			linalool	58.6	
			camphor	3.1	
			α-terpineol	1.0	
			cis-geraniol	1.0	
			β-caryophyllene	1.4	
			α-bergamotene	7.6	
			γ-muurolene	0.7	
			germacrene D	2.0	
			bicyclogermacrene	0.8	
			γ-cadinene	4.9	
			calamenene	0.7	
			spathulenol	0.5	
			viridiflorol	1.6	
			epi-α-cadinol	10.0	
Camomile	*Matricaria chamomilla* Linnaeus, 1753	0.62–0.75	*p*-cymene	0.11	Pirzad et al., 2006; Heuskin et al., 2009
			limonene	0.10	
			trans-β-ocimene	0.11	
			cis-α-ocimene	0.69	
			γ-terpinene	0.17	
			artemesia ketone	0.32	
			α-isocomene	0.26	
			β-caryophyllene	0.17	
			E-β-farnesene	42.59	
			germacrène D	2.93	
			β-selinene	0.22	
			(*Z,E*)-α-farnesene	0.83	
			bicyclogermacrene	1.99	
			(*E,E*)-α-farnesene	8.32	
			δ-cadinene	0.18	
			sesquirosefuran	0.18	
			trans-nerolidol	0.17	
			dehydronerolidol	0.09	
			dendrolasin	0.21	
			spathulenol	0.63	
			globulol	0.23	
			α-bisabolol oxide B	4.43	
			α-bisabolone oxide A	4.53	
			chamazulene	1.18	
			α-bisabolol oxide A	21.16	
			cis-eneyne-dicyclo ether	5.94	
			trans-eneyne-dicyclo ether	0.99	
			(*E*)-phytol	0.23	

The third experiment was performed in a container (50 x 33 x 19 cm) in which wheat flour of highest sort was put (400 g) in a 1 cm layer. Then, 17 plastic cups with removed bottom (100 mL capacity) were put in the container at a distance of 0.5 cm one from another with 80 g of flour and 5 cups with 5 larvae of *T. molitor* in each. In 15 cups, into flour, a cotton disk of 0.4 cm diameter, saturated with 0.06 mL of essential oil of one of the plants (0.48 mL/cm^2), was placed at a 3 cm depth. For each of the 20 studied types of essential oils (Table 3) we used one cup. The other two cups were the control (a 4 cm diameter cotton disk not processed with any of the essential oils was placed in them). Each cup was covered with a separate plastic cover to prevent mixing of the odours of the essential oils. The experiment was performed in five replications (n = 5). Duration of each experiment was 48 hours. After this period, the flour from the cups was sieved for counting live and dead insects. The results of the second and the third experiments were statistically analyzed in Statistica 8.0 (Statsoft Inc., USA) software pack. The differences between the selections were considered reliable at $P < 0.05$ (one-way ANOVA).

Table 3
Essential oils used in the experiment on determining migratory activity of *Tenebrio molitor*

Substance	Plant	Chemical composition		ISO	References
		compounds	concen-tration, %		
Tea tree oil	*Melaleuca alternifolia* (Maiden & Betche) Cheel, 1925	α-pinene	2.1	4730	Cox et al., 2001
		α-terpinene	8.3		
		p-cymene	2.3		
		limonene	1.1		
		1,8-cineole	4.5		
		γ-terpinene	17.8		
		α-terpinolene	3.3		

Substance	Plant	Chemical composition: compounds	Chemical composition: concentration, %	ISO	References
		terpinen-4-ol	39.8		
		α-terpineol	3.4		
		aromadendrene	1.2		
		viridiforene	1.2		
		δ-cadinene	1.5		
Eucalyptus oil	*Eucalyptus globulus* Labillardière, 1861	α-pinene	5.65	770	Abdossi et al., 2015
		β-pinene	0.31		
		sabinene	0.65		
		limonene	0.84		
		1,8-cineole	76.65		
		γ-terpinene	0.63		
		terpien-4-ol	0.37		
		α-terpineol	1.96		
		α-terpineol acetate	4.85		
		isoledene	0.54		
		α-gurjunene	0.85		
		β-gurjunene	0.36		
		alloaromadendrene	3.98		
		aromadendrene	0.51		
Lavender oil	*Lavandula angustifolia* Miller, 1768	camphene	1.37	3515	Jianu et al., 2013
		β-myrcene	2.03		
		D-limonene	2.10		
		β-phellandrene	16.00		
		1,8-cineole	15.69		
		terpinen-4-ol	9.57		
		borneol	5.07		
		α-terpineol	6.00		
		santalene	4.50		
		caryophyllene	24.12		
Orange oil	*Citrus sinensis* (Linnaeus) Osbeck (pro. sp.)	α-pinene	0.36	3140	Singh et al., 2010
		sabinine	0.37		
		β-myrcene	1.71		
		octanal	0.43		
		limonene	90.66		
		linalylacetate	2.80		
		t-sabinine hydrate	0.42		
		laevo-β-pinene	0.46		
		geranyl formate	0.65		
Grapefruit oil	*Citrus paradisi* Macfadyen, 1830	α-pinene	0.4	3053	Uysal et al., 2011
		sabinene	0.3		
		β-pinene	0.8		
		β-myrcene	0.7		
		α-terpinene	0.7		
		limonene	91.5		
		linalool	1.1		
		trans-limonene oxide	0.9		
		citronellal	0.4		
		α-terpineol	0.3		
		nerol	0.3		
		neral	0.4		
		geraniol	0.3		
		geranial	0.4		
Rosemary oil	*Rosmarinus officinalis* Linnaeus, 1753	α-pinene	14.90	1342	Gachkar et al., 2007
		camphene	3.33		
		β-octanone	1.61		
		myrcene	2.07		
		1,8-cineole	7.43		
		linalool	14.90		
		camphor	4.97		
		borneol	3.68		
		terpinen-4-ol	1.70		
		verbinone	1.94		
		piperitone	23.70		
		bornyl acetate	3.08		
		β-caryophyllene	2.68		
		cis-β-farnesene	1.26		
		α-bisabolol	1.01		
Cinnamon-oil	*Cinnamomum verum* J. Presl, 1825	heptanal	1.09	–	Jayaprakasha et al., 2002
		nonanal	1.09		
		α-copaene	23.05		
		α-bergamotene	27.38		
		trans-cinnamyl acetate	2.41		
		aromadendrene	1.79		
		α-humulene	6.19		
		germacrene D	2.10		
		viridiflorene	3.29		
		α-muurolene	2.70		
		γ-cadinene	1.57		
		δ-cadinene	5.97		
		ledol	1.29		
		spathulenol	2.02		
		globulol	1.67		
		β-bisabolol	1.26		
		tetradecanol	4.27		
		epi-α-bisabolol	2.08		
Juniper oil	*Juniperus communis* Linnaeus, 1753	α-thujene	1.68	8897	Chatzopoulou & Katsiotis, 1993
		α-pinene	41.25		
		sabinene	17.38		
		β-pinene	2.05		
		myrcene	2.66		
		α-terpinene	1.22		
		limonene	4.23		
		1,8-cineole	1.21		
		γ-terpinene	2.09		
		terpinolene	1.16		
		terpinen-4-ol	2.78		
		β-caryophyllene	1.69		
		α-humulene	1.56		
		germacrene D	1.83		
Ginger oil	*Zingiber officinale* Roscoe, 1807	camphene	3.0	16928	Singh et al., 2008
		β-phellandrene	1.4		
		1,8-cineole	1.9		
		borneol	2.1		
		neral	7.4		
		geraniol	3.4		
		geranial	25.9		
		ar-curcumene	6.6		
		α-zingiberene	9.5		
		(E,E)-α-farnesene	7.6		
		β-sesquiphellandrene	5.1		
		trans-nerolidol	1.5		
		zingiberenol	1.7		
		β-eudesmol	1.0		
Cedar oil	*Cedrus atlantica* (Endlicher) G. Manetti ex Carrière, 1855	α-terpinene	1.02	9843	Derwich et al., 2010
		cis-ocimene	1.62		
		humulene	1.30		
		β-caryophyllene	3.14		
		σ-himachalene	7.62		
		cis-α-atlantone	6.78		
		himachalol	5.26		
		α-himachalene	4.15		
		α-pinene	14.85		
		β-pinene	1.35		
		himachalene	10.14		
		cadinene	3.02		
		isocaryophillene	1.10		
		β-himachalene	9.89		
		germacrene-D	3.52		
		β-copaene	2.26		
		cymene	1.05		
		3-carene	1.10		
		verbenol	2.24		
		limonene	2.01		
		ylangene	2.20		
		β-phellandrene	2.19		
		γ-amorphane	2.22		
Spruce oil	*Picea abies* (Linnaeus) H. Karsten., 1881	santene	2.27	–	Radulescu et al., 2011
		α-pinene	5.40		
		camphene	7.55		
		limonene	9.29		
		borneol	1.11		
		bornyl acetate	11.78		
		α-muurolene	1.61		
		γ-cadinene	1.54		
		δ-cadinene	9.49		
		nerolidol	1.01		
		α-muurolol	11.01		
		δ-cadinol	1.48		

Substance	Plant	Chemical composition: compounds	concentration, %	ISO	References
		α-cadinol	21.39		
		manool	3.58		
Thuja oil	*Thuja occidentalis* Linnaeus, 1753	α-thujene	1.46	–	Jirovetz et al., 2006
		α-pinene	3.33		
		camphene	2.55		
		α-fenchene	2.04		
		sabinene	12.14		
		β-pinene	1.14		
		myrcene	4.05		
		p-cymene	2.37		
		α-terpinene	1.83		
		limonene	2.36		
		β-phellandrene	1.65		
		γ-terpinene	2.29		
		trans-sabinene hydrate	1.09		
		terpinolene	2.32		
		fenchone	12.87		
		linalool	1.89		
		α-thujone	2.76		
		β-thujone	9.48		
		camphor	1.24		
		terpinen-4-ol	3.32		
		linalyl acetate	1.24		
		sabinyl acetate	16.55		
		terpinyl acetate	1.17		
		β-caryophyllene	1.23		
		δ-cadinene	1.29		
Geranium oil	*Pelargonium graveolens* L'Héritier, 1789	linalool	5.60	4731	Boukhris et al., 2012
		rose oxide-*trans*	2.01		
		iso-menthone	4.42		
		β-citronellol	21.93		
		geraniol	11.07		
		citronellyl formate	13.24		
		geranyl formate	6.22		
		β-bourbonene	3.14		
		trans-caryophyllene	1.02		
		germacrene D	4.33		
		viridiflore	2.35		
		δ-cadinene	2.38		
		δ-cadinene	1.33		
		α-agarofuran	1.28		
		10-epi-γ-eudesmol	7.92		
		geranyl tiglate	2.39		
Sandalwood oil	*Pterocarpus santalinus* Linnaeus filius, 1782	*cis*-α-santalol	31.67	3518	Subasinghe et al., 2013
		epi-α-bisabalol	1.44		
		epi-β-santalol	2.36		
		cis-β-santalol	14.50		
		cis-nuciferol	1.02		
		γ-curcumen-12-ol	1.68		
		β-curcumen-12-ol	2.35		
Lime oil	*Citrus aurantiifolia* (Christmann) Swingle, 1913	2,3-dimethyl-2,3-butanediol	1.67	–	Sandoval-Montemayor et al., 2012
		resorcinol	3.65		
		1-methoxycyclohexene	8.00		
		linalool oxide	1.18		
		corylone	6.93		
		terpinen-4-ol	1.66		
		α-terpineol	5.97		
		3-methyl-1,2-cyclopentanedione	8.27		
		3,7-dimethyl-(z)-2,6-octadienal	1.09		
		geraniol	1.15		
		citral	2.21		
		7-methyl-(Z)-8-tetradecen-1-ol acetate	2.83		
		geranyl acetone	1.84		
		bergamotene	1.00		
		(z)-8-methyl-9-tetradecenoic acid	1.24		
		trans-α-bisabolene	1.02		
		caryophyllene oxide	3.02		
		spathulenol	1.95		
		umbelliferone	4.36		
		palmitic acid	6.89		
		5,7-dimethoxycoumarin	15.80		
		5-methoxypsoralen	1.14		
		5,8-dimethoxypsoralen	6.08		

Note: * – number of ISO standard.

All the variants of the experiment were performed in the same conditions. Fluctuations in temperature over the day did not exceed 3 °C (+18…+21 °C), length of daylight in October–November of 2018 equalled 8.30–11.00 h and was prolonged by artificial illumination to 14 hours; relative air moisture was 60–70%.

Results

The impact of essential oils on movement of *S. granaries* in conditions of a 48 h laboratory experiment is demonstrated in Figures 2–8. Essential oils from *C. sinensis* and *P. abies* stimulated migratory activity of *S. granarius* and are promising for use as repellents.

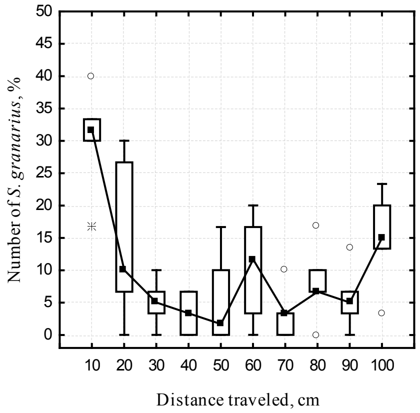

Fig. 1. Migration of *S. granarius* in pure fodder substrate over 48 hour laboratory experiment

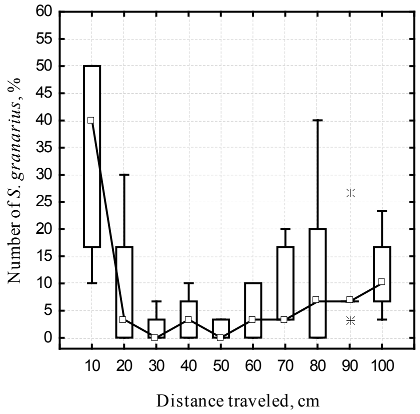

Fig. 2. Impact of essential oil of *M. alternifolia* on migratory activity of *S. granarius*: for 5 experiments $\chi^2 = 0.427$ (P = 0.999)

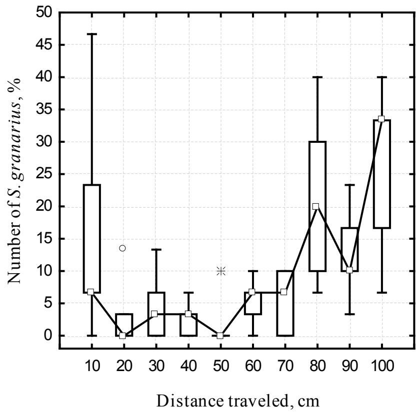

Fig. 3. Impact of essential oil from *E. globulus* on migratory activity of *S. granarius*: for 5 experiments $\chi^2 = 0.452$ (P = 0.999)

The influence of dry plants of movement of larvae of *T. molitor* in the laboratory experiment which lasted 48 hours is demonstrated in Table 4.

The strongest effect on movement activity of *T. molitor* larvae in the fodder substrate was shown by *O. vulgare* and *E. globosus* ($P < 0.01$). Both plants exert strong repellent action against larvae of *T. molitor*.

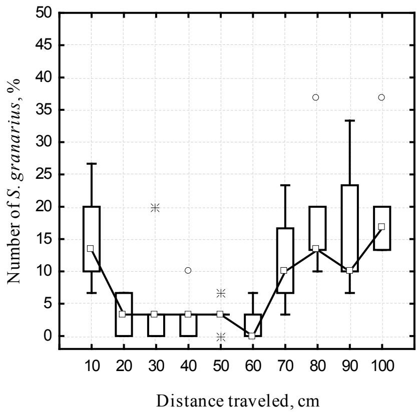

Fig. 4. Impact of essential oil from *L. angustifolia* on migratory activity of *S. granarius*: for 5 experiment $\chi^2 = 1.524$ ($P = 0.997$)

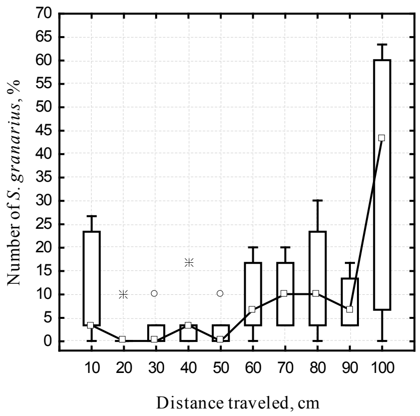

Fig. 5. Impact of essential oil from *M. officinalis* on migratory activity of *S. granarius*: for 5 experiments $\chi^2 = 2.614$ ($P = 0.978$)

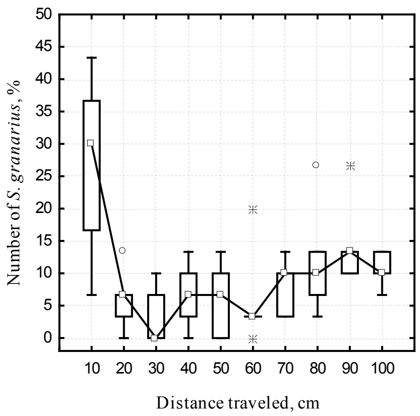

Fig. 6. Impact of essential oil from *C. bergamia* on migratory activity of *S. granarius*: for 5 experiments $\chi^2 = 0.900$ ($P = 0.999$)

Impact of essential oils on movement of imagoes of *T. molitor* in the 48 h laboratory experiment is demonstrated in Table 5. The strongest effect on distribution of larvae of *T. molitor* in the fodder substrate was exerted by essential oils from *J. communis*, *P. abies*, *P. santalinus*, *C. sinensis* and *C. aurantiifolia* ($P < 0.01$).

Discussion

The obtained data indicate that the essential oils from *C. sinensis* and *P. abies* exert notable repellent action towards *S. granarius* at concentration of 0.48 mL/cm^2. Repellent effect on *T. molitor* was displayed by dried and cut leaves of *O. vulgare* and *E. globulus*, and also essential oils from *J. communis*, *P. abies*, *P. santalinus*, *C. sinensis* and *C. aurantiifolia* ($P < 0.01$).

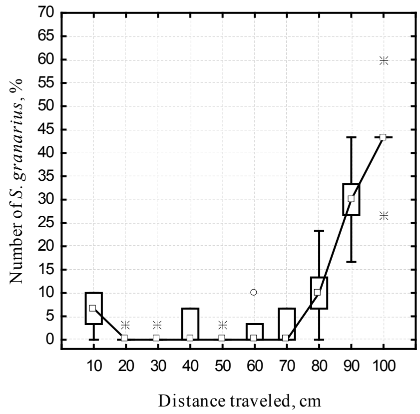

Fig. 7. Impact of essential oil from *C. sinensis* on migratory activity of *S. granarius*: for 5 experiments $\chi^2 = 1.604$ ($P = 0.996$)

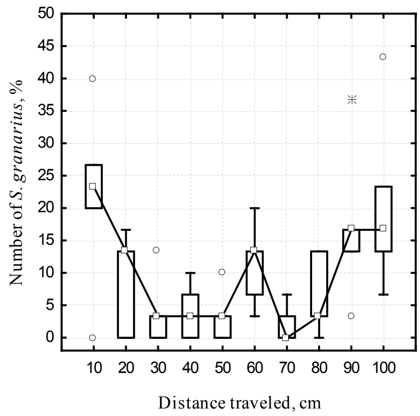

Fig. 8. Impact of essential oil from *C. paradisi* on migratory activity of *S. granarius*: for 5 experiments $\chi^2 = 0.598$ ($P = 0.999$)

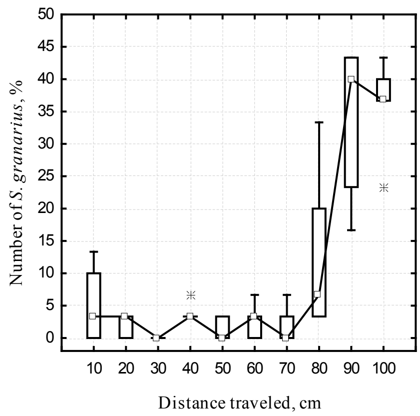

Fig. 9. Impact of essential oil from *P. abies* on migratory activity of *S. granarius*: for 5 experiments $\chi^2 = 3.202$ ($P = 0.956$)

Absence of notable effects among the rest of the tested samples can be related to insufficient concentration of essential oils, or resistance of the pest species. Resistance of insects to the vapours of essential oils can be associated with the activity of cytochromes of P_{450}-dependent monooxygenase, carboxyl esterase, superoxide dismutase and catalase (Ryan & Byrne, 1988; Boyer et al., 2012).

Today, the effect of essential oils and their constituents on *S. granarius* and *T. molitor* and other economically harmful species is described in a number a scientific works. Yildrim et al. (2005) studied efficiency of eight essential oils: *Hypericum scabrum* Linnaeus, 1753, *Hyssopus officinalis* Linnaeus, (1753), *Micromeria fruticosa* Druce, 1914, *Origa-*

num acutidens (Handel-Mazzetti) Ietswaart, *Satureja hortensis* Linnaeus, 1753, *Salvia limbata* C. A. Meyer, 1831 and *S. nemorosa* Linnaeus, 1762 against *S. granarius*. Mortality of insects at concentration of essential oils equaling 10 µL was 74%, 66%, 73%, 4%, 12%, 10% and 14%, respectively. Level of mortality rose with increase in the concentration of essential oils and duration of their action.

Table 4
Impact of dry medical plants (40 g of dry leaves per 1 kg of wheat grain) on distribution of larvae of *Tenebrio molitor* in fodder substrate in conditions of laboratory experiment

Species of plant	Plant with addition of dry leaves in grain, n = 50		Section without addition of dry leaves to the grain, n = 50		F ($F_{0.05}$ = 9.42)	P
	x, %*	SD, %*	x,%*	SD, %*		
Salvia officinalis	101.1	26.0	98.9	22.8	0.22	0.642
Helichrysum arenarium	99.0	17.7	101.3	19.3	0.39	0.536
Origanum vulgare	87.8	18.5	111.8	19.3	40.33	$6.7 \cdot 10^{-9}$
Rhododendron tomentosum	99.1	23.5	100.9	22.5	0.16	0.689
Aristolochia clematitis	99.6	19.0	100.6	17.9	0.07	0.787
Lavandula angustifolia	102.0	24.3	98.1	18.3	0.84	0.362
Melissa officinalis	99.2	22.6	100.6	19.7	0.11	0.742
Matricaria chamomilla	103.4	30.8	96.7	23.9	1.44	0.232
Ocimum basilicum	99.6	25.3	100.3	19.3	0.02	0.885
Mentha piperita	94.8	18.5	104.6	26.6	4.51	0.036
Eucalyptus globulus	88.5	24.0	112.1	27.3	21.10	$1.3 \cdot 10^{-5}$
Artemisia absinthium	98.5	23.3	101.8	22.6	0.50	0.480
Laurus nobilis	104.6	28.2	95.0	21.8	3.58	0.061
Thymus serpyllum	100.6	27.5	99.4	27.1	0.05	0.827
Rosmarinus officinalis	97.7	32.2	102.0	21.3	0.60	0.441
Syzygium aromaticum	99.9	23.6	100.1	23.6	0.01	0.962
Achillea millefolium	100.9	28.8	98.9	26.8	0.13	0.719
Tanacetum vulgare	97.9	24.6	102.4	30.0	0.67	0.416

Note: * – x is share of initial number of larvae distributed in particular section of the tube (%).

Table 5
Impact of essential oils on distribution of *T. molitor* larvae in fodder substrate in conditions of laboratory experiment

Essential oil	x, %*	SD, %*	F ($F_{0.05}$ = 10.83)	p
Control	78.8	29.8	–	–
Melaleuca alternifolia	68.2	14.0	0.84	0.370
Rosmarinus officinalis	65.9	14.2	1.25	0.276
Cinnamomum verum	103.5	33.4	3.24	0.086
Juniperus communis	32.9	31.4	11.63	$2.5 \cdot 10^{-3}$
Zingiber officinale	70.6	16.7	0.49	0.492
Cedrus atlantica	68.2	20.0	0.77	0.390
Picea abies	14.1	19.5	28.92	$2.1 \cdot 10^{-5}$
Thuja occidentalis	84.7	14.2	0.26	0.617
Pelargonium graveolens	82.4	20.0	0.08	0.773
Lavandula angustifolia	110.6	23.5	6.51	0.018
Eucalyptus globulus	63.5	20.0	1.60	0.219
Pterocarpus santalinus	14.1	16.7	30.18	$1.6 \cdot 10^{-5}$
Citrus aurantiifolia	40.0	25.5	9.36	$5.7 \cdot 10^{-3}$
Citrus sinensis	16.5	21.2	26.11	$4.0 \cdot 10^{-5}$
Citrus paradisi	87.1	26.5	0.41	0.527

Note: * – x is share of the initial number of larvae placed in the cup before the beginning of the experiment (%).

Rozman et al. (2006) studied the efficacy of essential oils from *L. angustifolia*, *L. nobilis*, *R. officinalis* and *Thymus vulgaris* Linnaeus, 1753, and also their components: 1,8-cineole, camphor, eugenol, linalool, carvacrol, thymol, borneol, bornylacetate and lynalylacetate against *S. granarius*. The studied substances in concentration of 0.1 µL/720 mL demonstrated high efficiency with average mortality of 96.5–100.0% after 24 h exposure.

Ebadollah & Mahboubi (2011) studied the efficacy of essential oil from *Azilia eryngioides* (Pau) Hedge & Lamond, 1987 against *S. granarius*. The studied oil had high insecticidal activity, 100% death rate was achieved at impact of concentration of 37.0 µL/L over 28 h. Values of LC_{50} of essential oil from *A. eryngioides* for *S. granarius* equaled 20.1 µL/L after 24 h of impact.

In a study on toxicity of different essential oils against *S. granarius*, Lamiri et al. (2001) determined that the highest toxic effect on the insect was caused by essential oils from *Mentha pulegium* Linnaeus, 1753, *M. spicata* Linnaeus, 1753, *E. globulus* and *Origanum compactum* Bentham, which exerted killing effect on the insect in concentration of 10 and 5 µL/mg over 24 and 48 h respectively.

Mahmoudvand et al. (2011) studied toxicity of essential oil from *C. sinensis* for *S. granarius*, *Tribolium castaneum* (Herbst, 1797) and *Callosobruchus maculatus* (Fabricius, 1775). Values of LC_{50} of the tested substance equaled 367.8, 391.3 and 223.5 µL/L of air after 24 h and 320.5, 362.4 and 207.2 after 48 h of exposure for *S. granarius*, *T. castaneum* and *C. maculatus*, respectively. Mortality of the insects depended on concentration and duration of impact of the tested essential oil.

Di Stefano (2016) studied insecticidal activity of essential oil from *L. angustifolia* against *S. granarius*. Mortality of insects at concentration of essential oil equaling 449.1 µg/mg equaled 91.7% and 100.0% after 24 and 48 h of impact, respectively. Values of LD_{50} and LD_{90} equaled 83.8 and 379.7 µg/mg after 24 h and reduced to 58.3 and 208.3 µg/mg after 48 h, respectively. Fumigant toxicity of essential oil from *L. angustifolia* for *S. granarius* reached its maximum at doses of 11.9 and 47.5 mg/L of air. Values of LC_{50} and LC_{90} equaled 1.6 and 4.1 mg/L at absence of substrate (grains of wheat) and 10.9 and 47.6 mg/L at presence of grains respectively. The studied essential oil had notable repellent activity against imagoes of *S. granarius*.

Study on toxicity of essential oils from *Artemisia absinthium*, *A. santonicum* Linnaeus, 1753 and *A. spicigera* K. Koch, 1851, and also their constituents against *S. granarius* were undertaken by Kordali et al. (2006). Essential oils of all three species killed 80–90% of the insects at concentration of 9 L/L of air during 48 h of exposure. Mortality increased with increase of doses of essential oils and duration of exposure. The main components of essential oils: borneol, bornyl acetate, camphor, α-terpineol killed 100% of *S. granarius* at concentration equaling 1.0 L/L of air, and 1,8-cineole and terpinen-4-ol – at concentration of 0.5 L/L of air, respectively, at over 12 h exposure.

Mohamed & Abdelgaleil (2008) studied toxicity of different essential oils against *Sitophilus oryzae* (Linnaeus, 1763) and *T. castaneum*. Highest toxicity for *S. oryzae* was exhibited by essential oil from *Citrus limon* (Linnaeus) Osbeck, 1765, *C. sinensis* and *C. paradisi*, LC_{50} for which equaled 9.9, 19.7 and 24.1 mg/L of air, respectively. Highest toxicity against *T. castaneum* was exerted by *C. sinensis* and *C. paradisi* with parameters of LC_{50} equaling 24.6 and 25.5 mg/L of air, respectively.

Abdelgaleil et al. (2015) studied insecticidal activity of plant essential oils against *S. oryzae*. At fumigation, the most toxic for the insect were essential oils from *O. vulgare*, *C. limon*, *Callistemon viminalis* (Solander ex Gaertner) G. Done x Loudon (1830), *Cupressus sempervirens* Linnaeus, 1753 and *C. sinensis*, values of LC_{50} of which equaled 1.64, 9.89, 16.17, 17.16 and 19.65 mg/L of air, respectively. The highest contact toxicity towards *S. oryzae* was exhibited by essential oils from

Artemisia judaica Linnaeus, 1759, *C. viminals* and *O. vulgare* with parameters of LC_{50} equaling 0.08, 0.09 and 0.11 mg/cm$_2$, respectively. Essential oil from *A. judaica* in concentration of 16.1 mg/L exerted inhibiting effect on the activity of acetylcholinesterase, whereas oils from *C. viminals* and *O. vulgare* were strong inhibitors of ATRs at concentration of 4.69 and 6.07 mg/L, respectively. In a similar study, Lee et al. (2001) determined that most toxic essential oils for *S. oryzae* were those from *E. globulus* and *R. officinalis*, LD_{50} of which equaled 28.9 and 30.5 L/L of air. Essential oils from *L. angustifolia*, *T. vulgaris*, *Cananga odorata* (Lamarck) Hooker & Thomson, 1855 and *C. paradisi* were less toxic: LD_{50} – 54.0, 63.9, 73.1 and 87.0 L/L of air, respectively. Most toxic for *S. oryzae* were the following components of essential oils: 1,8-cineole, p-cymene, α-pinene and limonene, LD_{50} of which equaled 23.5, 25.0, 54.9 and 61.5 L/L of air, respectively.

AbdEl-Salam (2010) studied toxic action of essential oils for *S. oryzae*. Percentage of mortality heightened with increase in concentration of different essential oils and period of exposure. Essential oils from *C. verum* and *M. alternifolia* killed 90.0% of insects at concentrations of 8.0 and 16.0 µL/50 mL of air, respectively at impact over 24 hours. Values of LC_{95} of essential oils from *C. verum*, *S. aromaticum* and *E. globulus* equaled 3.67, 4.07 and 8.73 µL/50 mL of air for *S. oryzae* at period of impact of 72 hours.

Insecticidal activity of essential oils against *S. oryzae* was studied by Yazdgerdian et al. (2015). The most active fumigants of the insect were *Gaultheria procumbens* Linnaeus, 1753, *Thuja plicata* Donn ex D. Don, 1824 and *Bursera graveolens* (Kunth) Triana & Planchon, 1872, values of LC_{50} of which equaled 6.8, 19.8 and 21.4 µL/L of air, respectively.

Rajkumar et al. (2019) studied insecticidal activity of essential oil from *M. piperita* and its constituents against *S. oryzae* and *T. castaneum*. Values of LC_{50} of essential oil, menthone and menthol for *S. oryzae* equaled 43.2, 46.7 and 49.4 µL/L of air, and for *T. castaneum* – 48.7, 51.9 and 54.5 µL/L of air, respectively. Both insect species were observed to have dose-dependant inhibition of activity of acetylcholinesterase when exposed to essential oil from *M. piperita*, menthone and menthol concentration, LC_{50} equaled 29.7%, 18.8% and 14.3% for *S. oryzae* and 20.7%, 13.7% and 9.2% for *T. castaneum*, respectively at 24 hours exposure. Also, under the impact of the studied substances in dose equal to LC_{50}, an increase was observed in the activity of superoxide dismutase by 17.4, 15.2 and 13.3 units/mg of protein and 31.9, 28.3 and 25.3 units/mg of protein for *S. oryzae* and *T. castaneum*, respectively.

Bertoli et al. (2012) studied biological activity of essential oils against *Sitophilus zeamais* (Motschulsky), 1855. Toxic effect of essential oils from *A. millefolium* and *Foeniculum vulgare* Miller, 1768 was displayed by minimum concentration of 0.05 µL, similar to the effect of *L. angustifolia* – at concentration of 0.10 µL. Level of mortality of insects was never higher than 76.0% (essential oil from *L. angustifolia* in dose of 0.75 µL during more than 96 hours of exposure).

Buneri et al. (2019) studied efficiency of essential oil from *Cedrus deodara* (Roxburghe x D. Don) G. Don, 1830 in concentrations of 0.8%, 1.5%, 3.0%, 6.0% and 12.0% as insecticide against larvae of *T. molitor*. Death rate of insects after 48 h equaled 17%, 33%, 49%, 64% and 87%, respectively. LC_{50} of oil from *C. deodara* equaled 3.1%. After the exposure, the insects were observed to have increase in the level of total protein from 2.12 to 4.14 mg/mL. Essential oil from *C. deodara* has a notable repellent action against larvae of *T. molitor*.

Fazolin et al. (2007) studied toxicity of essential oils from *Piper aduncum* Linnaeus, 1753, *P. hispidinervum* C. de Candolle, 1914 and *Tanaecium nocturnum* (Barbosa Rodrigues) Bureau & K. Schumann, 1896 against larvae of *T. molitor*. Values of LC_{50} for these essential oils were 0.045, 0.033 and 1.515 mL/cm^2, LD_{50} – 0.000025, 0,009 and 0.000015 mL/g, respectively.

Study on repellent activity of essential oils from *L. nobilis*, *C. bergamia*, *F. vulgare*, *Lavandula* x *intermedia* Emeric ex Loiseleur-Deslongchamps in 0.01% and 0.10% concentrations against larvae of *T. molitor* was performed by Cosimi et al. (2009). Essential oil from *F. vulgare* had a repellent effect in concentrations of 0.10% after 1 h of exposure, whereas the rest of the oils showed low effectiveness even after 5 h of exposure. Wang et al. (2016) studied the effect of essential oils and their components on larvae of *T. molitor*. Significant repellent effect on the insect was presented by geraniol, cis-3-hexenol and ionone in concentration of 1 mol/L, and also essential oil of eucalypt in concentration of 1%. Attractant effect on *T. molitor* was caused by isoeugenol and α-pinene in concentrations of 1.0 and 0.1 mol/L, and also peppermint oil and turpentine oil in concentrations of 1.0% and 0.1%.

Plata-Rueda et al. (2017) studied insecticidal activity of essential oil from *Allium sativum* Linnaeus, 1753 for different stages of *T. molitor*. The insect was more sensitive at the larva stage compared to the pupa and imago stages. Values of LC_{50} for the different stages equaled 0.771, 2.371, 2.032 µL/mL, respectively at impact over 48 h. Essential oil from *A. sativum* was noted for repellent action against *T. molitor* at all stages of the development, and also caused reduction of frequency of breathing of the insect after 1 h of impact.

George et al. (2009) studied toxicity of different essential oils for *T. molitor*. Most toxic for the insects were essential oils from *Carum carvi* Linnaeus, 1753, *Mentha spicata* Linnaeus, 1753 and *J. communis*, which killed 95%, 87% and 85%, respectively at concentration of substances of 0.14 mg/cm^3 after 24 h of impact. Less effective were oils from *T. vulgaris* and *Piper nigrum* Linnaeus, 1753, the killing power of which equaled 50% and 40%, respectively at the same concentration and duration of exposure.

Kuusik et al. (1995) studied toxicity of extract of *R. tomentosum* for pupaes of *T. molitor*. Exposure of the pupae with extract of *R. tomentosum* led to different morphological effects depending on duration of exposure. The affected pupae transformed into immature imagoes. Furthermore, changes were observed in the movement activity of the pupae – weak bending activity turned into energetic and more prolonged.

Effectiveness of plant essential oils against *T. molitor* was studied by Wang et al. (2015). Values of LC_{50} of essential oils from *Litsea cubeba* (Loureiro) Persoon, 1807 and *C. limon* equaled 19.6 and 42.2 mg/cm^2 respectively at 24 h exposure and 13.9 and 21.2 mg/cm^2 at 48 h exposure. The studied essential oils exhibited notable repellent activity against larvae of *T. molitor*, and also caused increase in duration of the development of larva stage.

Martínez et al. (2017) studied insecticidal activity of essential oils from *C. verum* and *S. aromaticum*, and also some of their components against *T. molitor*. Values of LC_{50} of essential oil from *C. verum* for larvae, pupae, and imagoes of *T. molitor* equaled 30.4, 10.7 and 29.8 µg/mL, and LC_{50} of *S. aromaticum* were 35.1, 6.5 and 21.6 µg/mL, respectively. LC_{50} of eugenol, caryophyllene oxide, α-pinene α-humulene and α-phellandrene for larvae of *T. molitor* were 9.2, 9.2, 14.0, 15.2 and 17.1 µg/mL, respectively. Caryophyllene oxide showed a notable repellent action towards larvae of *T. molitor*, while eugenol, α-humulene and essential oil from *C. verum* showed an attractant effect.

Despite the relevance of developing methods of using essential oils and their constituents as insecticidal preparations, their introduction into technologies of integrated control of pests remains impossible due to insufficient amount of data on this problem, difficulties in standardization and control of plant production.

Conclusions

Notable repellent activity against *S. granarius* was exhibited by essential oils from *C. sinensis* and *P. abies* at concentration of 0.48 mL/cm^2. Repellent effect on *T. molitor* was displayed by dried and cut leaves of *O. vulgare* and *E. globulus*, and also essential oils from *J. communis*, *P. abies*, *P. santalinus*, *C. sinensis* and *C. aurantiifolia* ($P < 0.01$). Therefore, out of 18 studied essential oils, only two samples had notable biological action on migratory ability of *S. granarius* and only five samples – on *T. molitor*. These data are confirmed by many studies on insecticidal activity of essential oils and the possibility of using them as ecologically safe natural pesticides. Studies on biological activity of essential oils against economically harmful species of insects is a relevant issue necessary for the development of ecologically-based control of agricultural pests.

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