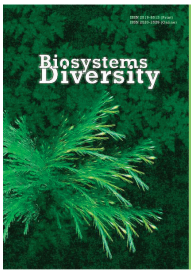

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Influence of essential oils of plants on the migration activity of *Tribolium confusum* (Coleoptera, Tenebrionidae)

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Pest control should be ecologically-based, therefore use of ecologically safe approaches is the best variant. Essential oils of plants can affect the main metabolic, biochemical, physiological and behavioural functions of insects. In the experiment, we evaluated the influence of 20 essential oils on migration activity of imagoes of *Tribolium confusum* Jacquelin du Val, 1863 in the conditions of a laboratory experiment. Notable repellent activity against *T. confusum* was exhibited by essential oils of *Jasminum officinale* and *Thuja occidentalis*. Essential oils of *Zingiber officinale* and *Cedrus atlantica* had an attractant effect on imagoes of *T. confusum*. Essential oils of *Rosmarinus officinalis*, *Melaleuca alternifolia*, *Lavandula angustifolia* and *Cinnamomum verum* exhibited repellent properties while essential oils of *Juniperus communis* and *Citrus sinensis* had an attractant effect on the pests. Therefore, out of 20 studied essential oils, only four samples had notable biological effect on migration activity of *T. confusum* imagoes. These data indicate the 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

Taking measures against pests should be ecologically-based (EBIPM) and be undertaken in the context of integrated management of agricultural crops and complex control of pests, which means that use of ecologically safe methods is the best variant (Koul & Walia, 2009). Over the past 50 years, pest control in the agriculture has been based on using synthetic chemical insecticides in field agrocenoses and in conditions of greenhouse cultivation.

However, synthetic insecticides are toxic, they have unfavourable effects on the environment, polluting soil, water and air, and also when broadly used provoke development of resistance of target species and significant damage to populations of non-target species of invertebrates (Benhalima et al., 2004; Pimentel et al., 2009; Brygadyrenko & Ivanyshyn, 2015; Martynov & Brygadyrenko, 2017, 2018; Shulman et al., 2017). Furthermore, synthetic insecticides negatively affect human health; strict ecological regulation of using pesticides has led to increase in the number of studies on use of natural plant extracts as alternative synthetic preparations (Isman, 2004; Pérez et al., 2010).

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

Essential oils are secondary metabolites and are present in all parts of plants. They are complex compounds which contain many components which determine the properties of the essential oils. Among the components, there are terpenes, aromatic and aliphatic compounds. The main terpenes are monoterpenes and sesquiterpenes (Bakkali et al., 2008; Koul et al., 2008). Monoterpenes make up to 90% of essential oils and are represented by compounds different in structure: acyclic (geraniol) and cyclic (terpineol) 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, are derivatives of phenylpropane and are present in lower content (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 respiratory tracts and lead to asphyxiation and death of pests (Kaufmann & Briegel, 2004; Rotimi et al., 2011). They can have toxic, fumigative, repellent, antifeedant, ovicidal, attractant and other effects (Werdin-Gonzalez et al., 2008). A number of scientists (Isman, 2000; Gutierrez et al., 2009) have reported neurotoxic, cytotoxic, phototoxic and mutagenic activity of essential oils on insects.

Botanical insecticides have a number of advantages: they do not persist in the environment, 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 easily digested by the animals, which receive sub-lethal doses (Grdiša & Gršić, 2013).

Reasons for the limited commercial development of botanical insecticides are their relatively slow impact, variable efficiency, absence of stability and non-constant availability (Isman, 2008) compared to synthetic analogues. Other obstacles for commercializing botanical insecticides are deficiency of natural resources, difficulties of standardisation, control of quality and registration (Isman, 1997).

Tribolium confusum Jacquelin du Val, 1863 is one of the commonest insect pests of storages, damage from which is 5–30% of global agricultural production. The reasons for broad distribution of *T. confusum* are the morphological, physiological and behavioural features of the insect, and also the favourable conditions created for it by humans (Hana & Mohammed, 2013).

The objective of this article was to evaluate the impact of different essential oils on the migration activity of *T. confusum* in the conditions of a laboratory experiment.

Materials and methods

In the experiment, we used imagoes of *T. confusum*. Before the experiment, the animals were kept in a common container with wheat flour. The beetles were selected randomly. The experiment included three stages. At the first stage, we planned to determine the essential oils which can frighten off or attract imagoes of *T. confusum* more efficiently than others. In the container (50 x 33 x 19 cm), we put wheat flour of higher sort (400 g) in a layer of 1 cm thickness. Then, in the container, we placed 44 plastic cups with the bottoms removed (0.1 L capacity) at a distance of 0.5 cm one from another with 80 g of flour and 30 imagoes of *T. confusum* in each one. In 40 cups, in flour on depth of 3 cm, we put a cotton pad of 0.4 cm diameter, saturated with 0.06 mL of essential oil (0.48 mL/cm^2). In one experiment, for each of 20 types of essential oil (Table 1), we used two cups. The other four cups were used as control (in them, we put cotton pads of 0.4 cm diameter without processing with any essential oil).

Table 1
Essential oils used in the experiment
for determining migration activity of *T. confusum*

Substance	Plant	Chemical composition: compounds	Chemical composition: concentration, %	ISO	References
Jasmine oil	*Jasminum officinale* Linnaeus, 1753	linalool	6.4	–	Wei & Shibamoto, 2007
		benzyl acetate	22.9		
		benzyl alcohol	6.5		
		cis-jasmone	2.9		
		p-cresol	1.4		
		cis-3-hexenyl benzoate	1.1		
		eugenol	3.0		
		methyl palmitate	1.2		
		isophytol	7.5		
		cis-phytol	15.0		
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		
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		
		terpinen-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		
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		
		verbenone	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		
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		
		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		
Sandalwood oil	*Pterocarpus santalinus* Linnaeus filius, 1782	*cis*-α-santalol	31.67	3518	Subasinghe et al., 2013
		epi-α-bisabolol	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		
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		

Substance	Plant	Chemical composition: compounds	Chemical composition: concentration, %	ISO	References
		(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		
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		
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		
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		
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		
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		
Pepper mint oil	*Mentha piperita* Linnaeus, 1753	1,8 cineole	6.69	856	Saharkhiz et al., 2012
		menthone	2.45		
		menthofuran	11.18		
		neomenthol	2.79		
		menthol	53.28		
		menthyl acetate	15.10		
		(z)-caryophyllene	2.06		
		germacrene D	2.01		
Jojoba oil	*Simmondsia chinensis* (Link) C. K. Schneider, 1912	saturated acids (C_{20}–C_{26})	1.64	–	Knoepfler et al., 1958
		palmitoleic acid	0.24		
		oleic acid	0.66		
		eicosenoic acid	30.30		
		docosenoic acid	14.20		
		eicosenol	14.60		
		docosenol	33.70		
		hexacosenol	2.00		
Lemon oil	*Citrus limon* (Linnaeus) Osbeck, 1765	β-pinene	5.20	855	Espina et al., 2011
		p-cymene	3.29		
		limonene	59.10		
		γ-terpinene	9.66		
		cis-*p*-mentha-1(7),8-dien-2-ol	1.33		
		geranial	2.11		
		cis-thujopsene	2.38		
		β-bisabolene	3.61		
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		
Almond oil	*Prunus dulcis* (Miller) D. A. Webb, 1967	myristic acid	0.0–0.07	–	Fernandes et al., 2017
		palmitic acid	4.7–15.8		
		palmitoleic acid	0.1–2.5		
		stearic acid	0.3–2.5		
		oleic acid	50.4–81.2		
		linoleic acid	6.2–37.1		
		linolenic acid	0.0–11.1		
		arachidic acid	0.04–0.20		
		campesterol	2.5		
		stigmasterol	2.5		
		β-sitosterol	55.9–95.1		
		Δ5-avenasterol	8.5–28.2		
		α-tocopherol	97.3		
		γ-tocopherol	2.8		

Note: * – number of ISO standard.

Each cup was covered with a separate plastic cover to prevent mixing of odours of essential oils. The experiment was made in five replications (n = 10, i.e. five tests with two replications for each essential oil). The duration of each experiment was 48 hours. At the end of this period, the flour from the cups was sieved for counting live and dead insects.

At the second stage of our research, we evaluated the influence on movement activity of *T. confusum* by the most efficient essential oils found at the first stage. In the container, we put wheat flour in 1 cm layer and 45 cups with 25 imagoes of *T. confusum*, of which 40 contained cotton pads processed with essential oil (one variant in four cups), and five cups – control. We used the earlier found repellent (*J. officinale*, *R. officinalis*, *T. occidentalis*, *M. alternifolia*, *C. verum*, *L. angustifolia*) and attractant (*Z. officinale*, *C. atlantica*, *J. communis*, *C. sinensis*) essential oils. The experiment which lasted 24 hours was made in three replications (n = 12, i.e. four cups in three experiments for each of the 10 essential oils).

At the third stage, we checked the patterns found earlier in the effect of the essential oils on the migration activity of *T. confusum* imagoes. In the experiment, we used polyethylene tubes of 4 cm in diameter and 150 cm in length with measurement marks put at each 10 cm of length. On either ends of the tubes, a cotton disk with essential oil was put: with a repellent on one, and with an attractant on the other. Evaporations of the following essential oils were used, selected during the two previous stages: thuja – ginger and jasmine – cedar. Each variant of the experiment lasted 24 h and was performed in eight replications (n = 8). By the end of the experiment, for each 10 cm of tube, the flour was collected and sieved through a laboratory sieve for measuring its presence in each section. All stages of the experiment were conducted in the laboratory with constant illumination and temperature, out of reach of direct sun light. Fluctuations in temperature over 24 hours did not exceed 2 °C (+21…+23 °C), duration of daylight in October–November 2018 was 8.30–11.00 hours and was prolonged to 14 h a day by artificial illumination, and air humidity equaled 60–70%.

The results were statistically analyzed in Statistica 8.0 software (Statsoft Inc., USA). Differences between the selections were considered reliable at $P < 0.05$ (one-way ANOVA).

Results

The property of the studied essential oils to attract or repel *T. confusum* (Fig. 1) at the first stage of the experiment allowed us to determine that repellent activity against *T. confusum* imago was exhibited by essential oils of *J. officinale*, *R. officinalis*, *T. occidentalis*, *M. alternifolia*, *L. angustifolia* and *C. verum*. Attractant property was also demonstrated by essential oils of *J. communis*, *Z. officinale*, *C. sinensis* and *C. atlantica*. The rest of the examined essential oils had no significant effect on movement activity of *T. confusum*.

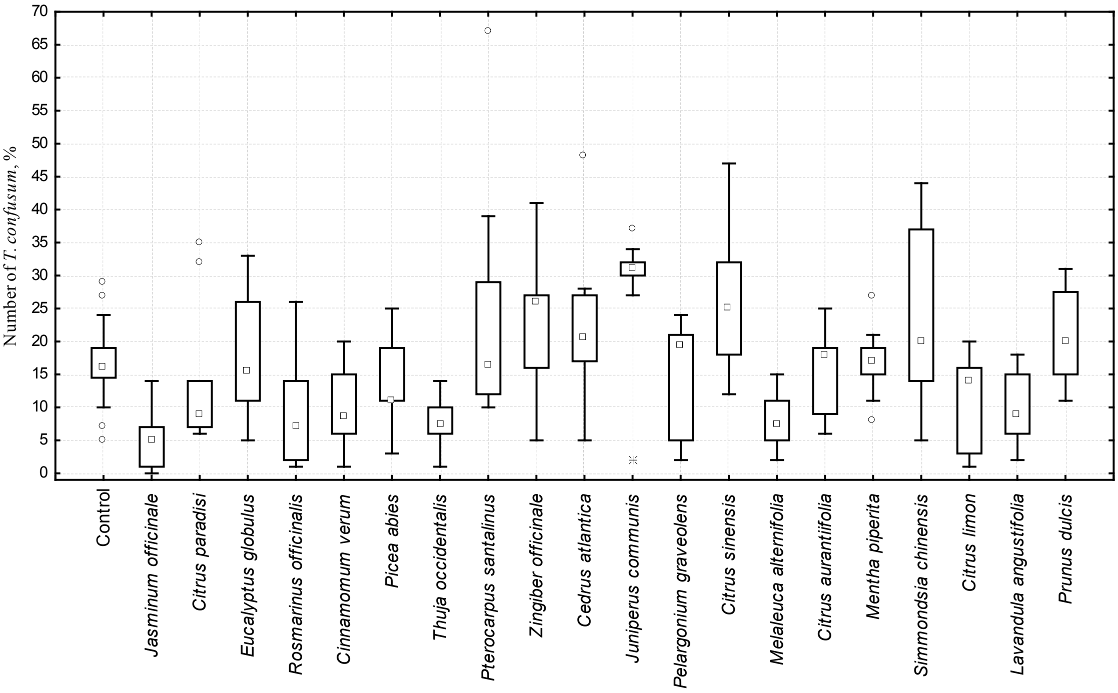

Fig. 1. Effect of essential oils on migratory ability of *T. confusum* in 48 h laboratory experiment

At the second stage of the research, we determined that the most active repellents against *T. confusum* were essential oils of *T. occidentalis* and *J. officinale*, and the most active attractants – essential oils of *Z. officinale* and *C. atlantica* (Fig. 2, 3, Table 2, 3).

At third stage, we studied distribution of *T. confusum* under simultaneous effect of repellent and attractant essential oils in evaporations of thuja-ginger and jasmine-cedar. Essential oil of *T. occidentalis* repelled imagoes at a distance of up to 30 cm. Essential oil from *Z. officinale* lured insects, but with low efficiency: attractant properties were exhibited at a distance of up to 20 cm (Fig. 4). Essential oil of *J. officinale* exhibited repellent properties at a distance of up to 20 cm, and *C. atlantica* lured insects with the same efficiency as oil of *Z. officinale* (Fig. 5).

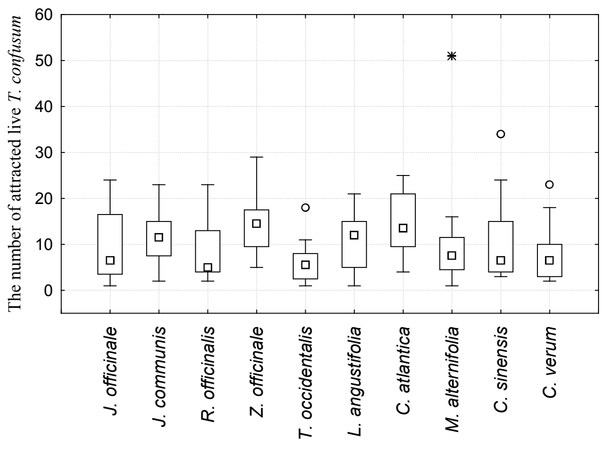

Fig. 2. Attractant effect of essential oils on *T. confusum* in conditions of laboratory experiment

Discussion

The data we obtained indicate that essential oils of *J. officinale* and *T. occidentalis* exert notable repellent activity on *T. confusum* at low concentrations, whereas essential oils of *Z. officinale* and *C. atlantica* attract insects.

Absence of notable effects in the rest of the examined samples can be related to insufficient concentration of essential oils or resistance of this pest species. Resistance of the insects to evaporations of essential oils can be related to activity of cytochrome P_{450}-dependent monooxygenase, carboxyl esterase, superoxide dismutase and catalase (Ryan & Byrne, 1988; Boyer et al., 2011).

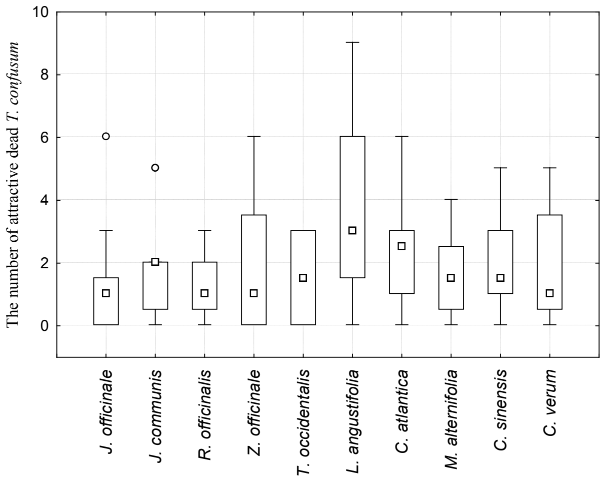

Fig. 3. Attractant effect of essential oils on *T. confusum* in conditions of laboratory experiment

Table 2
Effect of essential oils on distribution of *T. confusum* in the food substrate

Essential oil	Number of attracted individuals (x ± SD), spec.	P	F	$F_{0.05}$
Citrus sinensis	8.92 ± 8.88	0.161	1.489	1.966
Jasminum officinale	8.67 ± 8.72			
Zingiber officinale	13.08 ± 7.83			
Cedrus atlantica	12.42 ± 6.39			
Cinnamomum verum	6.33 ± 5.40			
Lavandula angustifolia	6.83 ± 4.17			
Rosmarinus officinalis	7.58 ± 6.46			
Thuja occidentalis	4.50 ± 4.03			
Melaleuca alternifolia	9.50 ± 12.49			
Juniperus communis	9.92 ± 6.91			

Table 3
Effect of essential oils on distribution of dead individuals of *T. confusum* in food substrate

Essential oil	Number of attracted individuals (x ± SD), spec.	P	F	$F_{0.05}$
Citrus sinensis	1.92 ± 1.62	0.056	1.922	1.966
Jasminum officinale	1.33 ± 1.70			
Zingiber officinale	1.83 ± 2.00			
Cedrus atlantica	2.33 ± 1.56			
Cinnamomum verum	1.92 ± 1.88			
Lavandula angustifolia	3.67 ± 2.81			
Rosmarinus officinalis	1.25 ± 1.14			
Thuja occidentalis	1.58 ± 1.38			
Melaleuca alternifolia	1.58 ± 1.31			
Juniperus communis	1.58 ± 1.38			

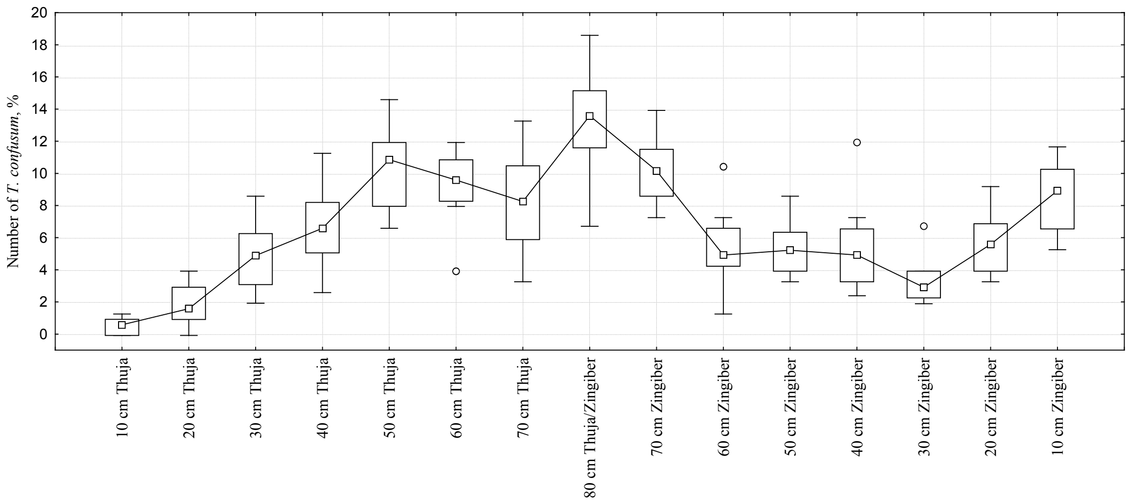

Fig. 4. Effect of essential oils of *T. occidentalis* and *Z. officinale* on distribution of *T. confusum* in fodder substrate

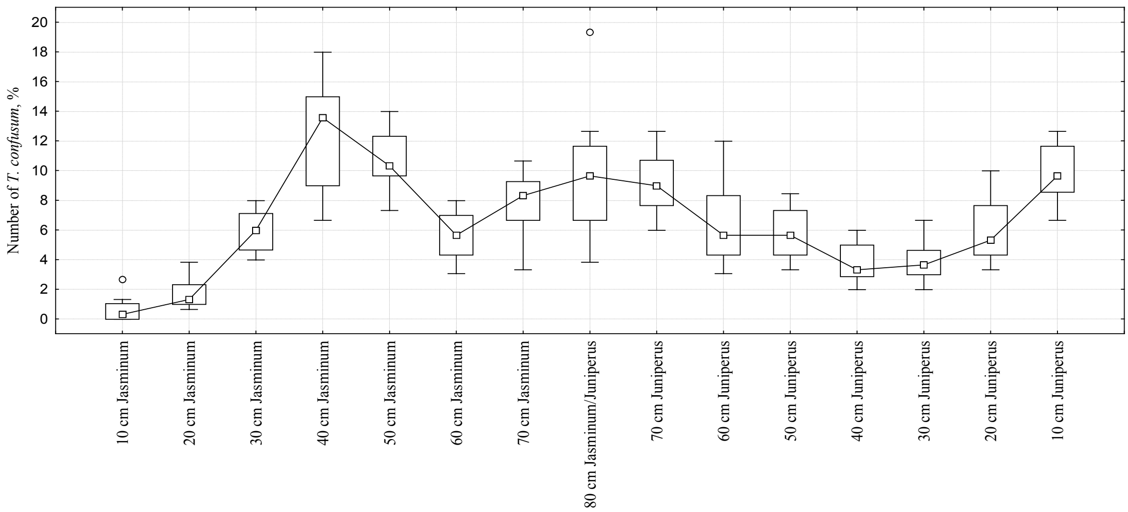

Fig. 5. Effect of essential oils from *J. officinale* and *C. atlantica* on distribution of *T. confusum* in fodder substrate

Effect of essential oils and their components on *T. confusum* and other economically harmful species is described in a number of publications. Haouas et al. (2007) studied biological activity of essential oils from *Chrysanthemum* spp. against *T. confusum*. Most efficient was the essential oil obtained from leaves of *Ch. grandiflorum*, which caused decrease in tempi of growth (by 0.03 mg/mg/24 hours), efficiency of consumption of food (by 50.7%), amount of ration consumed (by 66.4%) and increase in mortality of *T. confusum* larvae up to 80% after 7 days of the experiment. Under exposure to essential oil of leaves of *Ch. coronarium*, mortality reached 18%. Contact toxicity of essential oil of *Ch. grandiflorum* in 1% concentration equaled 27% after 7 days.

In a study of contact toxicity of essential oil of *Eucalyptus saligna* for *T. confusum*, Tapondjou et al. (2001) determined that complete mortality of insects was achieved at a dose of 0.78 and 1.56 mL/cm^2 over 4 days. Furthermore, cymol, one of the main components of the studied oil, in 1.30 mL/cm^2 concentration caused complete death of *T. confusum* after 24 hours.

Khani et al. (2017) studied toxicity and repellency of essential oils of *Juniperus polycarpus* and *J. sabina* against *T. confusum*. Mortality significantly increased with increase in concentration and duration of influence. Highest mortality (90%) was achieved at impact of essential oil of *J. polycarpus* in 611 mcL/L of air and 82% at impact of oil from *J. sabina* in concentration 666 μL/L of air after 24 hours. Values of LC_{50} for essential oils from *J. polycarpus* and *J. sabina* equaled 368.4 and 301.9 μL/L of air, respectively. Repellency of the tested substances depended on the concentration and equaled 96.0% at concentration of 15 μL/L of acetone and 6.7% and 10.0% at 1 μL/L concentration of essential oils from *J. polycarpus* and *J. sabina* respectively.

Isikber et al. (2006) investigated toxicity of essential oils of bay laurel (*L. nobilis*) and rosemary (*R. officinalis*) for different stages of *T. confusum*. Highest mortality (95.0%) after 24 hours of exposure was achieved at maximum tested concentration of essential oil from *R. officinalis* (431.5 mg/L of air), whereas essential oil of *L. nobilis* caused only 15.5% mortality in the same conditions. These parameters are related to insufficient time of exposure. The highest resistance to essential oil of rosemary, was presented by pupae, with LT_{90} equaling 89.5 hours at 172.6 mg/L of air, whereas imagoes were more sensitive (LT_{90} = 37.5 hours). Against essential oil of bay laurel, the most resistant were larvae (LT_{90} = 77.2 hours), whereas pupae were more sensitive (LT_{90} = 39.3 hours). Though essential oils from *L. nobilis* and *R. officinalis* have fumigant toxicity for all life stages of *T. confusum*, with different effectiveness, causing complete death of the insects requires using high doses.

Insecticidal action of essential oil from *C. sinensis* on *T. confusum* was researched by Oboh et al. (2017). At concentrations of 50 and 75 μL/L of air, essential oil exhibited moderate insecticidal activity: 50% and 60% mortality respectively after 24 h of impact. At maximum concentration of 150 μL/L of air, insecticidal activity was high with 100% mortality and LC_{50} 38.9, 26.9 and 14.5 μL/L after 24, 48 and 72 hours of impact respectively. Also there was studied inhibiting activity of acetylcholinesterase and Na^+/K^+-ATPase of *T. confusum* exposed to essential oil of *C. sinensis*: IC_{50} for these enzymes equaled 7.94 and 60.25 μL/L of air, respectively. Yunis (2014) studied impact of essential oil of *C. sinensis* on *T. confusum*: essential oil in 10% concentration caused 70.0%, 86.6% and 100.0% mortality after 1, 2 and 3 days, respectively. In a study of toxicity of essential oil of *C. sinensis* for *T. confusum*, *Callosobruchus maculatus* (Fabricius, 1775) and *Rhyzopertha dominica*, Tandorost & Karimpour (2012) determined that LC_{50} equaled 259, 158 and 124 μL/L of air after 24 hours of impact and 134, 106 and 93 μL/L of air after 48 hours for each insect respectively. Highest mortality was achieved using concentrations 53, 41 and 31 μL^{-1} against *T. confusum*, *C. maculatus* and *R. dominica*, respectively after 48 hours of exposure.

Campolo et al. (2013) studied biological activity of essential oils from five species of *Citrus* spp. against *T. confusum*. Maximum mortality was reached after 24 hours at absence of flour and concentration of 17.2 • 10^{-3}% of essential oils from *C. sinensis*, *C. aurantium* and *C. limon*. Addition of 10 mm of flour reduced efficiency, and 100% mortality was caused by maximum concentration of 69.0 • 10^{-3}% for these samples. LD_{50} equaled 4.03, 4.08 and 5.09, and LD_{90} for *C. sinensis*, *C. aurantium* and *C. limon* equaled 11.14, 11.90 and 15.46 respectively.

Russo et al. (2015) tested insecticidal action of essential oil from *Eucalyptus globulus* on *T. confusum*. Insecticidal effect increased depending on time and concentration of the studied substance. High concentration of 1.25 μL/cm^2 eliminated 90% of the pests after 30 minutes of exposure. After two hours of exposure, mortality close to maximum (98.3%) was reached by a lower concentration of 1.00 μL/cm^2, whereas at four-hour exposure, 100% mortality required 0.75 μL/cm^2.

Fathi & Shakarami (2014) undertook a research on larvicidal effect of essential oils of *Eucalyptus* spp. for *T. confusum* and *T. castaneum*. Larvae of *T. confusum* were more sensitive than *T. castaneum*. After 24 hours of exposure, LC_{50} for essential oils of *E. camaldulensis*, *E. viminalis*, *E. microtheca*, *E. grandis* and *E. sargentii* against larvae of *T. confusum* were 41.5, 20.7, 53.4, 26.4 and 110.5 μL/L of air respectively, whereas values of LC_{50} of these essential oils for larvae of *T. castaneum* equaled 110.3, 48.1, 117.0, 71.9 and 155.8 μL/L of air, respectively.

Khalis Ali (2013) explored toxicity of different plant extracts for *T. confusum*. Indicators of maximum mortality ranged depending on the plant species, therefore for *Anethum graveolens*, it equaled 56.7% at 4.5 hours exposure, for *Apium graveolens* – 93.3% after 5 h, *Eucalyptus glauca* – 90.0% after 2 h, *Malva parviflora* – 96.7% after 3 h, *M. longifolia* – 93.3% after 4 h and for *Z. officinalis* – 100% after 2 h.

Khani et al. (2012) studied toxicity of essential oil from *Aloysia citrodora* Palau, 1784 for *T. confusum* and *Callosobruchus maculatus*. It was determined that *C. maculates* was more sensitive for this fumigant (LC_{50} = 10.2 μL/L of air) than *T. confusum* (LC_{50} = 497.8 μL/L of air) at 24 h impact.

Karci & Işikber (2007) researched ovicidal activity of different essential oils in concentration of 100 μL/L of air against *T. confusum* over 24, 48 and 72 h. Strong ovicidal effect was exhibited by essential oils from *Allium sativum*, *A. cepa*, *Pimpinella anisum*, *Origanum dubium* and *Foeniculum vulgare*, with mortality parameters equaling 99.3%, 100.0%, 95.6%, 100.0% and 96.9% after 72 h of exposure and LT_{90} equaling 1.1, 22.1, 22.4, 13.8 and 51.1 h, respectively. Işikber et al. (2009) studied ovicidal action of different essential oils in concentration of 20 μL/L of air on *T. confusum* over 24 h. Use of essential oils of *A. sativum*, *Betula lenta* and *Cinnamonum zeylanicum* caused 100% mortality of the insects, whereas for *Pimpinella anisum*, this parameter equaled 50.7 ± 1.8%. Values of LC_{90} for essential oils of *A. sativum*, *B. lenta*, *C. zeylanicum* and *P. anisum* were 6.9, 4.5, 3.1 and 33.5 μL/L of air respectively.

Stamopoulos et al. (2007) studied biological effect of five monoterpenoids, components of essential oils, against different stages of *T. confusum*. The most toxic for all studied stages were terpinen-4-ol with LC_{50} in range of 1.1–109.4 μL/L of air, (R)-(+)-limonene (LC_{50} – 4–278 μL/L of air) and 1.8-cineole (LC_{50} – 3.5–466 μL/L of air). Toxicity of linalool was lower with LC_{50} in range of 8.6–183.5 μL/L, and geraniol was the least toxic: LC_{50} – 607–1627 μL/L of air. In all cases, except geraniol, most sensitive stage was third age larvae, and most tolerant – three-days old eggs. Also, a reduction of fertility and production of eggs was observed under the effect of evaporations of tested substances. Tripathi et al. (2001) investigated contact toxicity, fumigant and antifeedant activity of 1.8-cineole extracted from *Artemisia annua* against *T. castaneum*. The study revealed that adult individuals were more sensitive to 1.8-cineole than larvae. At 121.9 mg/g concentration, antifeedant effect for imago equaled 81.9%. 1.8-Cineole applied to the filter paper in 3.2–16.1 mg/cm^2 concentration significantly reduced number of matured eggs.

Malacrinò et al. (2016) studied toxicity of enantiomers of limonene, a component of different essential oils, against *T. confusum*. Mortality of insects depended on concentration of substance and temperature. In tests without flour, R-(+)-limonene caused 100% mortality at 20 °C and concentration equaling 85 mg/L of air, whereas mortality at impact of S-(−)-limonene was 80.0 ± 2.5% in the same conditions and heightened with increase in temperature up to 88.0 ± 4.9% at 30 °C and to 100% at 40 °C. Mortality caused by R-(+)-limonene at 40 °C reached maximum already at concentration of 42.5 mg/L of air. Addition of flour significantly reduced the parameters. At presence of 10 mm layer of flour and temperatures of 20 and 30 °C, no mortality of *T. confusum* was observed, whereas at 40 °C, effectiveness of R-(+)-limonene and S-(−)-limonene equaled 86.0 ± 2.5% and 66.0 ± 6.8%, respectively at maximum concentration (85 mg/L of air).

Kalita & Bhola (2012) investigated toxicity and repellence of different plant extracts for *T. castaneum*. Highest parameters of mortality of insects were obtained using extracts from *Viola arvensis* (68%), *M. chamomilla* (57%), *Brassica campestris* (56%) and *Jacaranda mimosifolia* (49%) after 7 days of impact. Furthermore, *J. mimosifolia*, *M. chamomilla* and *Tagetes minuta* exhibited high repellence (IR = 0.04) against *T. castaneum*. In the research by Al-Jabr (2006) on toxicity and repellence of different essential oils, *M. chamomila* had high repellence, equaling 81.9 and 84.7 at 1.0% concentration, against *O. surinamensis* and *T. castaneum* respectively.

Bhaskar Mi & Tripathi (2011) studied repellence of different essential oils for *Sitophilus oryzae* (Linnaeus, 1763) and *T. castaneum*. At highest tested concentration (0.2%) of essential oils from *S. aromaticum*, *A. marmelos*, *C. sativum* and *C. reticulate*, their repellence equaled 90.0%, 85.0%, 83.3% and 78.3% for *S. oryzae*, and 90.0%, 86.6%, 83.3% and 80.0% for *T. castaneum* respectively.

Maedeh et al. (2012) evaluated toxicity and repellence of essential oil from *Z. officinale* against *T. castaneum*. Values of LC_{50} and LC_{90} after 48 hours were assessed as 374.9 and 1124.2 μL/L of air, respectively. Repellence of essential oil was high even at low concentrations and reached 85% at 1.6 μL/L of air.

Wang et al. (2006) investigated fumigant and repellent action of essential oil from *A. vulgaris* on *T. castaneum*. Essential oil in concentration of 0.6 μg/mL and higher efficiently repelled the insects, and 100% mortality of imagoes was caused at 8.0 μg/mL. Mortality of larvae of different ages equaled 49–52%. The oil also had high fumigant activity against eggs of *T. castaneum* and caused 100% mortality at concentrations of 10, 15 and 20 g/L of air over 96 h.

Huang & Ho (1998) evaluated toxicity and antifeedant activity of cinnamaldehyde (one of the components of essential oil from *C. verum*) against *T. castaneum*. Cinnamaldehyde had no antifeedant effect on imagoes of *T. castaneum* in concentration up to 13.6 mg/g of fodder, though it significantly reduced consumption of food and growth of larvae in concentrations of 27.2 and 54.4 mg/g of fodder. With increase in concentration of cinnamaldehyde, antifeedant effect increased.

Arabi et al. (2008) studied insecticidal activity of essential oil from *Perovskia abrotanoides* Karelin (1841) against *S. oryzae* and *T. castaneum*. Maximum concentration of 645 mcL/L of air eliminated 80% of *T. castaneum* after five hours of exposure, whereas for *S. oryzae*, this parameter equaled around 10% in the same conditions. Maximum mortality was obtained using 322 μL/L concentration over 7 and 13 h, respectively. Values of LT_{50} for *S. oryzae* ranged from 8 hours for highest concentration (645 μL/L of air) to 11.5 hours at lowest concentration (32 μL/L of air), whereas for *T. castaneum*, LT_{50} was achieved in 4.5 hours (32 μL/L of air) and 2.8 hours (645 μL/L of air), which confirms the high sensitivity of *T. castaneum* to the fumigant compared to *S. oryzae*.

Kéita et al. (2001) investigated insecticidal effect of essential oil from *T. occidentalis* against *C. maculatus*. Using 100 g of kaolin powder aromatized with 3 μL of essential oil caused 95% mortality among females and 100% among males after 6 hours of exposure. LD_{50} for essential oil from *T. occidentalis* was 323, 162 and 52 μL/g at 12, 24 and 48 hours of exposure.

Abou-Taleb et al. (2015) studied toxicity of various essential oils for *T. castaneum* and determined that the most efficient were essential oils from *O. vulgare* (LC_{50} = 9.9 mg/L of air), *C. sinensis* (LC_{50} = 24.6 mg/L), *C. lemon* (LC_{50} = 25.5 mg/L) and *M. communis* (LC_{50} = 26.5 mg/L of air). Parameters of inhibition of acetylcholinesterase (IC_{50}) for *C. aurantifolia*, *C. lemon*, *O. vulgare* and *R. officinalis* equaled 105.8, 35.3, 24.4 and 20.8 mg/L, and for inhibition of ATPases – 44.4, 10.2, 10.2 and 11.4 mg/L respectively.

Despite the relevance of analysis of methods of using essential oils or their components as insecticidal preparations, their introduction into technology of integrated pest control remains impossible due to the insufficient amount of information on this problem, and difficulty of standardizing and ensuring quality control of the plant products.

Conclusions

Notable repellent activity against *T. confusum* has been demonstrated by essential oils from *J. officinale* and *T. occidentalis* at concentration of 0.48 mL/cm^2. Essential oils from *Z. officinale* and *C. atlantica* attracted the insect. We observed manifestations of repellent properties of essential oils from *R. officinalis*, *M. alternifolia*, *L. angustifolia* and *C. verum*, and that essential oils of *J. communis* and *C. sinensis* attracted the pest. Thus, out of 20 studied essential oils, only four samples had notable biological effect on migratory ability of *T. confusum*. These data support a lot of other research on insecticidal activity of essential oils and possibility of using them as natural pesticides. Study of biological activity of essential oils against economically harmful species of insects is a relevant task necessary for development of ecologically-based pest control.

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