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 agroecosystems 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 (Benthalina 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, pharmaceuticals 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 & Brieggel, 2004; Rotimi et al., 2011). They can exert toxic, fungicidal, repellent, antifeedant, ovicidal, attractant and other actions (Werdin-González et al., 2008). A number of researchers (Isman, 2000; Gutiérrez et al., 2009) report neurotoxic, cytoxic, 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 easily metabolized by the animals that receive sublethal doses (Grđića & Grsić, 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 of 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 grains of wheat, rye, barley, oat, rice, maize, buckwheat, panicgrass, and sometimes live in macaroni products and couscous. 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 & Mitchmor, 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; Schroederstein 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 imagos 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/cm² 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 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 χ² criterion.

Table 1

| Substances | Plant | Chemical composition | ISO References |
|------------|-------|----------------------|----------------|
| Parsley | Parley | α-pinene | 2.1 | 4730 Costa et al. 2001 |
| Nutmeg | (Linnaeus, 1753) | α-pinene | 0.05 | 9800 Costa et al., 2010 |
| Orange | Citrus | α-pinene | 0.36 | 3140 Singh et al., 2010 |
| Grapefruit | Citrus | α-pinene | 0.04 | 3053 Uysal et al., 2011 |
| Spruce | Picea | α-pinene | 2.27 | – Radulescu et al., 2013 |
400 g of grain with no additions was put in the other part. At 10 cm tube, 400 g of wheat grain with cut up plants was placed (Table 2), and intervals along the tube, 5 larvae of *T. molitor* were placed. The tubes were put randomly on the tables in the laboratory with some illumination 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

| Common name | Latin name | Content of essential oils, % | Chemical composition | References |
|-------------|------------|------------------------------|----------------------|------------|
| **Tarragon** | *Eugenia globulus* | 1.6–3.0 | α-pinene | Chelchuk et al., 1995; Abdosoi et al., 2015 |
| Blue gum | *Corymbia globulus* | 1.8-cineole | 76.65 |
| Larriane | *Dacrycarpus dacrydioides* | 1.8-cineole | 63.63 |
| **Lavender** | *Lavandula angustifolia* | 1.13–2.75 | α-thujene | Jianu et al., 2013 |

### Chemical composition

| Substance | Plant | Concentration, % |
|-----------|-------|------------------|
| β-eudesene | 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-eudesol | 0.46 |
| β-pinene | 0.42 |
| α-eudesol | 1.61 |
| γ-cadinene | 1.54 |
| δ-cadinene | 9.49 |
| nerolidol | 1.01 |
| 1,8-cineole | 0.52 |
| α-eudesol | 11.01 |
| δ-cadinene | 1.48 |
| α-linalool | 21.39 |
| manool | 3.38 |

*Note:* *β* – 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 every 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 some illumination 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.
| Common name | Latin name | Chemical composition | References |
|-------------|------------|----------------------|------------|
| Rosemary | *Rosmarinus officinalis* | o-pinenol, α-pinene, β-pinene | 1.90 14.90 3.33 1.61 0.56 2.07 0.71 7.43 14.90 0.75 4.97 3.68 1.70 0.83 1.94 23.70 3.08 2.68 1.26 0.52 1.01 1.01 | *Ocimum* et *Chalchat*, 2008; *Gachkar* et al., 2007 |
| Cloves | *Syzygium aromaticum* | eugenol, *eugenyl acetate*, δ-cadinene, *caryophyllene oxide* | 3.00 71.56 8.09 1.67 0.90 1.05 0.36 0.80 0.24 0.33 0.43 | *Lee* et al., 2009 |
| Yarrow | *Achillea millefolium* | *thymol*, *carvacrol*, *carvone*, *p-cymene*, *α-humulene* | 0.13–0.34 0.5 2.6 5.4 5.2 0.6 0.7 0.6 5.7 0.8 0.8 1.0 1.2 3.2 0.8 2.8 2.0 0.8 2.0 0.8 2.00 1.1 1.5 2.4 | *Pino* et al., 1998; *Rohlff* et al., 2000 |
| Oregano | *Origanum vulgare* | *thymol*, *carvacrol*, *carvone*, *p-cymene*, *α-humulene* | 2.50 2.2 0.7 1.0 1.3 3.7 0.9 1.6 1.5 11.6 0.9 2.1 2.6 | *Mechiargui* et al., 2010; *Telisiz* et al., 2013 |

| Common name | Latin name | Chemical composition | References |
|-------------|------------|----------------------|------------|
| Tansy | *Tanacetum vulgare* | *thymol*, *carvacrol*, *carvone*, *p-cymene*, *α-humulene* | 0.22 0.19 0.4 2.5 6.0 0.1 5.1 0.5 1.0 0.2 29.6 1.5 24.7 0.8 83.0 6.8 10.3 | *Scheiner*, 1984 |
| Immortelle | *Helichrysum armatum* | linalool, *α-pinene*, *caryophyllene* | 0.09 1.7 1.8 6.0 1.1 3.2 6.9 0.6 0.6 0.6 0.7 11.9 1.3 1.5 1.4 28.5 | *Zimmer* et al., 2000 |
| Sage | *Salvia officinalis* | *thymol*, *carvacrol*, *carvone*, *p-cymene*, *α-humulene* | 1.11 2.6 2.1 6.0 0.9 9.2 0.4 3.6 5.0 6.5 2.4 1.5 6.2 0.3 0.4 0.7 4.5 0.9 1.1 | *Perry* et al., 1999 |
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/cm²), 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 | concentration, % | References |
|-----------|-------|----------------------|------------------|------------|
| Tea tree oil | Melaleuca alternifolia | α-pinene | 2.1 | 4730 Cox et al., 2001 |
| | | α-terpineol | 1.4 | | |
| | | α-pinene | 1.0 | | |
| | | α-terpineol | 8.3 | | |
| | | α-pinene | 2.3 | | |
| | | α-terpineol | 1.1 | | |
| | | α-terpineol | 4.5 | | |
| | | α-terpineol | 17.8 | | |
| | | α-terpineol | 3.3 | | |

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| Sub-stance | Plant                 | Chemical composition                  | concen-tration, % | ISO References |
|------------|-----------------------|---------------------------------------|-------------------|----------------|
| terpinen-4-ol | Cinna-mon-         | 3.98                                  |                   |                |
| α-terpinol   | matory oil         | 3.4                                   |                   |                |
| aromadendrene|                      | 1.2                                   |                   |                |
| α-pinene     | Eucalyptus         | 3.65                                  | 770              | Abdossi et al.|
| Labillari-    | (endlicher)        | 0.31                                  | 2015             |                |
| dière, 1861  |                      | 0.65                                  | J. Presl, 1825    |                |
| limonene     |                      | 0.84                                  |                   |                |
| γ-terpinene  |                      | 0.63                                  |                   |                |
| terpinen-4-ol|                      | 0.37                                  |                   |                |
| α-terpinol   |                      | 1.96                                  |                   |                |
| α-pinene     |                      | 0.37                                  |                   |                |
| Δ9-veratrol  |                      | 0.36                                  |                   |                |
| aromadendrene|                      | 3.98                                  |                   |                |
| aromadendrene|                      | 0.51                                  |                   |                |
| Laven-der    | Lavandula angustif- | 1.37                                  | 3515             | Jianu          |
| oil         | olia                |                                       |                   |                |
| Miller,      |                      | 2.03                                  |                   | et al.         |
| 1768         |                      | 1.60                                  |                   | 2013           |
| 1,8-cineole  |                      | 15.69                                 |                   |                |
| borneol      |                      | 5.07                                  |                   |                |
| α-terpinol   |                      | 6.00                                  |                   |                |
| santalene    |                      | 4.50                                  |                   |                |
| Caryophyllene|                      | 24.12                                 |                   |                |
| Orange       | Citrus sinensis     | 0.36                                  | 3140             | Singh          |
| oil         | (Linnaeus)         | 0.37                                  |                   | et al.         |
| O stebeck    |                      | 1.71                                  |                   | 2010           |
| (pro. sp.)   |                      | 0.43                                  |                   |                |
| limonene     |                      | 90.66                                 |                   |                |
| linalool     |                      | 2.80                                  |                   |                |
| α-pinene     |                      | 0.42                                  |                   |                |
| γ-terpinene  |                      | 0.46                                  |                   |                |
| Caryophyllene|                      | 0.65                                  |                   |                |
| Orange       | Citrus paradisi     | 0.4                                   | 3053             | Uyssal et al. |
| oil         | (Linnaeus)         | 0.3                                   |                   | 2011           |
| Macfa-         |                      | 0.3                                   |                   |                |
| dyen, 1830   |                      | 0.8                                   |                   |                |
| limonene     |                      | 91.5                                  |                   |                |
| α-pinene     |                      | 1.1                                   |                   |                |
| β-pinene     |                      | 0.9                                   |                   |                |
| α-pinene     |                      | 0.3                                   |                   |                |
| α-pinene     |                      | 0.3                                   |                   |                |
| α-pinene     |                      | 0.3                                   |                   |                |
| α-pinene     |                      | 0.3                                   |                   |                |
| Rose- matory  | Rosmarin-         | 14.90                                 | 1342             | Gachkar et al.|
| oil         | us officinalis     | 3.33                                  |                   | 2007           |
| (Linnaeus)   |                      | 1.61                                  |                   |                |
| myrcene      |                      | 2.07                                  |                   |                |
| 1,8-cineole  |                      | 7.43                                  |                   |                |
| linalool     |                      | 14.90                                 |                   |                |
| camphor      |                      | 4.97                                  |                   |                |
| borneol      |                      | 3.68                                  |                   |                |
| bornyl acetate|                      | 3.08                                  |                   |                |
| β-caryophyllene|                  | 2.68                                  |                   |                |
| cis-β-farnesene|                    | 1.26                                  |                   |                |
| α-bisabolol  |                      | 1.01                                  |                   |                |
| Cinna- mon-   | Cinna- mon-       | 1.09                                  |                   | Jayapr... kasha|
| matory oil   | matory oil         | 1.09                                  |                   | et al.         |
| (Linnaeus)   |                      | 2.03                                  |                   | 2002           |
| limonene     |                      | 27.38                                 |                   |                |
| β-pinene     |                      | 2.41                                  |                   |                |
| α-pinene     |                      | 1.79                                  |                   |                |
| α-pinene     |                      | 6.19                                  |                   |                |

**Substance** | **Plant** | **Chemical composition** | **Concentration, %** | **ISO** | **References**
--- | --- | --- | --- | --- | ---
| germacrene D | | 2.10 | | | 16928
| γ-pinene | | 23.09 | | | 2010
| α-roseol | | 2.70 | | | 7.62
| γ-cadinone | | 1.57 | | | 6.78
| δ-cadinone | | 5.97 | | | 5.26
| α-pinene | | 1.29 | | | 4.15
| α-pinene | | 1.16 | | | 1485
| α-pinene | | 1.35 | | | 15.14
| α-pinene | | 1.0 | | | 3.02
| α-pinene | | 1.1 | | | 1.0
| γ-pinene | | 0.60 | | | 9.39
| γ-pinene | | 2.26 | | | 2.26
| α-pinene | | 1.05 | | | 2.24
| 3-carene | | 1.10 | | | 2.24
| α-pinene | | 2.01 | | | 2.24
| α-pinene | | 2.20 | | | 2.24
| α-pinene | | 2.19 | | | 2.24
| γ-pinene | | 2.22 | | | 2.22
| Santalene | | 2.27 | | | 5.40
| Santalene | | 1.11 | | | 7.55
| Limonene | | 9.29 | | | 9.29
| bornyl acetate | | 11.78 | | | 11.78
| α-roseol | | 1.61 | | | 1.61
| γ-cadinone | | 1.54 | | | 1.54
| δ-cadinone | | 9.49 | | | 9.49
| α-pinene | | 1.01 | | | 1.01
| α-pinene | | 11.01 | | | 11.01
| α-pinene | | 1.48 | | | 1.48


| Substance | Plant | Chemical composition | conc., % | ISO References |
|-----------|-------|----------------------|---------|----------------|
| Thuya Thuja occidentalis | oil | α-cadinol | 21.39 | |
| | | manool | 5.38 | |
| | | α-thujene | 1.46 | Jasovits et al., 2006 |
| | | α-pinene | 3.33 | |
| | | camphene | 2.55 | |
| | | α-fenchone | 2.04 | |
| | | santalene | 12.14 | |
| | | β-pinene | 1.14 | |
| | | myrcene | 4.05 | |
| | | p-cymene | 2.37 | |
| | | α-terpinene | 1.83 | |
| | | linalool | 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-thujene | 2.76 | |
| | | β-thujene | 9.48 | |
| | | camphor | 1.24 | |
| | | terpinen-4-ol | 3.32 | |
| | | linalyl acetate | 1.24 | |
| | | safrol | 16.55 | |
| | | terpinyl acetate | 1.17 | |
| | | β-caryophyllene | 1.23 | |
| | | β-santalol | 1.29 | |
| Germania Polangia mium | oil | linalool | 5.60 | Bookris et al., 2012 |
| | | rose oxide-trans | 2.01 | |
| | | iso-menthone | 4.42 | |
| | | L’Heritier, 1789 | 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 | |
| | | caryophyllene | 2.35 | |
| | | δ-cadinene | 2.38 | |
| | | δ-cadinene | 1.33 | |
| | | α-santalol | 1.28 | |
| | | 10-epi-α-santalol | 9.78 | |
| | | geranyl fglolate | 2.90 | |
| | | Santalum santoninum | linalool | 31.67 | Subasinghe et al., 2013 |
| | | α-santalol | 1.44 | |
| | | δ-santalol | 2.36 | |
| | | Linnaeus, 1782 | civ-β-santalol | 14.50 | |
| | | ess-β-santalol | 1.02 | |
| | | 1,2-cyclopentanone | 6.18 | |
| | | 1,2-cyclopentanone | 1.25 | |
| | | Lime Citrus aurantifolia | oil | 2,3-dimethyl-2,3-butanediol | 1.67 | Sandoval-Rosenthal et al., 2013 |
| | | linalool oxide | 1.18 | |
| | | cinnamyl acetate | 6.93 | |
| | | Swingle, 1913 | α-terpinol | 5.97 | |
| | | 1,2-cyclopentanone | 8.27 | |
| | | 3,7-dimethyl-(E)-2,6-octadienal | 1.09 | |
| | | geraniol | 1.15 | |
| | | citral | 2.21 | |
| | | 7-methyl-(Z)-8-tetradecenal-1-ol acetate | 2.83 | |
| | | geranyl acetone | 1.84 | |
| | | bergapten | 1.00 | |
| | | (Z)-8-methyl-9-tetradecanonic acid | 1.24 | |
| | | trans-α-bisabolene | 1.02 | |
| | | caryophyllene oxide | 3.02 | |
| | | spathulenol | 1.95 | |
| | | umbellulone | 4.36 | |
| | | p-cymene | 6.89 | |
| | | palmitic acid | 1.89 | |
| | | 5,7-dimethoxyxycoumarin | 15.80 | |
| | | 5-methoxypyrrolin | 1.14 | |
| | | 5,8-dimethoxyxycoumarin | 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 equaled 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. granarius in conditions of a 48 h laboratory experiment is demonstrated in Figures 2–8. Essential oils from C. sinensis and P. aibis 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. globulus* (*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 *χ²* = 1.524 (*P* = 0.997)

**Fig. 5.** Impact of essential oil from *M. officinalis* on migratory activity of *S. granarius*: for 5 experiments *χ²* = 2.614 (*P* = 0.978)

**Fig. 6.** Impact of essential oil from *C. bergamia* on migratory activity of *S. granarius*: for 5 experiments *χ²* = 0.900 (*P* = 0.999)

**Fig. 7.** Impact of essential oil from *C. sinensis* on migratory activity of *S. granarius*: for 5 experiments *χ²* = 1.604 (*P* = 0.996)

**Fig. 8.** Impact of essential oil from *C. paradisi* on migratory activity of *S. granarius*: for 5 experiments *χ²* = 0.598 (*P* = 0.999)

**Fig. 9.** Impact of essential oil from *P. abies* on migratory activity of *S. granarius*: for 5 experiments *χ²* = 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 P450-dependent mono-oxygenase, 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 of scientific works. Yildrim et al. (2005) studied efficiency of eight essential oils: *Hypericum scabrum* Linnaeus, 1753, *Hyssopus officinalis* Linnaeus, (1753), *Micromeria fruticosa* Druce, 1914, *Orange*
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 | P |
| 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 | 6.710 4 |
| Rhusodendron tomentosum | 99.1 | 23.5 | 100.9 | 22.5 | 0.16 | 0.689 |
| Artemisia chlorocephalos | 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 |
| Origanum balsamum | 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 globulifera | 88.5 | 24.0 | 112.1 | 27.3 | 21.10 | 1.310 4 |
| Artemisia absinthium | 98.5 | 23.3 | 101.8 | 22.6 | 0.50 | 0.480 |
| Laurels 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 | 32.3 | 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 (%)."
Artemisia judaica Linnaeus, 1759, C. viminalis and O. vulgare with parameters of LC50 equaling 0.08, 0.09 and 0.11 mg/cm3, 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. viminalis 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, LD50 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: LD50 = 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, p-pinene and limonene, LD50 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 LC50 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 Yagzherdian 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 LC50 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. piperrita and its constituents against S. oryzae and T. castaneum. Values of LC50 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-dependent inhibition of activity of acetylcholinesterase when exposed to essential oil from M. piperrita, menthone and menthol concentration, LC50 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 LC50, an increase was observed in the activity of superoxide dismutase by 17.4, 23.5, 25.0, 54.9 and 61.5 L/L of air, respectively. LC50 of oil from C. sinensis in concentration of 0.14 mg/cm3 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.

Kussik et al. (1995) studied toxicity of extract of R. tomentosum for pupae 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 imagos. 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 LC50 of essential oils from Litsea cubeba (Loureiro) Persoon, 1807 and C. limon equaled 19.6 and 42.2 mg/cm2 respectively at 24 h exposure and 13.9 and 21.2 mg/cm2 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.

Martinez 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 LC50 of essential oil from C. verum for larva, pupae, and imagos of T. molitor equaled 30.4, 10.7 and 29.8 µg/mL, and LC50 of S. aromaticum were 35.1, 6.5 and 21.6 µg/mL, respectively. LC50 of eugenol, carvophyllene 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. Carvophyllene 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. graniarius was exhibited by essential oils from C. sinensis and P. abies at concentration of 0.48 mL/cm2. 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.aurantifolia (P = 0.01). Therefore, out of 18 studied essential oils, only two samples had notable biological action on migratory ability of S. graniarius 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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