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ORIGINAL ARTICLE

The effect of plant essential oils on the Banded Greenhouse Thrips (*Hercinothrips femoralis* [O. M. Reuter 1891]) (Thysanoptera: Thripidae: Panchaetothripinae)

Martina Zvaríková[1] · Rudolf Masarovič[1] · Milan Zvarík[2] · Kristína Bagová[1] · Lucia Procházková[1] · Pavol Prokop[1,3] · Peter Fedor[1]

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Abstract

Hercinothrips femoralis (O.M. Reuter, 1891) is an important polyphagous pest species that feeds on a variety of ornamental plants and may cause severe damage to them. The species is known to be easily spread by anthropochory. The lethal and protective efficiency of 5 plant extracts was evaluated against adults of *H. femoralis* in the laboratory. A well-shaken essential oil of a certain concentration was sprayed from a distance of 15 cm into the inner space of a plastic box with leaves and thrips specimens. Standard protective and lethal concentrations and doses of selected oils were specified. The results showed differences in repellency and lethality among essential oil product types and their concentrations. Cinnamon (*Cinnamomum verum*) oil was identified ($p < 0.05$) as the most rapid (after 30 min of exposure) and effective biopesticide with the highest protective and lethal effect (PC50 = 0.66%, LC50 = 15,80%) compared with oils from rosemary (*Salvia rosmarinus*), dill (*Anethum graveolens*), black pepper (*Piper nigrum*), and eucalyptus (*Eucalyptus* sp.). Moreover, the protective effect of rosemary oil (PC50: 28.11%) and the lethal effect of dill oil (LC50: 42.85%) were identified as statistically significant. The application of cinnamon oil is proposed as eco-safe plant protection against *H. femoralis*, especially in households and indoor spaces, where the use of less toxic biopesticides is environmentally friendly.

Keywords *Hercinothrips femoralis* · Essential oils · Pest species · Biopesticides · *Cinnamomum verum*

Introduction

In recent decades, synthetic chemical pesticides have been overused for the treatment of plant crops (Koul et al. 2008), despite these pesticides having many negative effects on nature and human health (Isman 2000; Muthomi et al. 2008). They may also lead to disruption of natural biological control (Hamasaki 1987) and result in the development of pest resistance (Jensen 2000; Bediako 2012; Cloyd 2016). Their use is becoming more and more questionable due to their low sustainability in agriculture (Cabras et al. 1999; Martinez 2012; Kumar 2015). Therefore, scientific research has shifted towards the search of effective, selective, and nature-friendly bioproducts (Isman 2000; Yi et al. 2006, Basaid et al. 2021), such as essential oils, which are already commercially used (Grieneisen and Isman 2018; Isman 2019). Essential oils are secondary metabolites produced by plants (Dixon 1999; Isman 2000; Martinez 2012). They are fast-acting neurotoxins in insects (Isman 2019), which help plants maintain their fitness by protecting them against biotic external impacts, such as insect herbivores (Martinez 2012). Therefore, plant essential oils have the potential to be used as biopesticides or deterrents in insect pest management (Basaid et al. 2021) with the application for pest species control of thrips (Thysanoptera) as well (Koscheier 2006, 2008), having been previously tested several times against selected thrips pest species (e.g., Peneder and Koschier 2011; Picard

✉ Rudolf Masarovič
rudolf.masarovic@uniba.sk

1 Department of Environmental Ecology and Landscape Management, Faculty of Natural Sciences, Comenius University, Ilkovičova 6, 842 15 Bratislava, Slovakia

2 Department of Nuclear Physics and Biophysics, Faculty of Mathematics, Physics and Informatics, Comenius University, Mlynská dolina, F1 323, 842 48 Bratislava, Slovakia

3 Institute of Zoology, Slovak Academy of Sciences, Dúbravská Cesta 9, 845 06 Bratislava, Slovakia

et al. 2012; Abtew et al. 2015; Costa et al. 2015; Pobożniak et al. 2016).

Thrips (Thysanoptera) may be defined as a group of tiny insects, within which one tenth of 6200 described species are regarded as pests in agriculture, horticulture, or forestry (Palmer et al. 1989; Lewis 1997; Mound and Teulon 1995). Many of their features, such as their minute size, often cryptic nature, thigmotactic behaviour or effective dispersal mechanisms, predispose them as potentially dangerous pests with the ability to significantly affect the condition of plants and crops (Lewis 1997; Kirk et al. 2021; Stopar et al. 2021). In addition, some of them are exclusive vectors of tospoviruses, causing severe yield losses to important crops worldwide with significant economic impact (Riley et al. 2011). Moreover, many exotic thrips species can easily spread into non-native countries, especially by human activities (e.g., Jenser and Czenz 1988; Pelikán 1989, 1991; Lewis 1997; Collins 1998; Vierbergen et al. 2006; Fedor and Varga 2007; Varga and Fedor 2008). Therefore, the intensive world trade of biological commodities in recent decades provides many opportunities for widespread artificial dispersal of many pest thrips species (Mound 1983; Vierbergen 1995; Lewis 1997). In this regard, plenty of non-native and invading pest species have been recorded in Europe over the last few decades (Trdan 2002; Karadjova and Krumov 2003; Trdan et al. 2003, 2005; Rodikatis et al. 2006; Vierbergen et al. 2006).

One of them, the banded greenhouse thrips (*Hercinothrips femoralis* [O. M. Reuter, 1891]) (Thysanoptera: Thripidae: Panchaetothripinae), is a well-known polyphagous pest species that feeds on a variety of ornamental plants (Trdan et al. 2007). They may cause, among others, severe damage to banana fruits with typical smoky-red discoloration (Houston et al. 1991, Rodikatis et al. 2006), which can occasionally lead to skin cracks as a typical symptom of *H. femoralis* infestation (Lewis 1997). It is originally an African species (Mound et al. 1976); however, it currently has a cosmopolitan distribution (Houston et al. 1991) distributed throughout Europe (Vierbergen 2021). It has also been introduced into the temperate regions of Europe as well (e.g., Seczkowska 1974; Pelikán 1977; Jenser and Czencz 1988; Varga 2008). *H. femoralis* is a glasshouse phytopathogenic species in temperate regions (Mound et al. 1976) that is successfully moving from greenhouses into private households (Lee and Lee 2016). In addition, this species can also spread outside greenhouses into previously inaccessible, non-hostile environments (Masarovič et al. 2014) quite likely by the mechanism of passive migration with the assistance of wind currents (Lewis 1997; Fedor et al. 2011) or by passive dispersion, in which anthropochory may play an unintentional crucial role (Štefánik et al. 2019). Although it seems that *H. femoralis* cannot survive outdoors in Central Europe throughout the whole year, indoor conditions, such as offices and households with ornamental plants, which are kept at relatively constant temperatures, provide a potential niche that could be exploited year-round (Trdan et al. 2007; Lee and Lee 2016; Štefánik et al. 2019). Moreover, climate change alters the distribution of new, potentially invasive species (e.g., Hellmann et al. 2008), suggesting that timely anticipation of *H. femoralis* invasion should be a priority that could help reduce any potential economic threat. Moreover, chemical and biological control of *H. femoralis* may be often ineffective (Rodikatis et al. 2006).

As a consequence, there is a need to develop eco-friendly control methods for this species. Hence, the aim of this study was to examine the efficacy of selected essential oils as biopesticides against *H. femoralis*. We tested the protective and lethal effect of 5 essential oils on the occurrence of *Hercinothrips femoralis*, which had been reared on *Melissa officinalis* L. plants. Moreover, our goal was to find effective plant-based repellent with rapid response against *H. femoralis* after short exposure (30 min) to prevent unnecessary re-use of pesticides at home.

Material and methods

Testing of the essential oils took place in the insect laboratory at the Department of Environmental Ecology and Landscape Management (Comenius University in Bratislava) between April, 2019 and February, 2020. In all tests, 669 adult thrips specimens were used. Thrips that entered the experiments had been previously bred on plants of *Melissa officinalis* L. under relatively stable temperature (25 °C ± 0,5 °C) and humidity (65% ± 10%.) conditions. Light regime was set at 16:8 (light hours: dark hours) and was maintained by LED strip lights (SYLVANIA LED CHEER ALL in One LED, 400 lm/m, 17W, cool white – 5500 K).

According to relevant literature (Koschier and Sedy 2003; Koschier et al. 2002; Pobożniak et al. 2016; Abtew et al. 2015; Yi et al. 2006; Sukmuang et al. 2017), we selected 5 essential oils for the experiments – cinnamon (*Cinnamomum verum*), rosemary (*Salvia rosmarinus, syn. Rosmarinus officinalis*), dill (*Anethum graveolens*), black pepper (*Piper nigrum*), and eucalyptus (*Eucalyptus* sp.). The trade names and suppliers of selected oils were Cinnamon oil—Saloos; Rosemary—Bugala-Slow Nature; Dill—Eco Vonacik; Black pepper—Eco Vonacik; Eucalyptus—Natural Trade. We commenced with 100% essential oil in order to observe the effect of individual oils repeated 3× (mean values calculated). The most powerful oils were selected for further analyses. We tried to specify the PC 50 and 99 (protective concentration), PD 50 and 99 (protective dose), LC 50 and 99 (lethal concentration), and LD 50 and 99 (lethal dose) of selected oils. PC 50 means the concentration of oil by which 50% of thrips left leaves (dead or not), while PC 99 is the concentration of oil by which 99% of thrips left leaves (dead or not). PD 50 and 99 is the dose (µl of oil/l of air in the box) of the oil where 50% or 99% of thrips left leaves (dead or not). LC means the lethal oil concentration, where 50% (LC 50) or 99% (LC 99) of thrips died, while LD stands for lethal dose of oil (µl/l) by which 50% (LD 50) or 99% (LD 99) of thrips died during the experiment.

Experiment design

For each experiment, several leaves with approximately 25 thrips specimens were cut from the source plants to avoid damage and disturbance of the thrips and placed into a Petri dish. The number of specimens that entered all 3 repetitions (tests) is shown in Table 1. Afterwards, the Petri dish was put into a plastic box (22 l; 39 cm × 28 cm × 28 cm). Then, 0.5 ml of well-shaken essential oil of a certain concentration was sprayed into the inner space of the box from a distance of approximately 15 cm from leaves. After the oil application, the box was closed. The thrips were then observed for 30 min. The methodology was modified according to e.g., Yi et al. 2006; Cloyd et al. 2009; Stepanycheva et al. 2019.

Statistical analyses

All data were processed and analysed using the R software 4.2.2 (R Core Team 2022). The relationship between oil concentration (dose) and the lethal and protective effect was investigated using probit regression (GLM). The likelihood ratio test was used to assess the overall model significance, whereas the Wald statistic was used to test the significance of variable (dose). The "ecotox" package was used to estimate the lethal and protective doses by probit analysis (Hlina et al. 2021).

Results

In terms of protective and lethal effect evaluation, the first experiment of 100% oils was conducted. When comparing the 100% essential oils for their protective effectivity (Fig. 1), it was clear that the most effective oils were cinnamon, rosemary, and dill. The protective effect of the oils increased with time. As seen in Fig. 1, cinnamon oil reached almost 66% protective effect after 15 min and approximately 87% effect after 30 min of the experiment. Relatively high protective effects were obtained by the essential oils from rosemary (after 15 min 56%, after 30 min almost 62%) and dill (after 15 min 51%, after 30 min 70%). Black pepper and eucalyptus oils reached dramatically lower protective effects (black pepper 18% after 30 min, eucalyptus 31% after 30 min).

When taking the lethal effect of oils into consideration (Fig. 1), cinnamon oil had the most lethal effect on thrips. After 30 min of the experiment, almost 42% of thrips were dead. The lethal effect of rosemary was almost 23% at the end of the experiment and dill oil reached almost 26% effect. Essential oils from black pepper and eucalyptus did not exceed 14% of lethal effect. From the experiments with 100% essential oils, we chose cinnamon, rosemary and dill oils for further analyses of PC, PD, LC and LD.

Table 1 Number of thrips specimens in individual tests

Essential oil	Test1	Test2	Test3
Cinnamon	26	22	22
Rosemary	24	23	23
Black pepper	25	22	25
Eucalyptus	23	26	22
Dill	22	23	22

Protective effect and setting the PC and PD

Each of these selected oils was tested in 100%, 50%, and 25% concentration and then modified according to the results obtained. The number of specimens that left leaves or died together with the number of specimens on leaves at the very beginning of the experiment is shown in Table 2.

As can be seen in Fig. 2A, there is a strong increasing trend of cinnamon oil protective effect; PD 50 is calculated as 0.15 µl/l and PD 99 as 19.90 µl/l in statistically significant (Table 3) probit model of cinnamon essential oil. Based on the PD 50 and PD 99, the PC50 and PC 99 were calculated and are shown in Table 4.

Rosemary oil protective effect curve has a moderate increasing character (Fig. 2B). PD 50 was set at 6.39 µl/l and PD 99 on 21.80 µl/l. Protective concentrations in accordance to protective doses are shown in Table 4.

Even though the model of dill oil protective effect was not proved to be statistically significant ($p > 0.05$), there is a potential for follow-up analyses of this essential oil according to the data obtained (Fig. 2C), since the protective effect of dill oil seems to be very strong at higher concentrations (> 10%).

Lethal effect and setting the LC and LD

Experiments on the lethal effect of the essential oils were conducted in the same way as for protective effect. The number of specimens entering the experiment together with the number of dead specimens at the end of the experiment is shown in Table 5.

Relationship between the lethal effect and the dose of cinnamon oil was statistically proven to be significant ($p < 0.05$; Table 6). The model curve has a relatively steep character

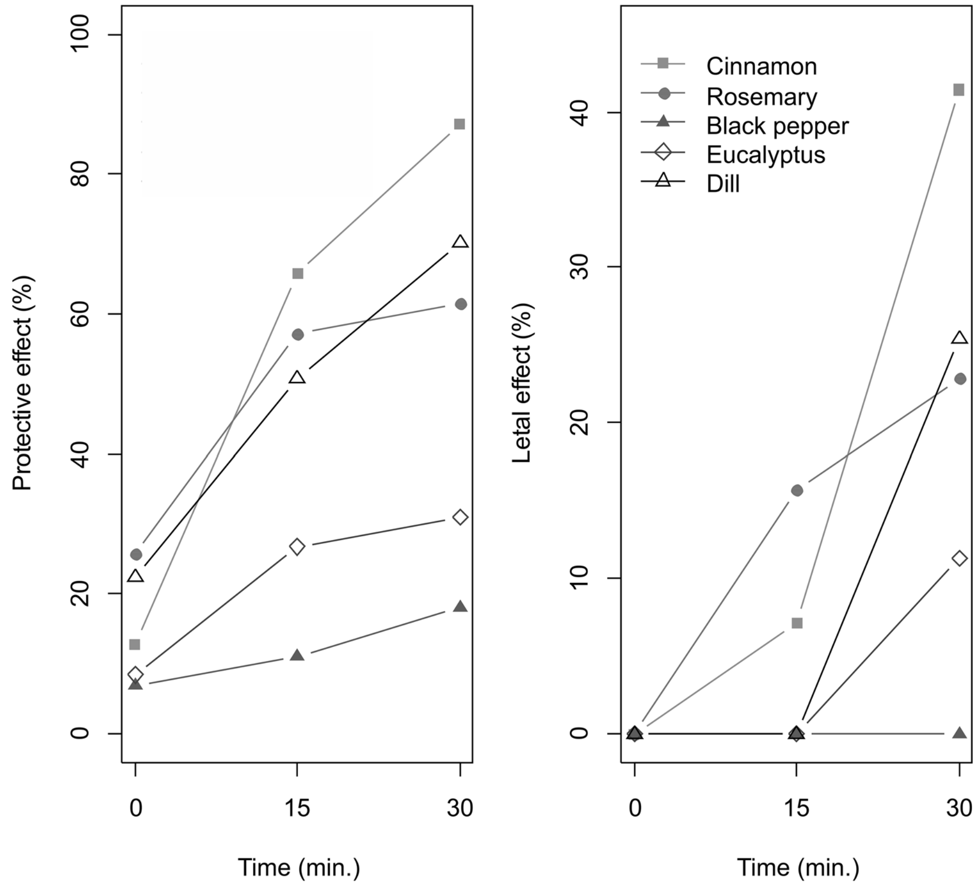

Fig. 1 Mean protective and lethal effect of 100% essential oils

Table 2 Protective effect of various concentrations of selected oils (specimens on leaves at the beginning of the experiment/specimens out of leaves or dead at the end of the experiment)

Concentration (%)	Cinnamon oil	Rosemary oil	Dill oil
50	25/25	23/19	23/23
40		25/19	
30		22/15	
25	25/25	20/6	25/25
15	21/20		21/21
10	22/19		20/0
5	25/17		
2.5	22/19		
1.25	24/18		
1	25/12		

(Fig. 3A). Standard LD50 a LD99 were set at 3.59 µl/l and 67.70 µl/l. Lethal concentrations LC 50 and LC99 are shown in Table 7.

The lethal effect of dill oil proved to be statistically significant (Table 6). The curve is quite linear and has a moderate character (Fig. 3B). There is a relatively even correlation between the number of dead specimen and the concentration of oil. As stated in Table 7, LD 50 of dill oil was set on 18.80 µl/l and LD 99 on 910 µl/l. Concentrations of oil according to the LD 50 and LD 99 are shown in Table 7.

On the other hand, the rosemary oil lethal effect curve is of a very shallow character (Fig. 3C), however, the model was not proven to be statistically significant ($p > 0{,}05$).

Discussion

The effective and nature-friendly control of the polyphagous pest thrips *H. femoralis*, in which conventional insecticidal or biological control may be ineffective (Rodikatis et al. 2006), was tested by the use of the five essential oils in our study. *H. femoralis* is easily transported between indoor spaces (from glasshouses to households and working offices) by humans (Štefánik et al. 2019). In this regard, the use of biopesticides, which is characterised by rapid degradation of the environment and less toxic to vertebrate pets and humans in enclosed spaces (Tripathi et al. 2009; Chauhan et al. 2016), is highly desirable and often discussed for these places (Phillips and Appel 2010; Chauhan et al. 2016). Therefore, our goal was to find a strong and effective plant-based repellent with rapid response against *H. femoralis* after short exposure (30 min) to prevent unnecessary re-use of pesticides at home.

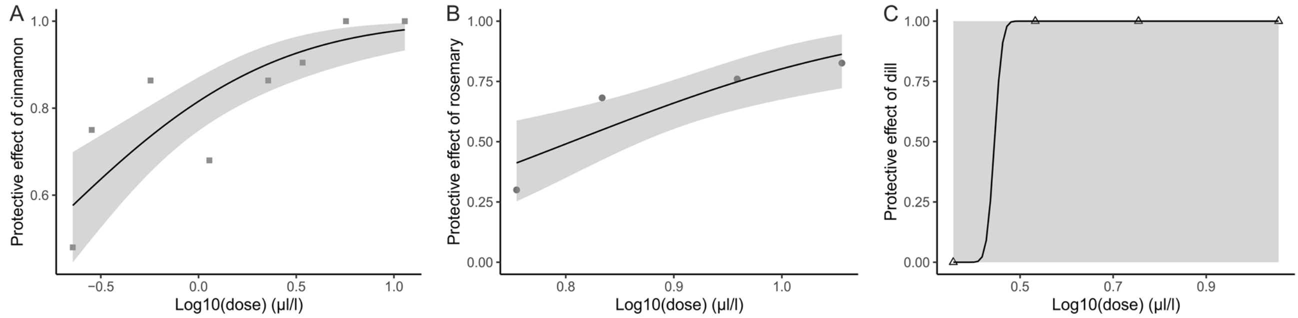

Fig. 2 Probit model of cinnamon (**A**), rosemary (**B**), and dill (**C**) oil protective effect

Table 3 Output values of linear regression for cinnamon and rosemary oil protective effect

Oil	Intercept			Log10(dose)		
	Coefficients (CI)	Z value	*P*-value	Coefficients (CI)	Z value	*P*-value
Cinnamon	0.899 (0.673 to 1.137)	7.631	< 0.001	1.098 (0.666–1.575)	4.860	< 0.001
Rosemary	− 3.518 (− 5.836 to − 1.279)	-3.024	0.002	4.368 (1.885–6.956)	3.367	< 0.001

CI – 95% confidence interval

Table 4 Standard protective doses (μl/l) and concentrations of selected oils

	PD 50	PD 99	PC 50 (%)	PC 99 (%)
Cinnamon oil	0.15	19.90	0.66	87.56
Rosemary oil	6.39	21.80	28.11	95.92

Table 5 Lethal effect of various concentrations of selected oils (specimens on leaves at the beginning of the experiment/dead specimens at the end of the experiment)

Concentration (%)	Cinnamon oil	Rosemary oil	Dill oil
50	25/25	23/3	23/7
40		25/0	
30		22/0	
25	25/11	20/0	25/8
15	21/14		21/5
10	22/11		20/0
5	25/3		
2.5	22/1		
1.25	24/0		
1	25/0		

In our experiment, cinnamon (*Cinnamomum verum*) essential oil appeared to be the most effective in evaluating the protective and lethal effects against the model species. Cinnamon oil achieved the highest protective and lethal effect compared to other tested oils. The lethal effect value of 100% cinnamon oil reached an efficiency of almost 42% after only 30 min of the experiment. Cinnamon is known to have a repellent and toxic effect on several insect species (e.g., Samarasekera et al. 2006; Ratnasekera and Rajapakse 2009; Chang et al. 2006). For example, the combination of 70% cinnamon (*C. zeylanicum*) oil with 4.2% orange oil caused a fourfold reduction in the abundance of *Thrips tabaci* in the onion fields in Poland (Pobożniak et al. 2016). In our experiment, standard protective concentrations reached the values PC50: 0.66% and PC99: 87.56%. Furthermore, potent fumigant toxicity was observed in ho wood (*Cinnamomum camphora*) oil against *Thrips palmi* in closed containers by using the vapor phase toxicity bioassay at 80.13 mg/litre air during a 24-h exposure. Fumigant toxicity in *Cinnamomum camphora* oil was 4.4 times more toxic than dichlorvos insecticide (Yi et al. 2006). In addition, a high repellent effect of 0.01, 0.1, and 1% cinnamon (*C. zeylanicum, C. cassia*) oil was demonstrated against females of *Megalurothrips sjostedti* (Trybom, 1910) during olfactometer bioassay (Abtew et al. 2015). During a methodologically-different experiment, Sukmuang et al. (2017) tested the insecticidal effect of cinnamon (*C. zeylanicum*) oil against adults of *Frankliniella schultzei* by using the leaf dipping method, where the plant leaves were soaked in the oil and then placed in a petri dish with thrips. The authors recorded more than 90% mortality at a concentration of 0.6% cinnamon oil at 24 h after treatment, when LC50 reached the value 0.28%. In general, lethal concentrations were different in our experiment (LC50: 15.80%), which could be due to the different factors summarized at the end of the discussion. In contrast,

Table 6 Output values of linear regression for cinnamon oil lethal effect

Oil	Intercept			Log10(dose)		
	Coefficients (CI)	Z value	*P*-value	Coefficients (CI)	Z value	*P*-value
Cinnamon	− 1.013 (− 1.411 to − 0.647)	− 5.316	< 0.001	1.824 (1.235 to 2.459)	5.945	< 0.001
Dill	− 1.76 (− 2.751 to − 0.852)	− 3.764	< 0.001	1.381 (0.204 to 2.613)	2.32	0.02

CI – 95% confidence interval

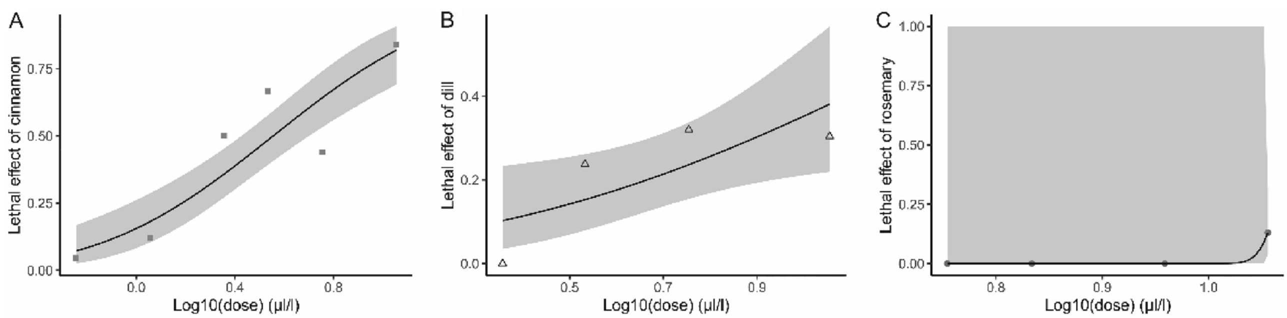

Fig. 3 Probit model of cinnamon (**A**), dill (**B**), and rosemary (**C**) oil lethal effect

Table 7 Standard lethal doses (µl/l) and concentrations of selected oils (only statistically significant models)

	LD 50	LD 99	LC 50 (%)	LC 99 (%)
Cinnamon oil	3.59	67,70	15.80	297.88
Dill oil	18.80	910	42.85	4004

selected cinnamon oil products did not have a significant lethal effect (less than 30%) on the control of *Frankliniella occidentalis* (Cloyd et al. 2009).

Dill (*Anethum graveolens*) oil was the second most repellent and toxic oil after 30 min of exposure, and it was distinguished by 100% mortality during testing in 50% to 15% concentrations. Nevertheless, its protective effect in application against *H. femoralis* has not been statistically confirmed in our experiment. In contrast, lethal effect was statistically significant in the concentration LC50: 42.85%. Abtew et al. 2015 classified dill oil as a moderate repellent against females of *Megalurothrips sjostedti*, when they showed a significant difference in thrips repellence at 1% concentration of the extract compared to the control in olfactometer bioassay. Therefore, we propose follow-up analyses of this oil according to our obtained data and its promising repellent and insecticidal activity against different insect species (e.g., Ebadollahi et al. 2012; Abtew et al. 2015; El-Gizawy et al. 2018; Kaur et al. 2021).

Similarly, the effectiveness of rosemary (*Salvia rosmarinus*) oil as a protective element against *H. femoralis* has been statistically proven in our study with protective doses and concentrations PD50(PC50): 6.39 µl/l (28.11%) and PC99: 21.80 µl/l (95.92%). In contrast, the lethal effect was not statistically significant. In this regard and similar to our research, significant repellency and toxicity of rosemary against several thrips species (e.g. *Frankliniella occidentalis, F. intonsa*, *Thrips palmi* and *Thrips tabaci*) have been previously described by many authors (Bennison et al. 2002; Koschier and Sedy 2003; Yi et al. 2006; Li et al. 2021).

Even though black pepper (*Piper nigrum*) and eucalyptus (*Eucalyptus* sp.) essential oils and their constituents were previously identified as potential biopesticides with a strong and repellent effect against selected thrips species (Koschier and Sedy 2003; Abtew et al. 2015; Li et al. 2021), these essential oils (100% concentration) had a weak protective and lethal effect against *Hercinothrips femoralis* after 30 min of experiment. Therefore, these essential oils were not tested in further analyses. This suggests that *H. femoralis* may have different resistance against biopesticides in comparison with other thrips species, and thus the results obtained from a single species cannot be generalized for other species (Brevik et al. 2018; Hawkins et al. 2019).

Based on the repellency and mortality response of *Hercinothrips femoralis* to 5 selected plant extracts, cinnamon, dill and rosemary oils were the most effective against this species. *Cinnamomum verum* oil appeared to be significantly the strongest. Nevertheless, varying results during the scientific evaluation of the protective and lethal effect of selected plant extracts might be due to differences in research methodology, such as exposure time of the oil (e.g., 30 min vs. 24-h exposure), size of the container (e.g., 22 l container vs. petri dish), bioassay type or biopesticide application (e.g., spraying 15 cm from leaves vs. leaf dipping method). Moreover, oil concentrations (Li et al. 2021), specific plant species extracts (Abtew et al. 2015), thrips species tested (Sedy and Koschier 2003) or their behavioural and ontogenetic attributes (Choi et al. 2003) may play an important role. In addition, the essential oil products from the same plant species created by a specific procedure may differ in the composition and representation of chemical molecules, which could influence the evaluation of their effectiveness (Chiasson et al. 2001; Katerinopoulos et al. 2005). Ours, as well as many other scientific papers (e.g., Yi et al. 2006; Abtew et al. 2015; Pobożniak et al. 2016; Sukmuang et al. 2017) suggest that plant essential oils could be used as strong natural repellents for thrips control. Therefore, further studies need to be done to find essential oils and their combinations (e.g., cinnamon oil with dill oil or rosemary oil) with maximum efficiency against selected thrips pest species. Finally, appropriate spraying schedules for selected oils application against specific thrips species in different environments need to be created. In this regard, the use of essential oils in thrips control can become an important part of "push–pull" strategies, where the thrips are repelled ("push") away from the main crop by using a deterrent agent.

Conclusion

The adverse effects of synthetic pesticides have increased the demand for biodegradable, yet effective pesticides. Essential oils and their ingredients are considered natural substances against insect pests. They are renewable, non-persistent in the environment, and relatively safe for non-target organisms, mainly mammals and humans. Therefore, essential oils and their main components could be applied to insect pests to reduce the ecologically and environmentally harmful effects of synthetic insecticides. The effectiveness of 5 essential oils was tested in our study, of which the three strongest oils were further tested to determine effective concentrations in plant protection. Of these, based on the experiments, the cinnamon oil was significantly identified ($p < 0.05$) as the most rapid (after 30 min of exposure) and effective biopesticide with the highest protective and lethal effect against the model species *Hercinothrips femoralis*. However, the results of rosemary and dill oil are not negligible either. We propose the application of these oils for plant protection against *H. femoralis*, especially in households, where it is undesirable to use toxic chemical insecticides against pets and human.

Author contributions All authors contributed to the study conception and design. Material preparation and data collection: MZ, KB, LP; Data curation: MZ, MZ; Methodology: MZ, RM, PP, PF; Data analysis: MZ; Writing—original draft preparation: MZ, RM; Writing – review and editing: PF, PP; Formal analysis and investigation: RM, LP; Visualization: MZ, MZ; Funding acquisition: PF, PP; Resources: PF, PP; Supervision: PF, PP; All authors read and approved the final manuscript.

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Declarations

Conflict of interest The authors do not declare any conflict of interest, related to this paper.

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