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Effects of five essential oils on three generalist predators and two important whitefly parasitoids

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Abstract

The experiment was conducted in the Entomology Laboratory of the Department of Plant Protection, Faculty of Agriculture, Bursa Uludag University in October 2020 – May 2021. The aim of the study was to determine the toxic effects of five essential oils on five important biological control agents. The commercially obtained essential oils of carrot, wintergreen, ginger, wormwood, and clove were shown to be toxic to biological control agents *Orius laevigatus*, *Nesidiocoris tenuis*, *Macrolophus pygmaeus*, *Encarsia formosa*, and *Eretmocerus eremicus* in three doses: 0.125, 0.25, and 0.5 v/v. After 3 hours, for the predator *O. laevigatus*, the most effective (100%) oils were wintergreen and clove oils, while for *N. tenuis*, the most effective were wintergreen (100%), wormwood (100%), and clove (97%) ones. After 24 hours, ginger oil showed a 95% mortality effect on *M. pygmaeus*. The parasitoids *E. formosa* and *E. eremicus* were less affected by the oils, only wormwood oil had a slightly deleterious effect on the parasitoids *E. formosa* and *E. eremicus* (mean 53% and 43%, respectively).

Keywords: plant oils, natural enemies, toxic effect, mortality.

Introduction

Integrated Pest Management (IPM) strategies, including both biological control agents and pesticides, are having preference to an approach for sustainable production (Roditakis et al., 2014). Thrips and whiteflies are important pests that can be controlled by the biological control methods. Agricultural pests, such as aphids, mites, and caterpillars, are commonly controlled by non-chemical techniques including biological control. However, when this method is not sufficient to suppress these pests, farmers must turn to chemical control using either synthetic or natural compounds (Bielza et al., 2020).

Whiteflies have many natural enemies, both predators and parasitoids species. *Orius laevigatus* (Fieber, 1860) (Hemiptera: Anthocoridae) is an important predatory bug in controlling mainly whiteflies and thrips in greenhouses (Mendoza et al., 2020). *Orius* spp. are considered to be important predators of *Tetranychus urticae* (Koch, 1836) (Acari: Tetranychidae); however, they are rarely used for biological control of mites (Rahman et al., 2022). Some *Orius* species have been observed to survive and reproduce by feeding on mealybugs (Amer et al., 2021). *Nesidiocoris tenuis* (Reuter, 1895) (Hemiptera: Miridae) is one of the predators widely used in current biocontrol programmes, is commercially available, and plays a crucial role in IPM programmes (Pérez-Hedo, Urbaneja, 2016; van Lenteren et al., 2018). *Macrolophus pygmaeus* (Rambur, 1839) (Hemiptera: Miridae) is an extremely polyphagous predator and is already used as a biocontrol agent against various phytophagous pests under greenhouse conditions (Sanchez et al., 2018). The parasitoids *Encarsia formosa* (Gahan, 1924) (Hymenoptera: Aphelinidae) and *Eretmocerus eremicus* (Rose & Zolnerowich, 1997) (Hymenoptera: Aphelinidae) are the most commercialised species easily available in many countries for control of whiteflies (Reddy, 2016).

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In recent decades, essential oils have been a possible alternative for many applications, such as antimicrobial, antifungal or herbicide uses (Lins et al., 2019). Biological insecticides based on botanical extracts have a negative effect on pests (Selvaraj, Kaushik, 2014; Kuhar, Doughty, 2016). Moreover, essential oils have a strange property to displace synthetic insecticides (Oliveira et al., 2017; Huang et al., 2020). Also, most essential oils have low mammalian toxicity compared to synthetic insecticides and are considered to be eco-friendly (Mossa, 2016). Essential oils have neurotoxic activity in insects due to their ability to inactivate acetylcholinesterase (AChE), modulate the octopaminergic system, and bind to gamma-aminobutyric acid (GABA) receptors (Pavela, Benelli, 2016). In addition to target pest mortality, the studies conducted over the past few years have determined the toxic effects of essential oils on a wide range of pests.

It is important to understand that exposure of non-target organisms such as natural enemies to essential oils is concussing. Based on recent studies, before recommending the use of oils, it is necessary to determine how they affect other organisms. The toxic effect of essential oils on numerous pests has been determined. However, the effects of essential oils on non-target organisms such as natural enemies must also be known. In a study of Castilhos et al. (2018), it was reported that the effect of thyme oil on *Chrysoperla externa* (Hageni, 1861) (Neuroptera: Chrysopidae), which is the predator of *Macrosiphum rosae* (L., 1758) (Hemiptera: Aphididae), was relatively high, as in the case of aphids.

It was found that the essential oil obtained from carrot (*Daucus carota* L., 1763) (Apiales: Apiaceae) has a highly toxic effect on three mosquito larvae species *Aedes aegypti* (L., 1762), *Culex pipiens* (L., 1758), and *C. restuans* (Theobald, 1901) (Diptera: Culicidae) (Muturi et al., 2019). It was reported that wintergreen (*Gaultheria procumbens* L., 1758) (Ericales: Ericaceae) essential oil has a highly toxic effect on the pest *Sitophilus oryzae* (L., 1763) (Coleoptera: Curculionidae) (Jayakumar et al., 2017). In the study of Yi et al. (2006), the toxic effects of wintergreen, ginger (*Zingiber officinale* Roscoe, 1807) (Zingiberales: Zingiberaceae), wormwood (*Artemisia absinthium* L., 1763) (Asterales: Asteraceae), and clove (*Syzygium aromaticum* Merril & Perry, 1989) (Myrtales: Myrtaceae) essential oils on *Thrips palmi* (Karny, 1925) (Thysanoptera: Thripidae) were examined, and it was concluded that wintergreen was highly toxic, while the other essential oils showed moderate to low toxicity. In the study of Kim et al. (2011), it has been reported that wintergreen and carrot oils have a high toxic effect (100%) on whiteflies, while wormwood oil had less than 70% toxicity.

In addition, plant essential oils are known to have multiple ways of action, which may cause unexpected effects on non-target organisms. These countenances should be considered for their implications during the registration process of new biopesticides and the effective and sustainable inclusion of these products in IPM (Haddi et al., 2020).

The aim of this study was to determine the toxic effects of carrot, wintergreen, ginger, wormwood, and clove essential oils on five biological control agents: generalist predators *O. laevigatus*, *N. tenuis*, and *M. pygmaeus*, and whitefly parasitioids *E. formosa* and *E. eremicus*, which have not previously been studied for these natural enemies.

Material and methods

The experiment was conducted at the Entomology Laboratory, Plant Protection Department, Faculty of Agriculture, Bursa Uludag University between October 2020 and May 2021.

Plant material. As a test plant, the sterile bean (*Phaseolus vulgaris* L.) (Fabales: Fabaceae) cultivar 'Magnum' (MayAgro Seed Corp., Turkey) was used. Klasmann TS1 peat, perlite, pots (1.5 L, 12 × 11 cm), and Peters brand fertiliser (NPK 20:10:20) were used for the cultivation of plant material. During the experiment, four bean seeds were implanted into each pot at two-day intervals to obtain persistent green bean leaves. Plants were grown under laboratory conditions at 23°C, 50% relative humidity, and 16/8 h light/dark.

Natural enemies. The main material of the experiment was the generalist predators *Orius laevigatus*, *Nesidiocoris tenuis*, and *Macrolophus pygmaeus*, and whitefly parasitoids, *Encarsia formosa* and *Erotmocerus eremicus*, obtained from Koppert Biological Control and Pollination Systems Ltd.,Turkey. There were 500 adults of *O. laevigatus*, *N. tenuis*, and *M. pygmaeus* in 100 ml plastic boxes, which were assigned to each predator species separately. Mummy cards of *E. formosa* and *E. eremicus* contained 3000 parasitised whitefly pupae in each box.

Essential oils and doses. The common oils obtained in pure form were purchased from the markets (Biotoma, Turkey) – the oils that are in the fixed oil class: carrot (*Daucus carota* L.) oil and wintergreen (*Gaultheria procumbens* L.) oil, and the oils that are in the essential oil class: ginger (*Zingiber officinale* Roscoe) oil, wormwood (*Artemisia absinthium* L.) oil, and clove (*Syzygium aromaticum* Merril & Perry) oil. In the experiment, three different doses of each oil were determined: 0.125, 0.25, and 0.5 v/v. Oils were prepared by dissolving in ethanol (99.99% purity, Isolab), well known and recognised as a safe organic solvent (Neto et al., 2018). It was prepared by mixing three different doses into 100 ml of ethanol solvent. In the control treatment, only 100 ml of pure water was prepared and used.

Application of essential oils to natural enemies. The method (contact or residual) used in this experiment was adapted from Yu (2015). Firstly, 10 holes were made in each Petri dish lid by a heated stainless-steel straight dissecting needle (1 microlitre, Isolab) in a spirit burner. Pre-cut filter paper (40 × 40 cm, Macherey-Nagel) was also placed inside each Petri dish. For *O. laevigatus*, *N. tenuis*, and *M. pygmaeus* adults, firstly, clean bean leaves were placed in plastic Petri dishes (60 × 15 mm). Then the essential oils were sprayed with a plastic hand holding spray bottle (500 ml, spray/spray nozzle, 16 oz).

After one hour of drying under laboratory conditions, predatory adults were released into the Petri dishes. In case of parasitoid treatments, first *E. formosa* and *E. eremicus* pupae were transferred to Petri dishes and then sprayed with different doses of oils. Three replicates were performed for one dose of each oil using 10 individuals for each repetition. For each natural enemy species, 9 Petri dishes and 90 adult individuals were used for each oil; therefore, a total of 225 Petri dishes and 2250 individuals were used for all natural enemy species. Mortality rates were recorded after 1, 3, and 24 hours.

Determination of mortality rate and lethal dose. The dead individuals in Petri dishes, where the mortality treatments of predatory adults were conducted, were counted at certain intervals (after 1, 3 and 24 hours). For parasitoid individuals, the mortality of pupae was observed at certain intervals (after 1, 3 and 24 hours) with the collapse and discolouration caused by interaction with essential oils. To determine the lethal dose, the mortality values observed during the experiment were corrected according to Abbott's (1925) formula:

$$\text{Mortality rate} = \frac{\text{Number of living organisms in control (\%)} - \text{number of living organisms after treatment (\%)}}{\text{Number of living organisms in control (\%)}} \times 100.$$

Statistical analysis was performed using the program JMP (JMP Statistical Discovery LLC, USA). Data obtained were analysed at the 99% confidence interval level by the analysis of variance (ANOVA) followed by Tukey's multiple comparison test, and differences between treatments were determined. The toxicity levels of essential oils applied to insects during laboratory experiments were classified according to the International Organisation for Biological Control (IOBC) and presented as toxicity categories (TC) (death rates %): 1 – <30% harmless, 2 – 30–79% slightly harmful, 3 – 80–99% moderately harmful, and 4 – >99% harmful (Hassan, 1994).

Results

Mortality rates of essential oils on generalist predators and two whitefly parasitoids. The mortality rates of the oils for *O. laevigatus*, *N. tenuis*, *M. pygmaeus*, *E. formosa*, and *E. eremicus* after one-hour exposure are shown in Table 1. The predator species were more affected than the parasitoids after one hour of oil application. Of the predator species, the most sensitive to the oils were *N. tenuis*, *O. laevigatus*, and *M. pygmaeus*, and similar effects were observed among the parasitoid species. At the end of the first hour, the most effective was wintergreen oil followed by clove and carrot oils, while wormwood and ginger oils were the least effective. In the first hour after exposure, the highest mortality of *O. laevigatus* adults was observed from clove oil with an average of 83–100%, while the lowest mortality was from wormwood and carrot oils: 0–16% and 3–6%, respectively.

Table 1. Mortality rate of natural enemies after one-hour exposure to the essential oils

Species	Essential oil	Mortality %						Toxicity category[1]
		0.125 v/v (mean ± SE)		0.25 v/v (mean ± SE)		0.5 v/v (mean ± SE)		
O. laevigatus	clove	83.33 ± 3.33	abc	90.00 ± 0	ab	100 ± 0	a	3–4
	wormwood	0 ± 0	n	10.00 ± 0	lmn	16.67 ± 3.33	j–n	1
	wintergreen	86.67 ± 3.33	ab	93.33 ± 6.67	ab	100 ± 0	a	3
	ginger	0 ± 0	m	0 ± 0	m	63.33 ± 3.33	cde	1–2
	carrot	3.33 ± 6.67	mn	3.33 ± 8.82	mn	6.67 ± 3.33	lmn	1
N. tenuis	clove	43.33 ± 6.67	e–i	56.67 ± 6.67	def	80 ± 5.77	abc	2–3
	wormwood	40.00 ± 13.33	f–j	50.00 ± 0	efg	73.33 ± 3.33	bcd	2
	wintergreen	86.67 ± 3.33	ab	96.67 ± 3.33	a	100 ± 0	a	3–4
	ginger	10.00 ± 0	lmn	20.00 ± 0	j–n	46.67 ± 16.67	e–h	1–2
	carrot	100 ± 0	a	100 ± 0	a	100 ± 0	a	4
M. pygmaeus	clove	16.67 ± 3.33	j–n	20.00 ± 0	j–n	50 ± 5.77	efg	1–2
	wormwood	16.67 ± 3.33	j–n	20.00 ± 0	j–n	23.33 ± 3.33	i–m	1
	wintergreen	16.67 ± 3.33	j–n	20.00 ± 0	j–n	26.67 ± 6.67	h–l	1
	ginger	3.33 ± 3.33	mn	10.00 ± 5.77	lmn	16.67 ± 3.33	j–n	1
	carrot	13.33 ± 3.33	k–n	10.00 ± 0	lmn	23.33 ± 3.33	i–m	1
E. formosa	clove	0 ± 0	n	0 ± 0	n	0 ± 0	n	1
	wormwood	6.67 ± 3.33	lmn	10 ± 10	lmn	20.00 ± 5.77	j–n	1
	wintergreen	0 ± 0	n	0 ± 0	n	0 ± 0	n	1
	ginger	0 ± 0	n	3.33 ± 3.33	mn	6.67 ± 3.33	lmn	1
	carrot	0 ± 0	n	0 ± 0	n	0 ± 0	n	1
E. eremicus	clove	0 ± 0	n	0 ± 0	n	6.67 ± 3.33	lmn	1
	wormwood	10.00 ± 5.77	lmn	13.33 ± 3.33	k–n	13.33 ± 6.67	k–n	1
	wintergreen	0 ± 0	n	0 ± 0	n	0 ± 0	n	1
	ginger	0 ± 0	n	0 ± 0	n	0 ± 0	n	1
	carrot	0 ± 0	n	3.33 ± 3.33	mn	6.67 ± 3.33	lmn	1

Note. The same letter(s) in the same column are not significantly different at $P \leq 0.001$; $F = 14.01$; df = 48; [1] – 1 – harmless, 2 – slightly harmful, 3 – moderately harmful, 4 – harmful.

After one-hour exposure, the toxicity categories of clove oil for *O. laevigatus* adults were moderately harmful and harmful (3 and 4, respectively). The highest mortality in *N. tenuis* adults was determined after exposure to carrot oil: all adult predators died within the first hour at all doses, thus their toxicity category was classified as harmful (4). In addition, *N. tenuis* adults were more sensitive to a dose of 0.5 v/v of wintergreen oil compared to other oils, and all individuals died within the first hour. At the end of the first hour, wormwood oil had the lowest effect on *O. laevigatus*, while ginger oil had the least effect on *N. tenuis* and *M. pygmaeus*. Clove and carrot oils had the least effect on *E. formosa*, and clove and ginger oils were the least effective on *E. eremicus*.

After 3 hours of application of the oils, the predator species were more affected than the parasitoids. Among the predator species, *N. tenuis*, *O. laevigatus*, and *M. pygmaeus* were the most sensitive to oils, while low effect was determined among the parasitoid species. After 3 hours exposure, the most effective was wintergreen oil followed by clove and wormwood ones, while carrot and ginger oils were the least effective. After 3 hours exposure, *O. laevigatus* adults were extremely affected by all doses of wintergreen oil resulting in the death of all individuals, and all individuals died at a dose of 0.25 v/v of clove oil, so their toxicity categories were classified as harmful (4) (Table 2). All doses of wormwood oil had a very toxic effect against *N. tenuis* adults, and all individuals died in the Petri dishes at 0.5 v/v dose of clove oil (toxicity category 4).

Table 2. Mortality rate of natural enemies after 3-hour exposure to the essential oils

Species	Essential oil	Mortality %						Toxicity category[1]
		0.125 v/v (mean ± SE)		0.25 v/v (mean ± SE)		0.5 v/v (mean ± SE)		
O. laevigatus	clove	96.67 ± 3.33	ab	100 ± 0	a	–		3–4
	wormwood	3.33 ± 3.33	jk	36.67 ± 3.33	e–h	70.00 ± 5.77	bcd	1–2
	wintergreen	100 ± 0	a	100 ± 0	a	100 ± 0	a	4
	ginger	0 ± 0	m	16.67 ± 8.82	g–k	83.33 ± 3.33	abc	1–3
	carrot	13.33 ± 8.81	h–k	10 ± 6.67	h–k	13.33 ± 3.33	h–k	1
N. tenuis	clove	90.00± 0	ab	100 ± 0	a	100 ± 0	a	3–4
	wormwood	100 ± 0	a	100 ± 0	a	100 ± 0	a	4
	wintergreen	100 ± 0	a	100 ± 0	a	–		4
	ginger	16.67 ± 3.33	g–k	80.00 ± 0	abc	86.67 ± 3.33	ab	1–3
	carrot	–		–		–		–
M. pygmaeus	clove	33.33 ± 3.33	e–i	36.67 ± 3.33	e–j	100 ± 0	a	2–4
	wormwood	33.33 ± 3.33	e–i	43.33 ± 5.77	d–g	56.67 ± 3.33	cde	2
	wintergreen	36.67 ± 3.33	e–h	43.33 ± 8.82	d–g	56.67 ± 12.01	cde	2
	ginger	30.00 ± 3.33	e–j	43.33 ± 6.67	d–g	43.33 ± 8.82	d–g	2
	carrot	23.33 ± 3.33	f–k	30.00 ± 0	e–j	46.67 ± 8.82	def	2
E. formosa	clove	6.67 ± 3.33	ijk	10.00 ± 5.77	h–k	16.67 ± 3.33	g–k	1
	wormwood	16.67 ± 3.33	g–k	33.33 ± 13.33	e–i	26.67 ± 6.67	f–k	1–2
	wintergreen	3.33 ± 3.33	jk	6.67 ± 3.33	ijk	10.00 ± 5.77	h–k	1
	ginger	13.33 ± 3.33	h–k	13.33 ± 3.33	h–k	16.67 ± 3.33	g–k	1
	carrot	6.67 ± 3.33	ijk	10.00 ± 5.77	h–k	13.33 ± 3.33	h–k	1
E. eremicus	clove	0 ± 0	k	3.33 ± 3.33	jk	13.33 ± 3.33	h–k	1
	wormwood	13.33 ± 6.67	h–k	30.00 ± 5.77	e–j	33.33 ± 3.33	e–i	1–2
	wintergreen	10 ± 0	h–k	10.00 ± 5.77	h–k	13.33 ± 3.33	h–k	1
	ginger	6.67 ± 3.33	ijk	6.67 ± 3.33	ijk	10.00 ± 0	h–k	1
	carrot	0 ± 0	m	6.67 ± 3.33	ijk	16.67 ± 3.33	g–k	1

Note. Since the mortality rates were 100% after one hour, mortality rates were not given after 3 hours; results with the same letter(s) in the same column are not significantly different at $P \leq 0.001$; $F = 10.95$; df = 48; [1] – 1 – harmless, 2 – slightly harmful, 3 – moderately harmful, 4 – harmful.

After 24 hours of application of the oils, the predator species were more affected than the parasitoids. Among the predator species, the most sensitive to oils were *N. tenuis*, *O. laevigatus*, and *M. pygmaeus*, while low effect was determined among the parasitoid species. After 24 hours exposure, the most effective were wintergreen and wormwood essential oils, while the clove, carrot, and ginger oils were also found to be effective. After 24 hours exposure, in the treatments conducted with *O. laevigatus*, it was observed that all adults died from clove oil, and all adults died at the doses of 0.25 and 0.5 v/v of wormwood oil; therefore, the toxicity category can be classified as harmful (4) (Table 3). In the adults of *N. tenuis*, by the end of 24 hours, all individuals died from the remaining doses of clove oil. In the adults of *M. pygmaeus*, it was observed that all individuals died at 0.125 and 0.25 v/v doses of ginger oil and at 0.5 v/v, the highest dose of wormwood oil (toxicity category 4 – harmful).

Table 3. Mortality rate of natural enemies after 24-hour exposure to the essential oils

Species	Essential oil	Mortality %						Toxicity category[1]
		0.125 v/v (mean ± SE)		0.25 v/v (mean ± SE)		0.5 v/v (mean ± SE)		
O. laevigatus	clove	100 ± 0	a	–		–		4
	wormwood	20.00 ± 3.33	klm	100 ± 0	a	100 ± 0	a	1–4
	wintergreen	–		–		–		–
	ginger	6.67 ± 3.33	m	20.00± 11.54	j–m	96.67 ± 3.33	ab	1–3
	carrot	20.00 ± 6.67	j–m	20.00± 12.01	j–m	30.00 ± 12.01	g–m	1–2
N. tenuis	clove	100 ± 0	a	100 ± 0	a	–		4
	wormwood	–		–		–		–
	wintergreen	100 ± 0	a	–		–		4
	ginger	86.67 ± 3.33	abc	93.33 ± 6.67	ab	100 ± 0	a	3–4
	carrot	–		–		–		–
M. pygmaeus	clove	46.67 ± 6.67	e–j	50.00 ± 5.77	e–i	–		2
	wormwood	53.33 ± 3.33	d–h	63.33 ± 6.7	c–f	100 ± 0	a	2–4
	wintergreen	73.33 ± 0	b-e	90.00 ± 5.77	abc	80.00 ± 11.54	a–d	3–4
	ginger	70.00 ± 5.77	b-e	100 ± 0	a	86.67 ± 8.81	abc	3–4
	carrot	43.33 ± 3.33	e–k	90.00 ± 8.81	abc	70.00 ± 5.77	b–e	2–4
E. formosa	clove	16.67 ± 3.33	klm	20.00 ± 5.77	j–m	26.67 ± 3.33	h–m	2
	wormwood	23.33 ± 3.33	i–m	53.33 ± 8.82	d–h	53.33 ± 3.33	d–h	2
	wintergreen	6.67 ± 6.67	m	13.33 ± 3.33	lm	20.00 ± 5.77	j–m	1
	ginger	23.33 ± 3.33	i–m	23.33 ± 3.33	i–m	26.67 ± 3.33	h–m	1
	carrot	13.33 ± 3.33	lm	10.00 ± 3.33	m	26.67 ± 6.67	h–m	1
E. eremicus	clove	13.33 ± 3.33	lm	13.33 ± 3.33	lm	30.00 ± 0	g–m	1–2
	wormwood	20.00 ± 5.77	j–m	33.33 ± 3.33	g–m	43.33 ± 0	e–k	1–2
	wintergreen	16.67 ± 3.33	klm	23.33 ± 3.33	i–m	26.67 ± 0	h–m	1
	ginger	6.67 ± 3.33	m	20.00 ± 3.33	j–m	26.67 ± 3.33	h–m	1
	carrot	13.33 ± 3.33	lm	13.33 ± 3.33	lm	30.00 ± 0	g–m	1

Note. Since the mortality rates were 100% after 1 and 3 hours, mortality rates were not given after 24 hours. Results with the same letter(s) in the same column are not significantly different at $P \leq 0.001$; $F = 8.34$; df = 48; [1] – 1 – harmless, 2 – slightly harmful, 3 – moderately harmful, 4 – harmful.

During the experiment, the response of the parasitoid species to the oils was lower than that of the predator species, and the wormwood oil was found to be the most toxic to the parasitoid species. This oil was revealed to be mostly low to moderately toxic even at the highest dose. By the end of the 24th hour, when all the predators in the Petri dishes were counted, *N. tenuis* was the most susceptible species to the tested oils followed by *M. pygmaeus*, and *O. leavigatus*. In parasitoid pupae, although the effect of essential oils on both species was similar, it can be mentioned that *E. eremicus* pupae were proportionally more sensitive. The most effective wormwood oil was followed by ginger and clove oils. *E. eremicus* was the most affected by wormwood oil followed by clove and wintergreen oils.

Some of the parasitoid species were the least affected by essential oils. The emergence of adults was observed 24 hours after application of the lowest dose of 0.125 v/v of carrot, clove, and ginger oils against *E. formosa* pupae. The outflow of *E. eremicus* adults was observed after 24 hours in the treatments with wintergreen, carrot, and clove oils at a dose of 0.125 v/v and in the treatment with ginger oil at the doses of 0.25 and 0.125 v/v.

Discussion

The toxic effects of various plant oils on eggs, nymphs, and adults of *Trialeurodes vaporariorum* (Westwood, 1856) (Hemiptera: Aleyrodidae) were investigated. Clove essential oil contains the component eugenol (76.8%) (Jirovetz et al., 2006). It has been determined that essential oils obtained from various parts of cloves are highly toxic against the eggs, nymphs, and adults of the greenhouse whitefly. The essential oil of wormwood has a very high toxic effect against the nymphs and adults of the greenhouse whitefly, so the effects of these oils should also be studied on natural enemies of the whiteflies (Choi et al., 2003). In another study, clove oil has been reported to have high fumigant toxicity against the thrips and mealybug (Pumnuan, Insung, 2016). The eugenol has demonstrated toxic effects on *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae) (Essoung et al., 2020).

In present experiment, it was found that clove oil has a highly toxic effect on predators *O. laevigatus* and *N. tenuis*. In some studies, it has been determined that one of the most important natural enemies of the storage pest *S. oryzae* was the *Orius* species (Ballal,

Yamada, 2016). Although wintergreen oil has a strong repellent effect on *S. oryzae* adults, it has been found to have moderately and highly toxic effects depending on the doses (Jayakumar et al., 2017). Wintergreen oil had a moderate toxic effect on Q-biotype females of *Bemisia tabaci* (Gennadius,1889) (Hemiptera: Aleyrodidae) (Kim et al., 2011). Similar to the toxic effects of clove, wormwood, and wintergreen oils on the whitefly and storage pest, results of present experiment revealed that these essential oils also have a highly toxic effect on their predators.

It has been found that the most important components of carrot seed oil are caratol and daukol (30.55% and 12.60%, respectively) (Özcan, Chalchat, 2007). Kaur et al. (2016) study results showed that essential oil from carrot seeds has antifeedant, repellent and insecticidal effects on *Tribolium castaneum* (Herbst, 1797) (Coleoptera: Tenebrionidae). It has been found that essential oil obtained from the carrot plant had a highly toxic effect on some mosquito larvae (Muturi et al., 2019). Hori (1999) study results revealed that ginger and carrot seeds oil repelled *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae) even at a much lower dose.

Additionally, ginger oil repelled *Aphis gossypii* (Glover, 1877) (Hemiptera: Aphididae), *A. craccivora* (Koch, 1854) (Hemiptera: Aphididae), *Macrosiphum euphorbiae* (Thomas, 1878) (Hemiptera: Aphididae), and *Capitophorus formosartemisiae* (Takahashi, 1921) (Hemiptera: Aphididae) (Hori, 1999). In present experiment, it was observed that ginger essential oil was moderately toxic to *O. laevigatus*. *Ephestia kuehniella* (Zeller, 1879) (Lepidoptera: Pyralidae) and *Plodia interpunctella* (Hübner, 1813) (Lepidoptera: Pyralidae) are used in the cultivation of *Orius* spp. (Ferkovich, Shaprio, 2004; Montoro et al., 2020; Gallego et al., 2022). Similar to the results of present experiment, ginger essential oil was found to have a repellent and very strong fumigant toxic effect on *E. kuehniella* and *P. interpunctella* (Maedah et al., 2011).

Ginger, clove, and wintergreen oils were found to have a very high fumigant toxic effect on third instar larvae of *Camptomyia corticalis* (Loew, 1851) (Diptera: Cecidomyiidae) (Kim et al., 2012). In present experiment, wintergreen oil was found to have a very high toxicity to predatory insects in the first hours.

The results of the experiment demonstrated that the most important components of wormwood oil were β-pinene (27.88%) and linalool (23.41%). Wormwood oil and its compounds tested had repellent activity and contact toxicity to *B. tabaci* (Li et al., 2022). The high toxicity of wormwood oil at different hours after application was found to be harmful to hemipteran predators but slightly harmful to parasitoids. It is possible that the results of present experiment can help to provide programmes for mass cultivation as well.

Conclusion

1. Based on the results of the experiment with five parasitoids, it was observed that there was no significant toxic effect on the parasitic pupae. It was found that the adult species were not affected by the oils tested and continued their biology, while the biological development of the unhatched parasitoid species was stopped by these oils.

2. Some of the oils used in the experiment were found to have no significant effect on the parasitoids compared to the predators, so even if oil is applied, the parasitoids can exit the pupa, and this will increase the success of biological control.

3. For predator species, the most effective (100%) were wintergreen, clove, and wormwood oils; however, in the experiment, only wormwood oil had a slightly deleterious effect on the parasitoids *Encarsia formosa* (53.33%) and *Eretmocerus eremicus* (43.33%). For this reason, these oils are not recommended to use for Integrated Pest Management (IPM) biocontrol programmes.

4. Since the wintergreen and carrot oils have low toxic effects on two whitefly parasitoids (*E. formosa* and *E. eremicus*) in present experiment, they can be recommended to be used together at the beginning of biological control.

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