



The effect of spices, essential oils and extracts on the locomotor activity of *Porcellio laevis* (Isopoda, Porcellionidae)

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Porcellio laevis Latreille, 1804 plays a significant role in soil formation processes, in particular in the decomposition of organic residues. It is also an important component of food chains. At the same time, when present in excessive numbers, woodlice can act as secondary pests, particularly in the storage of plant products. This study examines the effects of 20 natural aromatic plant materials – spices, essential oils, and plant extracts – on the locomotor activity of *P. laevis*. The movement of the individuals was analyzed over a 3-min period using a T-shaped experimental chamber. Most of the tested materials significantly reduced the isopod motility compared with the control conditions. Notably, nutmeg, coffee, and basil demonstrated both attractant and deterrent effects, while allspice, clove, essential oils of *Mentha piperita* and *Melaleuca alternifolia*, and extract of *Petroselinum crispum* acted as repellents. These findings highlight the potential of natural aromatic compounds as environmentally friendly means to regulate isopod populations without the use of toxic insecticides.

Keywords: Oniscidea; swift woodlouse; aromatic compounds; curcuma; ginger; clove; cinnamon; nutmeg; coffee; basil; garlic; allspice pepper; vanillin.

Introduction

Porcellio laevis Latreille, 1804 (Isopoda, Porcellionidae) is a species of woodlice from the family Porcellionidae, which are widely used in biological and ecological research (Wolters & Ekschmitt, 1997). Isopods play a significant role in the decomposition of organic remains such as plant debris, thus contributing to the restoration of nutrients in the soil. Analysis of this process can enhance our understanding of biological cycles in different ecosystems (Bredon et al., 2019). Woodlice contribute to aeration by moving through soil and leaf litter. Their burrowing and feeding activities help improve the soil structure and promote the movement of air and water through the soil. This is useful for the growth of plant roots (Kishore et al., 2024). They are sensitive to changes in the environment, in particular to moisture levels and temperature (Đurajková et al., 2022). Declines in woodlice populations may indicate environmental stress such as pollution or habitat degradation (Solomou et al., 2019). Therefore, woodlice can be used as environmental bioindicators. Moreover, previous studies have shown that *P. laevis* has the ability to transport and even accumulate heavy metals in its body, making it a potential candidate for the bioremediation of soils contaminated with heavy metals (Gospodarek et al., 2022). However, when woodlice populations exceed normal levels, they can inflict damage to plants or stored plant products. Due to their important ecological role, their control must be carefully considered, with an emphasis on minimizing environmental impact.

The use of aromatic compounds for pest control is an environmentally friendly approach. This method consists of using natural odours or the chemical properties of certain aromatic compounds to repel, deter, or kill harmful organisms (Karunamoorthi, 2012). These compounds are often derived from plants, essential oils and other natural sources, making them an attractive alternative to synthetic pesticides. Although the mechanisms of action of aromatic compounds are not yet fully understood and depend on phytochemical characteristics, this approach is becoming popular in both industry and households for pest control. Aromatic compounds affect the main metabolic, biochemical, physiological, and behavioural processes of

arthropods (Martínez et al., 2017; Brasesco et al., 2017). Thus, they can cause toxic, fumigant, repellent, antifeedant, ovicidal, or attractant effects (Mossa, 2016; Bedini et al., 2020a; Taha-Salaime et al., 2020; Tlak & Dar, 2021).

In recent years, studies of the effects of individual aromatic compounds and their mixtures on the locomotor activity of barn pests have garnered considerable attention (Conti et al., 2010; Martynov & Brygadyrenko, 2017, 2018; Martynov et al., 2019a, 2019b; Titov & Brygadyrenko, 2021). In order to reduce the negative impact on natural ecosystems, research has been conducted on the use of natural products for organic methods of controlling insects (Seo et al., 2014; Kim et al., 2016), their parasites (Parhomenko & Brygadyrenko, 2023; Lazurska & Brygadyrenko, 2024; Parhomenko et al., 2024), vertebrate and human parasites (Boyko & Brygadyrenko, 2017, 2019), molluscs (Radwan & Gad, 2021; Remezok et al., 2022), and mites (Al-Assiuty et al., 2019; Moshkin & Brygadyrenko, 2022; Tykhanova & Kolombar, 2022). The objective of this study was examining the specific effects of 20 aromatic materials of natural origin on the locomotor activity of *P. laevis*. The results will be useful for developing methods to regulate isopod activity on farms, where they can act as pests, without harming their lives, as well as other beneficial organisms and the environment.

Materials and methods

We selected 20 aromatic compounds of natural origin for experiments, including plant extracts, essential oils, and spices (Tables 1 and 2). Spices have a wide range of applications in everyday life; they are used not only for cooking but also for medicinal purposes, aromatherapy, and cosmetics. Plant extracts and essential oils are also powerful natural ingredients with many applications in various areas of life, in particular, in medicine, cosmetology, aromatherapy, and cooking. They are the basis of many natural products that provide health benefits and improve the quality of life.

A culture of *P. laevis* was grown in the amount of 250 specimens at the initial stage of the study. The isopods were collected from natural conditions in the area of the rural settlement of Obuhivka. The col-

lection was done manually into a container with the substrate (soil, fallen leaves, and plant debris). The woodlice were kept at a constant temperature (25 °C) and humidity (45.0–47.0%) using a heater and a water sprayer for several months. A T-shaped chamber was used as an experimental setup. The experimental tube was made of polyethylene, rolled into a tube, 100 cm long and 30 mm in inner diameter. This structure of the tube allowed the studied individuals to move freely and change the direction of movement. The tube was placed on paper with marks every 10 cm to record the distance travelled by the

individuals over a certain period (Fig. 1a). At the beginning of each test, 10 individuals of *P. laevis* were placed in the tube using the upper half of a plastic bottle that served as a funnel and was connected to the middle of the tube (Fig. 1b). A video camera was installed above the experimental setup. An aromatic material was placed at one end of the tube. Both ends of the tube were tightly closed with lids. The woodlice were transported through a funnel into the middle of the experimental tube. The video camera recorded the movement of individuals for 180 seconds.

Table 1
Characteristics of the spices used in the experiment

The name of the spice	Plant	Chemical composition	References
Curcuma	roots of <i>Curcuma longa</i> L. (Zingiberaceae)	coumaric acid, calebin A, bisdemethoxycurcumin, demethoxycurcumin, curcumin	Wu et al. (2024)
Ginger	roots of <i>Zingiber officinale</i> Roscoe (Zingiberaceae)	zingiberene, valencene, β -funebrene, selina-4(14),7(11)-diene, citronellyl n-butyrate, β -phellandrene, camphene, α -pinene	Sharma et al. (2016)
Clove	buds of <i>Syzygium aromaticum</i> (L.) Merr. & L. M. Perry (Myrtaceae)	eugenol, eugenol acetate, quercetin, β -caryophyllene	Razafimamonjison et al. (2014)
Cinnamon	barks of <i>Cinnamomum verum</i> J. Presl (Lauraceae)	(E)-cinnamaldehyde, linalool, β -caryophyllene, eucalyptol, eugenol	Behbahani et al. (2020)
Nutmeg	seeds of <i>Myristica fragrans</i> Houtt. (Myristicaceae)	sabinene, terpinen-4-ol, β -pinene, limonene	Nikolic et al. (2021)
Coffee	fruits of <i>Coffea arabica</i> L. (Rubiaceae)	3-methylheptane, trimethylsilyl methanol, d-limonene, 5,6-dimethyldecane, dibutyl phthalate, 7-methyl-z-tetradecen-1-ol acetate	Alamri et al. (2022)
Basil	leaves of <i>Ocimum basilicum</i> L. (Lamiaceae)	methyl-chavicol, linalool, trans-a-bisabolene, terpinen-4-ol	Saikia et al. (2004)
Garlic	bulbs of <i>Allium sativum</i> L. (Amaryllidaceae)	diallyl sulfide, diallyl disulfide, diallyl trisulfide, allyl methyl disulfide, allyl methyl trisulfide	Satyal et al. (2017)
Allspice	berries of <i>Pimenta dioica</i> (L.) Merr. (Myrtaceae)	limonene, 1,8 cineole, terpinolene, β -caryophyllene, β -selinene, methyl eugenol	Rao et al. (2012)
Vanillin	–	4-hydroxy-3-methoxybenzaldehyde	Walton (2003)

Table 2
Characteristics of the extracts and essential oils of plants used in the experiment

Name	Chemical composition	Commonest uses	References
<i>Calendula officinalis</i> L. (Asteraceae) extract	α -thujene, 1,8-cineole, δ -cadinene, α -pinene, γ -cadinene	it has antiseptic, bactericidal, anti-inflammatory, regenerating, wound healing, softening and sun-protective effects	Kaskonienė et al. (2011)
<i>Capsicum frutescens</i> L. (Solanaceae) extract	octadecane, eicosane, docosane, 9,12-octadecadienoic acid, methyl ester, hexadecanoic acid	it helps to stimulate blood circulation and opens clogged pores; it is used in hair cosmetics against dandruff and to nourish hair roots; it increases blood circulation; it is an antioxidant	Gumani et al. (2016)
<i>Salvia officinalis</i> L. (Lamiaceae) extract	camphor, α -thujone, 1,8-cineole, viridiflorol, β -thujone, β -caryophyllene	it is an antiseptic and astringent	Khedher et al. (2017)
<i>Cucumis sativus</i> L. (Cucurbitaceae) extract	palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid	it is used in a wide range of products, including bath products, soaps and detergents, lotions, cleaning products, nail care products, eye makeup and hair care products	Burnett et al. (2017)
<i>Punica granatum</i> L. (Lythraceae) extract	punicic acid, conjugated linolenic acid, phenolic acids, quercetin, naringenin, 3-methyl-1-butanol, 2,3-butanediol, phenylethyl alcohol	it is used in many cosmetic and medical products, as its components relieve irritation and fatigue, improve blood circulation and stimulate the collagen production	Costa et al. (2019)
<i>Petroselinum crispum</i> (Mill.) Fuss (Apiaceae) extract	menthatriene, β -phellandrene, apiol, myristicin, terpinolene	it is used as a diuretic and antispasmodic for kidney diseases, intestinal spasms and flatulence; it has antibacterial properties	Snoussi et al. (2016)
<i>Aesculus hippocastanum</i> L. (Sapindaceae) extract	stearic acid, palmitic acid, oleic acid, linoleic acid, linolenic acid	in cosmetics chestnut extract helps the skin stay moisturized and elastic; it improves blood flow, regulates metabolic processes in the skin; it fights free radicals	Ehlers & Hill (1951)
<i>Melaleuca alternifolia</i> (Maiden & Betche) Cheel (Myrtaceae) essential oil	terpinen-4-ol, γ -terpinene, α -terpinene, α -terpineol, α -pinene, terpinolene, 1,8-cineole	it has bactericidal, antiviral and antifungal effects; it is used for acute respiratory infections; it is an antipyretic agent	Liao et al. (2017)
<i>Mentha piperita</i> L. (Lamiaceae) essential oil	menthol, menthone, methyl acetate, carveone, neomenthol, 1,8-cineole, limonene	it disinfects, promotes rapid healing, eliminates inflammatory processes, cleanses, soothes; it has an insecticidal effect, eliminates fungi and bacteria, destroys viruses	Mahboubi & Kazempour (2014)
<i>Citrus sinensis</i> (L.) Osbeck (Rutaceae) essential oil	limonene, β -myrcene, α -pinene, sabinene, β -pinene	it has an aseptic effect, helps with gingivitis, periodontal disease, helps with insomnia, depression, stress, lowers blood pressure, increases concentration, normalizes intestinal function, carbohydrate and fat metabolism, prevents the appearance of gallstones	Ngan et al. (2020)

The aromatic compounds and woodlice individuals were changed after each experiment. Each material was tested in triplicate. The tests were also conducted without a compound for the control. The distance travelled by the woodlice in 180 seconds was video-recorded. These results were entered into a table, and an Analysis of Variance (ANOVA) was performed to assess the variability in the locomotor activity. In addition, the location of each specimen was recorded at the end of the test to determine the direction of their movement. The isopods that moved into the part of the tube with the aromatic material and stopped within 0–30 cm were counted separately from

those specimens that moved in the opposite direction (70–100 cm). The ratio of individuals within these areas to their total number determined the degree of repellent or attractant effect of the compound. The statistical analysis of the obtained results was performed using the Statistica 12.0 software (StatSoft Inc., Tulsa, USA).

Results

All the spices used in the experiment significantly slowed down the movement of the isopods (Fig. 2). The aroma of nutmeg had the

greatest influence (105.7 ± 43.9 , Table 3). The analysis of the locations of each individual at the end of the test showed that five out of ten splices attracted the woodlice, for example, nutmeg (60.0% of individuals were within the 0–30 cm mark, control – 36.7%), coffee (50.0%), and basil (60.0%). Vanillin, curcuma, garlic, cinnamon, and ginger had no effect on the behaviour of woodlice. The individuals spread evenly throughout the tube during the tests with these spices, as well as during the control study. Allspice and clove exerted a repellent effect on *P. laevis* (respectively 63.3% and 46.7% of individuals were within the 70–100 cm mark, control – 33.3%).

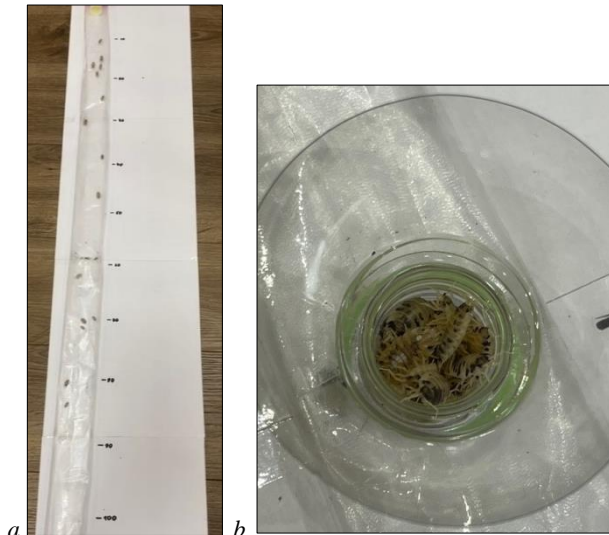


Fig. 1. The experimental stand (a), funnel for transporting *Porcellio laevis* to the tube (b)

Table 3
Locomotor activity of *Porcellio laevis* under the influence of the spices (n = 30)

Substance	Distance (cm) covered by individuals during 3 minutes, $\bar{x} \pm SD$	Ratio to control, %	P
Control	300.0 \pm 56.8	100.0	–
Nutmeg	105.7 \pm 43.9	35.2	2.13*10 ⁻²¹
Cinnamon	109.0 \pm 44.6	36.3	6.15*10 ⁻²¹
Allspice	110.0 \pm 50.9	36.7	9.48*10 ⁻²⁰
Coffee	111.3 \pm 53.7	37.1	3.75*10 ⁻¹⁹
Clove	112.7 \pm 43.9	37.6	1.12*10 ⁻²⁰
Basil	114.3 \pm 50.5	38.1	2.17*10 ⁻¹⁹
Garlic	117.0 \pm 50.7	39.0	4.49*10 ⁻¹⁹
Ginger	122.3 \pm 56.9	40.8	1.63*10 ⁻¹⁷
Vanillin	128.3 \pm 45.7	42.8	1.09*10 ⁻¹⁸
Curcuma	130.0 \pm 49.7	43.3	7.21*10 ⁻¹⁸

Notes: \bar{x} – mean value, SD – standard deviation, P – significance of difference from control based on the results of ANOVA with the Bonferroni correction.

Table 4
Locomotor activity of *Porcellio laevis* under the influence of the essential oils and plant extracts (n = 30)

Substance	Distance (cm) covered by woodlice individuals within 3 minutes, $\bar{x} \pm SD$	Ratio to control, %	P
Control	300.0 \pm 56.8	100.0	–
<i>Petroselinum crispum</i> (extract)	173.7 \pm 70.2	57.9	2.23*10 ⁻¹⁰
<i>Mentha piperita</i> (essential oil)	173.7 \pm 57.1	57.9	6.18*10 ⁻¹²
<i>Melaleuca alternifolia</i> (essential oil)	178.7 \pm 65.6	59.6	2.26*10 ⁻¹⁰
<i>Capsicum frutescens</i> (extract)	185.7 \pm 62.2	61.9	5.45*10 ⁻¹⁰
<i>Cucumis sativus</i> (extract)	189.7 \pm 69.8	63.2	8.63*10 ⁻⁹
<i>Citrus sinensis</i> (essential oil)	190.7 \pm 59.1	63.6	8.94*10 ⁻¹⁰
<i>Salvia officinalis</i> (extract)	197.7 \pm 66.0	65.9	2.55*10 ⁻⁸
<i>Calendula officinalis</i> (extract)	270.3 \pm 63.2	90.1	0.061
<i>Aesculus hippocastanum</i> (extract)	300.0 \pm 51.1	100.0	1.000
<i>Punica granatum</i> (extract)	371.0 \pm 67.23	123.7	4.38*10 ⁻⁵

Note: see Table 3.

The extracts from cucumber and the essential oils of sage and orange changed the direction of movement of most of the studied woodlice (respectively 60.0%, 63.3%, and 66.7% of the individuals were within 0–30 cm). Thus, these compounds can be identified as attractants. They, as well as the extracts from parsley and red pepper and the essential oils of tea tree and mint slowed down the movement of isopods during the study (by 1.5–1.7 times, $P < 0.001$, Table 4). The extracts from calendula, chestnut, and pomegranate exhibited no effect on the spatial distribution of *P. laevis* during the experiment. However, *Punica granatum* increased the speed of movement of the isopods by 1.2 times ($P < 0.001$). The other two extracts demonstrated results identical to the control (Fig. 3). Repellent properties were observed during the tests with the essential oils of *Mentha piperita* (66.7% of individuals were within the 70–100 cm mark) and *Melaleuca alternifolia* (53.3%), and the extract of *Petroselinum crispum* (49.7%).

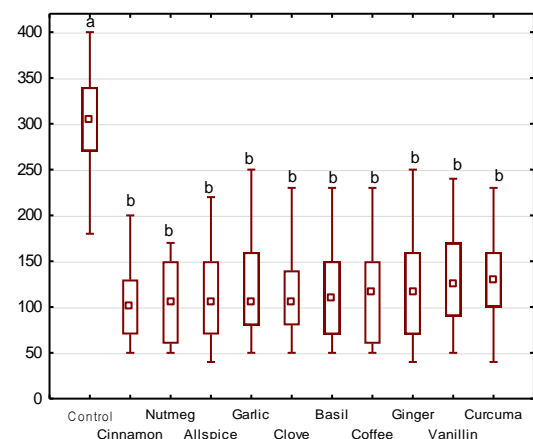


Fig. 2. Variability of locomotor activity of *Porcellio laevis* under the influence of spices (n = 30): on the abscissa axis – spices, on the ordinate axis – distance (cm) travelled by the individuals of woodlice within 3 minutes

The study found that most of the aromatic materials slowed down the movement of *P. laevis*. In particular, the essential oils and plant extracts slowed it down by 1.5–1.7 times, while the spices slowed it by 2.3–2.8 times ($P < 0.001$). The extracts of *Calendula officinalis* and *Aesculus hippocastanum* did not affect either the distribution or the speed of movement of the isopods within the experimental field. Among the attractants, it is worth noting nutmeg, coffee, basil, extract of *Cucumis sativus*, the extract of *Salvia officinalis*, and the essential oil of *Citrus sinensis*. Spices such as allspice and clove, the essential oils of *Mentha piperita* and *Melaleuca alternifolia*, and the extract of *Petroselinum crispum* exerted a repellent effect on the woodlice.

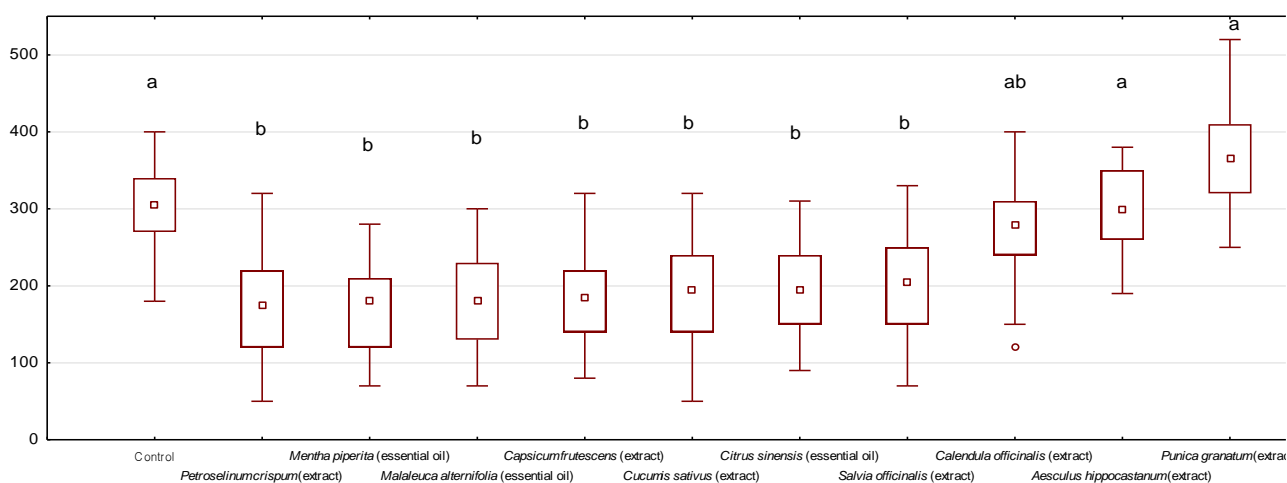


Fig. 3. Variability of locomotor activity of *Porcellio laevis* under the influence of the essential oils and plant extracts (n = 30): on the abscissa axis – material, on the ordinate axis – distance (cm) travelled by the woodlice individuals within 3 minutes

Discussion

The difficulty of controlling *P. laevis* as a pest is that the main products used for this purpose can be harmful to their lives, as well as to other non-target species. The results of our study demonstrate that the use of natural aromatic materials can significantly affect the locomotor activity of *P. laevis*. Most of the spices and plant extracts tested in our experiments reduced the isopod movement by 1.5–2.8 times compared with the control group. These findings highlight the potential of using such substances as environmentally friendly tools to regulate the behaviour of *P. laevis* in places where they act as pests. Our results are consistent with a number of recent studies reporting the effectiveness of natural products in influencing invertebrate behaviour.

It is worth noting that *Myristica fragrans*, *Coffea arabica*, and *Ocimum basilicum* displayed both an attractive effect and a pronounced ability to reduce movement speed. This indicates their dual potential for trapping and managing isopod populations. Nutmeg contains up to 35.0% fat, including up to 11.0% essential oil, which determines the distinctive aroma. Active compounds such as trimyristin, myristic acid, myristicin, safrole, elimicin, and other in essential oils can have various effects on humans (Asgarpanah & Kazemivash, 2012), vertebrates (Dhingra & Sharma, 2006; Paul et al., 2014; El Shanawany et al., 2024), and invertebrates. Thus, the results of the study by AL-Nujiban (2020) demonstrated that nutmeg essential oils can be used as a repellent for biological control of the date pest *Ephestia cautella* (Walker, 1863) (Lepidoptera, Pyralidae) (the repellency was 86.4%). Wagan et al. (2017) reported the effectiveness of *M. fragrans* essential oil in greenhouse to control the whitefly *Bemisia tabaci* (Gennadius, 1889) (Hemiptera, Aleyrodidae). Chaubey (2023) noted its effectiveness against *Sitophilus zeamais* (Motschulsky, 1855) (Coleoptera, Curculionidae). However, there are also reports of the attractant effect of *Myristica fragrans*. For example, behavioural bioassays in the study by Rosa et al. (2018) showed that the fixed oil obtained from *M. fragrans* exhibited an attractive effect on *Ceratitis capitata* (Wiedemann, 1824) (Diptera, Tephritidae). It also acted as an attractant in a laboratory experiment with the larvae of *Costelytra zealandica* (White, 1846) (Coleoptera, Scarabaeidae) (Osborne & Boyd, 1974).

Beans of *Coffea arabica* contain a variety of chemical compounds such as caffeine, chlorogenic acids, and volatile aromatics that can affect the behaviour of invertebrates. Most studies indicate that coffee has repellent, insecticidal, anti-nutritional, and regulatory properties. For example, Maliza et al. (2023) concluded that active compounds from the methanol extract of the Arabica coffee fruit skin have a potential as a mosquito repellent. The use of coffee grounds in the study by Derraik & Slaney (2005) caused a significantly high mortality of the larvae of *Aedes notoscriptus* (Skuse, 1889) (Diptera, Culicidae) within a few days. This may be considered as a cost-

effective, environmentally friendly method of controlling these malaria vectors. However, the authors emphasize the need for further, more detailed research. In addition, studies evaluated and confirmed coffee's fumigant toxicity, repellent effect, and effects on feeding behaviour on invertebrates, in particular, the 1-week-old adults of the red flour beetle *Tribolium castaneum* (Herbst, 1797) (Coleoptera, Tenebrionidae) (Phankaen et al., 2017), as well as on *Tapinoma indicum* Forel, 1895 (Hymenoptera, Formicidae), *Pheidole megacephala* (Fabricius, 1793) (Hymenoptera, Formicidae), and *Monomorium pharaonis* (Linnaeus, 1758) (Hymenoptera, Formicidae) (Yeoh et al., 2018). However, studies also reported the attractive effect of coffee beans and other components of *Coffea arabica* plant, in particular for *Ceratitis capitata* (Prokopy et al., 1997; Warthen et al., 1997).

Basil is an important medicinal plant that is widely used in medicine and food industry. Its essential oil contains over 200 chemical compounds, including monoterpenes, flavonoids, and aromatic compounds. These compounds exerted antibacterial, antifungal, antioxidant, anti-inflammatory, and antitumor properties (Tchoumboungang et al., 2006). They can also be used in pest control. In our studies, we observed the *O. basilicum* leaves to cause the attractive effect on *P. laevis*. Similar results were yielded by scientists in studies with fruit flies (Abdullah et al., 2020; Singh & Agrawal, 2021; Rubiyanto et al., 2022) and termites (Diba et al., 2022). The essential oil from *O. basilicum* displayed repellent activity (Bhuwan Bhaskar Mishra et al., 2012) in the experiments with the adults of *Tribolium castaneum* and *Sitophilus oryzae* (Linnaeus, 1763) (Coleoptera, Curculionidae). It also had a similar effect on mosquitoes (Murugan et al., 2007; Adam et al., 2019) and ticks (Del Fabbro & Nazzi, 2008).

Among the ten extracts and essential oils that we tested, the extracts from *Cucumis sativus* and *Salvia officinalis* and the essential oil of *Citrus sinensis* displayed an attractant effect. Cucumber showed a similar effect in the experiments with the snails *Deroceras agreste* (Linnaeus, 1758) (Stylommatophora, Agriolimnidae) (Remezok et al., 2022) and the melon flies *Bactrocera cucurbitae* (Coquillett, 1899) (Diptera, Tephritidae) (Njuguna et al., 2018). This may be due to the similar food preferences of these species. Most of the results of research around the world indicate the repellent and fumigant effects of *S. officinalis* extract on invertebrates. For example, the study by Alcalá-Orozco et al. (2019) reported that its essential oil is a promising method in the integrated control of granary pests *Tribolium castaneum* and *Ulmoides dermestoides* (Fairmaire, 1893) (Coleoptera, Tenebrionidae), serving as a repellent. Sage was observed to have the same effect on *Calliphora vomitoria* (Linnaeus, 1758) (Diptera, Calliphoridae) (Bedini et al., 2020b), *Neoseiulus californicus* McGregor, 1954 (Mesostigmata, Phytoseiidae), and *Phytoseiulus persimilis* Evans, 1952 (Mesostigmata, Phytoseiidae) (Salman et al., 2018). However, Laborda et al. (2013) highlighted the opposite effect of sage. The authors noted that its essential oil attracted the adults of *Ceratitis capitata*. It may be useful as an adjunct to other forms of pest control.

Essential oil of *C. sinensis* exerted similar effects on other fruit fly species. For example, Akotsen-Mensah et al. (2013) conducted a comparative analysis of the effects of synthetic baits and natural plant components (for example, sweet orange juice) on *Bactrocera invadens* Drew, Tsuru & White, 2005 (Diptera, Tephritidae). Liu et al. (2024) demonstrated that d-limonene in this oil is one of the key attractants for *Bactrocera dorsalis* (Hendel, 1912) (Diptera, Tephritidae) and suggested its use in the development of a control agent in the future. A bioassay test in the study by Mursiti et al. (2019) showed that d-limonene is both a repellent and a fumigant against human ectoparasites (*Cimex* Linnaeus, 1758 (Hemiptera, Cimicidae)). It caused the mortality of *Cimex cimicidae* at a level of more than 50.0%. The ethanolic extract of *C. sinensis* also demonstrated a 100.0% repellent activity against *Aedes stephensi*, *Aedes aegypti* (Linnaeus in Hasselquist, 1762) (Diptera, Culicidae), and *Culex quinquefasciatus* Say, 1823 (Diptera, Culicidae) (Murugan et al., 2012). Boanyah & Boakye (2022) also reported the efficacy of essential oils against mosquitoes. A number of articles also examined the repellent effect of orange-based herbal remedies on pests such as *Tribolium castaneum* (Heidari et al., 2017), *Sitophilus zeamais* (Motschulsky), 1855 (Coleoptera, Curculionidae) (Kidane, 2011), and *Camponotus nearcticus* Emery, 1893 (Hymenoptera, Formicidae) (Adusei-Mensah, 2014).

Pimenta dioica and *Syzygium aromaticum* exerted a repellent activity against *P. laevis*. Allspice has been poorly studied in terms of its biological efficacy, but a number of studies confirmed its repellent, larvicidal, adulticidal, and anticholinesterase effects on various invertebrate species. Gomes da Rocha Voris et al. (2018) noted the effectiveness of essential oils of spices, including *P. dioica*, in controlling third-instar larvae and adults of *Aedes aegypti*, which opens the possibility of developing a natural, safe, and environmentally friendly bioinsecticide to combat Zika virus vectors. Narayanankutty et al. (2021) recommend the use of *P. dioica* essential oil as an environmentally safe larvicidal and biopesticidal compound against storage pests such as *Sitophilus* sp., *Tribolium* sp., and *Callosobruchus* sp. Similar reactions to pepper were seen in *Callosobruchus maculatus* (Fabricius, 1775) (Coleoptera, Chrysomelidae) (Tenne & Karunaratne, 2018). Pepper also inhibited the growth of *Aspergillus flavus* Link (1809) (Eurotiales, Aspergillaceae) (Chaudhari et al., 2018). However, it is worth noting that leaf extract of *P. dioica* attracted *Bactrocera invadens* (Akotsen-Mensah et al., 2013) and *Haliotis discus* Reeve, 1846 (Lepetellida, Haliotidae) (Harada et al., 1996).

Clove is a traditional medicinal material used as a disinfectant, antiseptic, and spice. Many scientific articles examined its antifungal activity, for example, against *Aspergillus glaucus* (L.) Link (1809) (Eurotiales, Aspergillaceae), *Aspergillus flavus*, *Penicillium citrinum* Thom, C. 1910 (Eurotiales, Aspergillaceae), *Rhizopus nigricans* Vuillemin (1902) (Mucorales, Mucoraceae) (Qulian et al., 2004), as well as antimicrobial activity against *Escherichia coli* (Migula 1895) Castellani and Chalmers 1919 (Enterobacteriales, Enterobacteriaceae), *Klebsiella pneumoniae* (Schroeter 1886) Trevisan 1887 (Enterobacteriales, Enterobacteriaceae), *Pseudomonas aeruginosa* (Schröter 1872) Migula 1900 (Pseudomonadales, Pseudomonadaceae), and *Staphylococcus aureus* Rosenbach 1884 (Bacillales, Staphylococcaceae) (Alzahrani, 2018). In addition, clove has attracted the attention of scientists as a means of controlling pests. Clove can be effective against pests *Tribolium castaneum*, *Sitophilus zeamais*, *Rhyzopertha dominica* (Fabricius, 1792) (Coleoptera, Bostrichidae), *Sitophilus oryzae* (Qunxin et al., 2006; Zeng et al., 2010; Abo-El-Saad et al., 2011), *Anthrenus verbasci* (Linnaeus, 1767) (Coleoptera, Dermestidae) (Faheem & Abduraheem, 2019), ants *Solenopsis invicta* Buren, 1972 (Hymenoptera, Formicidae) (Kafle & Shih, 2013), and blood-sucking species *Aedes aegypti*, *Anopheles minimus* Theobald, 1901 (Diptera, Culicidae), *Anopheles stephensi*, *Culex quinquefasciatus* (Phasomkulsil & Soonwera, 2010; Harismah et al., 2017; Sheikh et al., 2021), and *Leptotrombidium* Nagayo et al., 1916 (Trombidiformes, Trombiculidae) (Eamsobhana et al., 2009).

The essential oils of *Mentha piperita*, *Melaleuca alternifolia*, and the extract of *Petroselinum crispum* also showed repellent properties during our experiments with *P. laevis*. Peppermint oil is the most popular essential oil used in flavourings, pharmaceuticals, confection-

ery, and medicine. Numerous studies have been focused on the repellent effect of mint essential oil against mosquitoes. For example, Ansari et al. (2000) demonstrated not only its repellent activity against the adults of *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus*, but also larvicidal activity against their third-instar larvae. The authors of the articles presented a comparative analysis of the effects of essential oils from mint and other plants (Kalita et al., 2013) and the results of studies on the effectiveness of a nanoemulsion and a nanogel (Mohammadi et al., 2019; Sane-Dehkordi et al., 2022), both of which were developed from this oil. The latter article confirmed its repellent effect on mosquitoes; furthermore, it also exhibited the antibacterial effects against *Escherichia coli* and *Staphylococcus aureus*. Essential oil of *M. piperita* – aside from its anti-mosquito effects – has been noted as a repellent to *Tribolium castaneum*, *Lasioderma serricornis* (Fabricius, 1792) (Coleoptera, Ptinidae), and *Liposcelis bostrychophila* Badonnel, 1931 (Psocodea, Liposcelididae) (Pang et al., 2020), *Musca domestica* Linnaeus, 1758 (Diptera, Muscidae) (Kumar et al., 2012), *Brevicoryne brassicae* (Linnaeus, 1758) (Hemiptera, Aphididae) (Wubie et al., 2014), and *Drosophila melanogaster* Meigen, 1830 (Diptera, Drosophilidae) (McCallum, 2018).

Tea tree oil has exerted antimicrobial (Carson & Riley, 1993; Cox et al., 2021), acaricidal (Walton et al., 2004; Iori et al., 2005), and repellent properties. A number of scientific works explored the repellent effect of *M. alternifolia* on various species of invertebrates, including *Stomoxys calcitrans* (Linnaeus, 1758) (Diptera, Muscidae) (Dillmann et al., 2020), *Aedes aegypti*, *Culex quinquefasciatus* and *Culex annulirostris* Skuse, 1889 (Diptera, Culicidae) (Duarte et al., 2020), *Haematobia irritans* (Linnaeus, 1758) (Diptera, Muscidae) and *Chrysomya megacephala* (Fabricius, 1794) (Diptera, Calliphoridae) (Klauck et al., 2015), *Helicoverpa armigera* (Hübner, [1808]) (Lepidoptera, Noctuidae) (Liao et al., 2017), *Tribolium castaneum* and *Solenopsis invicta* (Edris, 2016), and *Rhipicephalus australis* Fuller, 1899 (Ixodida, Ixodidae) (Yim et al., 2016).

Parsley extract is widely known as an effective compound for managing mosquito resistance in current and future control programs (Ateyim et al., 2022). For example, Intirach et al. (2016, 2018) showed that oil of *P. crispum* and its components can be utilized alone or in combination with other chemicals and control strategies in the integrated management of *Aedes aegypti*, especially in areas with high levels of resistance to pyrethroids and organophosphorus compounds. Seghier et al. (2020) observed this essential oil to exhibit larvicidal and pupicidal properties against *Culex pipiens* Linnaeus, 1758 (Diptera, Culicidae) and *Culiseta longiareolata* Macquart, 1838 (Diptera, Culicidae) in a dose-dependent manner. Junkum et al. (2021) conducted a study that promoted the use of *P. crispum* essential oil and its main components not only as alternative larvicides but also as attractive synergists to enhance the efficacy of existing conventional insecticides. Besides mosquitoes, there are species of invertebrates for which *P. crispum* acts as a repellent or fumigant, for example, storage pests *Trogoderma granarium* Everts, 1898 (Coleoptera, Dermestidae) and *Tribolium castaneum* (Elmadawy & Omar, 2022), *Callosobruchus maculatus*, *Ephesia kuehniella* Zeller, 1879 (Lepidoptera, Pyralidae), *Plodia interpunctella* (Hübner, 1813) (Lepidoptera, Pyralidae) (Maroufpoor et al., 2016), *Dinoderus porcellus* Lesne, 1923 (Coleoptera, Bostrichidae) (Estelle et al., 2021), and phytophagous pest *Trialetrodes vaporariorum* Westwood, 1856 (Hemiptera, Aleyrodidae) (Mahmoodi et al., 2014).

Furthermore, it is documented in the literature that *Allium sativum* exhibited a significant repellent effect on animals (Stjernberg & Berglund, 2000), including invertebrates such as *Hyalomma rufipes* (Nchu et al., 2016), *Myzus persicae* (Sulzer, 1776) (Hemiptera, Aphididae) (Lai et al., 2024), *Calliphora vomitoria* (Bedini et al., 2020b), *Sitophilus oryzae* (Chaubey, 2016), and *Anopheles* sp. (Denloye et al., 2003). However, it had no effect on the behaviour of woodlice in our study. A similar situation was observed with other spices. Nonetheless, the effectiveness of the studied spices is known from various literary sources. For example, curcuma is often used as a repellent in the protection of storage products from pests and blood-sucking species such as *Tribolium castaneum* (Abida et al., 2009), *Aedes albopictus* (Skuse, 1894) (Diptera, Culicidae) (Bhoopong et al.,

2022), *Aedes aegypti* and *Anopheles quadrimaculatus* Say, 1824 (Diptera, Culicidae) (Ali et al., 2015), and other. Ginger is also used as an acaricide (Madreseh-Ghahfarokhi et al., 2019), mosquito repellent (Govindarajan et al., 2016; Madreseh-Ghahfarokhi et al., 2018), and as a means of controlling storage pests (Ukeh et al., 2009). Vanillin is often proposed as an attractant, for example, for fruit flies (Mahadevan et al., 2024), bees (Némésio et al., 2013), noctuides (Wei et al., 2023), and nematodes (Oka, 2021a, 2021b). Nevertheless, this aroma did not change the locomotor behaviour of the woodlice in our study.

Conclusion

Most of the aromatic materials significantly reduced the locomotor activity of *Porcellio laevis* in our study, confirming their potential as bioregulators of invertebrate behaviour. Nutmeg, cinnamon, allspice, coffee, and clove had the most pronounced effects on reducing the locomotor speed of isopods. The attractant effect was demonstrated by the nutmeg, coffee, basil, cucumber, and sage extracts, as well as the orange essential oil. This suggests their potential usefulness in monitoring traps for controlling populations of woodlice. The essential oils of allspice, clove, peppermint, and tea tree, and the extract from parsley had a repellent effect. Thus, they can be recommended for environmentally safe repelling of woodlice. Our results can be used to develop natural means of controlling the number of *P. laevis* without the use of toxic insecticides, contributing to environmentally friendly regulation of populations of these invertebrates.

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