Repellency of Urtica dioica (Urticaceae) and Erigeron anuus (Asteraceae) to Plodia interpunctella (Lepidoptera: Pyralidae) larvae

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Abstract

Plodia interpunctella Hübner 1813 (Lepidoptera: Pyralidae) is a cosmopolitan insect pest that attacks a wide range of stored food commodities. In the last decade, the search for effective plant-based insecticides as alternatives to synthetic agents has become a very important issue. The objective of this study was to test the repellent activity of 1%, 2% and 5% methanolic extracts of two weed plant species, *Urtica dioica* L. (Urticaceae) and *Erigeron annuus* (L) Perss. (Asteraceae) against two maturity groups of *P. interpunctella* larvae - younger (II-III larval stage) and older (IV-V larval stage). Total phenolics, tannins, flavonoids and antioxidative activity were determined for both tested extracts by spectrophotometric analyses. The 2% extract of *U. dioica* had an extremely repellent effect (class V) on the younger group of larvae, while the 5% extract had a strongly repellent effect (class IV) on the older group. Oppositely, the 5% extract of *E. annuus* was strongly repellent (class IV) against the younger, while it was extremely repellent (class V) against the older group of larvae. Both tested weeds' extracts have a high potential to be used as botanical repellents against larvae of *P. interpunctella*.

Introduction

Due to the rapid growth of the human population, the world has an increasing need to raise the quantity and quality of production of basic crops. Stored grain pests destroy all these efforts and reduce both the quantity and, more significantly, the quality of food and feed (Mahmoud et al. 2023). Chemical pesticides are widely used to suppress these insect pests, despite their multiple disadvantages, such as potential toxicity to humans and animals, as well as their negative impact on the environment (Hanif et al. 2022).

Botanical insecticides have shown great efficacy (Isman 2007, 2014) and that is why they are attracting increasing research attention as a promising alternative (Cerda et al. 2017), particularly those already used in ethno-tradition for the same purposes (Jovanović et al. 2007). The main problem with their use is an unexplained mechanism by which they achieve evident biological activity (Isman 2007, 2014; Macías et al. 2007). By using locally available plants in pest management practices, producers could have the opportunity to reduce production costs because the plants often grow wild around farms and can be obtained with minimal effort and cost (Cerda et al. 2017).

Repellency is certainly an important property of many plants. According to Isman (2000), this property is the phenomenon of the self-defense mechanism of plant leaves, which are toxic to most insects, herbivores, annelids, and other destructive animals. To reduce insect attacks, plants have evolved a variety of defenses, while insects have evolved different mechanisms or developed strategies to outplay them. Plant allelochemicals are useful against most vertebrates. A mixture of secondary metabolites can deter insects and herbivores longer than a single compound, such as those found in synthetic insecticides, and makes it more difficult for resistance to develop (Rattan 2010). The secondary metabolites of plants, including terpenes, phenols, alkaloids, lipids, tannins, sugars, etc., protect them from microbial pathogens and invertebrate pests (Gottlieb 1990; Wink and Schimmer 1999).

Stinging nettle, *Urtica dioica* L. (Urticaceae) is a flowering perennial herb, originally native to Europe has become widespread worldwide, and is often considered a weed in agricultural production (Shreejana et al. 2022). *U. dioica* is one of the plants traditionally used in Mexico as an alternative to protect the seeds of mesquite, in the form of an aqueous extract (*Prosopis laevigata* M.C. Johnst, Fabaceae) (Gonzáles-Macedo et al. 2021).

Studies confirmed that all parts of the nettle have antioxidant, antimicrobial, and health-promoting properties (Chrubasik et al. 2007; Shreejana et al. 2022). This ordinary plant with some extraordinary properties (Kregiel et al. 2018) has an incredibly high value, but its multiple benefits are often underestimated, and its potential as a botanical pesticide is poorly studied.

Nettle is rich in bioactive compounds such as polysaccharides, carbohydrates, essential amino acids, fatty acids, vitamins such as A, B and C sterols, chlorophyll, carotenoids, minerals such as iron, potassium, calcium and magnesium, tannins, isolectins and terpenoids (Rutto et al. 2013). It is one of the plants traditionally used in Mexico as an alternative to protect the seeds of mesquite (*Prosopis laevigata* M.C. Johnst, Fabaceae) (Gonzáles-Macedo et al. 2021). The main function of nettle in combination with *Artemisia*, garlic, chili, neem, etc. in the botanical pesticides is to create an inhospitable environment for the pest insects. The needle-like structure and thorns in the leaves, negatively affect the female insects by interfering with the ovipositor, resulting in low infestation (Shreejana et al. 2022). Planted with other plants, the stinging nettle has a defensive role and serves as the main low-infestation plant thanks to its pest resistance characteristics. The reason we chose stinging nettle is its known insecticidal properties as evidenced by its local use to repel or kill pests in the field, but also its main constituents known for their insecticidal activity, such as formic acid and sambunigrin (Sekulović et al. 1996).

Plants of the genus *Erigeron* (family Asteraceae) also have a long tradition of folk medicinal use (Blue 1955; Coon 1963). Insecticidal properties of the flower heads of *E. strigosus* were known to American settlers - they repelled fleas by using the flower heads wrapped in linen (El-Razek 2006 **according to** Hood and Hood (1969)). The annual fleabane *E. annuus* is native to North America but is now distributed worldwide as common in wastelands and roadsides (Hood and Hood 1969).

Plodia interpunctella Hübner 1813 (Lepidoptera: Pyralidae), known as the Indian meal moth, is a cosmopolitan, polyphagous stored food pest **(Mohandas et al. 2007)**. Various synthetic insecticides are most commonly used to control *P. interpunctella* in warehouses, but due to various adverse effects, many have been phased out. Today, there are only a limited number of insecticides that can be used effectively (Mohandass et al. 2007). Half a century ago, resistance of *P. interpunctella* to some synthetic insecticides such as synergized pyrethrins (Zettle et al. 1973) and malathion (Attia 1977) was confirmed. *P. interpunctella* has developed resistance to some organophosphates and several others, which was later confirmed and well documented (Arthur 1996; Fields and White 2002; Arthur and Phillips 2003). Several products, usually contact insecticides, that can be used to control *P. interpunctella* are registered in Serbia. They are based on two organophosphate insecticides: malathion (EC -emulsifiable concentrate and DP -dustable powder) and pirimiphos-methyl (EC), and on deltamethrin as a single pyrethroid used in combination with Piperonyl butoxide (EC) **(Andrić et al. 2014)**. There is a real need to replace synthetic pesticides with harmless to non-target organisms and humans, and therefore environmentally acceptable biopesticides (Hanif et al. 2022).

The objective of this study was to investigate the possibility of using 1, 2 and 5% methanolic extracts of aerial parts of two widely available weeds, stinging nettle *U. dioica* and annual fleabane *E. annuus*, as potential larval repellents to control *P. interpunctella*. Also, total phenolics, flavonoids, tannins content, and antioxidant activity of the methanolic extract of *U. dioica* and *E. annuus* (aerial parts) were determined by spectrophotometric analyses.

Material and methods

Preparation of the extracts

Whole aerial parts of *U. dioica* (collected in May and June 2020), and *E. annuus* (collected in November 2022) from Kragujevac, Serbia were used for preparation of the extracts. U. dioica was collected at the locality Čumić, Kragujevac, while E. annuus was collected at Šumarice, Kragujevac (central Serbia). The identification of the plants was confirmed on the Department of Biology and Ecology, Faculty of Science, Kragujevac, Serbia and voucher specimens deposited in the Herbarium in this Faculty. The plants were dried at room temperature in a windy place, then finely ground and prepared for extraction. Finely ground plant material was poured with methanol and left at room temperature for two days, and then was twice filtered through a fine medical gauze. The obtained extract with methanol was left at room temperature for a few days to slowly dry out, i.e., to allow the methanol to evaporate. Finally, after complete drying (confirmed by multiple weighing), the extract was weighed, transferred to a dark glass bottle and stored in the refrigerator until the experiment. The reason why we chose this more traditional method of making extracts, instead of the usual procedure that involves an Soxhlet evaporator, is because with this simple method farmers could very easily make the extract themselves from the plants that grow like weeds on their property.

Insect material

Plodia interpunctella larvae used in this study were obtained from laboratory populations reared for several years at 22 ± 2°C in clear plastic containers for mass rearing (1.2 L volume) using the standard laboratory diet (SLD) for *P. interpunctella* (Silhacek and Miller 1972). Paired couples of *P. interpunctella* were isolated from the mass rearing containers and each pair was transferred separately in a glass vial. The eggs were collected after two days and transferred into the plastic container with the SLD to obtain the larvae of a specific maturity group needed for the experiment. The larval stage was determined by measuring the larval head capsule width of some randomly selected larvae under the binocular microscope. The first experimental larval maturity group was from the 15-day-old larvae (belonging to the II-III larval stage), while the second group consisted of older (≥ 25 days) larvae (IV-V larval stage).

Repellency bioassay

The repellency of the methanolic extracts of *U. dioica* and *E. annuus* in three concentrations each (1, 2, and 5%) was tested using the "area preference method" on filter paper in Petri dishes. Each concentration, extract type, and larval maturity group was repeated three times, i.e. 36 replicates in total. Water dilutions of the methanolic plant extracts were prepared by dissolving 1, 2, or 5 g of the crude methanolic extracts to 100 mL of distilled water.

Repellency was determined using the area preference method according to Cosimi et al. (2009) and Zhang et al. (2011). Three filter papers Whatman No. 1. (R = 150 mm) were cut into two halves (P = 88.31 cm2), and 1.66 mL of the aqueous solution of the extracts (concentrations of 0.02 mL/cm2) was applied to one half for each concentration of each extract. The control half of the filter paper was treated with distilled water only. Both halves were allowed to dry at room temperature for 24 hours. The treated and control halves of the paper were taped and placed on the bottom of a Petri dish (R = 150 mm). Ten *P. interpunctella* larvae of a particular maturity group were placed in the center of the paper disk. The dishes were closed, wrapped with Parafilm M to prevent larvae from escaping, and placed in the chamber at 26°C in the dark. The number of larvae on the treated and the control half-disks was counted after 1 and 3 hours of exposure. The following formula was used to calculate the repellency index (RI) **(Hassanali 1990; Wekesa 2011)**:

$$RI = [(NC - NT)/(NC + NT)] \text{ x } 100$$

where:

NC – is the number of insects on the control half, and

NT – is the number of insects on the treated half (treatment)

Negative results indicate attractancy, while positive results confirm repellency, and are classified within repellency classes, according to Talukder and Howse (1993**)** (Table 1).

Table 1
Repellency classes by Talukder and Howse (1993)

Class	Repellency index (RI)	Level of repellency
	< 0.01	Attractive
0	0.01–0.1	Neutral
I	0.1–20	Neutral
II	20.1–40	Slightly repellent
III	40.1–60	Repellent
IV	60.1–80	Strongly repellent
V	80.1–100	Extremely repellent

Determination of the content of total phenolic and flavonoid compounds

Total phenolic content was determined using the Folin-Ciocalteu reagent (Wootton-Beard et al. 2011). Gallic acid (Sigma-Aldrich, St. Louis, MO, USA) was used as a standard. The concentration of total phenols was expressed as milligrams of gallic acid equivalents per gram of extract (mg GAE / g).

Total flavonoid concentration was determined using aluminum chloride (Quettier-Deleu et al. 2000). Rutin (Sigma-Aldrich, St. Louis, MO, USA) was used as a standard. The concentration of total flavonoids was expressed as milligrams of rutin equivalents per gram of extract (mg RUE / g).

DPPH radical-scavenging capacity assay

The ability of *U. dioica* and *E. annuus* to scavenge DPPH free radicals was evaluated using the method described by **Takao et al. (1994)**. The tested concentration range of the plant extracts was between 7.80 µg/mL and 500 µg/mL. The absorbance of the reaction mixture was measured in a spectrophotometer at 517 nm. Ascorbic acid was used as a positive control.

The radical scavenging activity was expressed as IC_{50} value, calculated from the nonlinear plot of scavenging activity (%) against the concentration of the samples. The IC_{50} value is the effective concentration at which 50% of DPPH radicals were captured. A lower IC_{50} value indicates a stronger DPPH scavenging ability. Antioxidant activity was expressed as an antioxidant activity index (AAI), which was calculated as follows: AAI = DPPH final concentration (µg/mL) / IC_{50} (µg/mL). An AAI below 0.5 indicates weak antioxidant activity; between 0.5 and 1 moderate activity; between 1 and 2 strong activity, and above 2 indicates very strong antioxidant activity (Scherer and Godoy 2009).

Statistical analysis

The data for the repellency tests were statistically processed using the IBM SPSS Statistics 21 software package (IBM 2012). The data were subjected to a Repeated Measures ANOVA to evaluate the effect of extracts concentration, time of exposure, larval age on larval mortality. One-way Anova was used for the analysis of the influence of one factor if it showed significance in the previous test. Independent Samples Test ($P < 0.05$) was carried out to compare mean RI values. All tests were performed at the level of significance of 95% ($p < 0.05$).

Results

Several studies indicate that plant phenolics are among the most important defenses against insects (Barbehenn et al. 1996; Henn 1997; Morant et al. 2008; Isman 2014). Because of the importance of secondary metabolites in plant defense and defense against insects, results on total phenolics, flavonoids, tannins, and antioxidant activity are presented first.

Total phenolics, tannins, flavonoids content and antioxidant activity

The quantities of total phenolics, tannins, flavonoids and antioxidative activity of *U. dioica and E. annuus* methanolic extracts (aerial parts), determined by spectrophotometric analyses, are presented in Table 1.

Table 1
Total phenolics, flavonoids and tannins content, and antioxidant activity of the methanolic extract of *Urtica dioica* and *Erigeron annuus* (aerial parts)

Plant species	Total phenolics[1]	Total flavonoids[2]	Tannins[3]	Antioxidant activity (DPPH)	
				IC_{50} (μg/mL)[3]	AAI[4]
U. dioica	50.389 ± 1.686	18.28 ± 0.124	0.34 ± 0.043	123.87	0.646
E. annuus	54.50 ± 0.828	19.31 ± 0.121	1.26 ± 0.138	233.58	0.343
[1] mg of gallic acid equivalent (GAE)/g of extract;					
[2] mg of rutin equivalent (RUE)/g of extract;					
[3] IC_{50} – effective concentration at which 50% of DPPH radicals were scavenged;					

[4] Antioxidant activity index (AAI) = final DPPH concentration (μg/ml)/IC_{50} (μg/ml).

Results are expressed as mean ± *SE*.

The results revealed that *E. annuus* exhibited higher values of total phenolics, flavonoids, and total tannins compared to *U. dioica* in the methanol extracts. In contrast, *U. dioica* showed superior antioxidant activity compared to *E. annuus* in terms of DPPH radical scavenging. The antioxidant activity of *U. dioica* methanolic extracts was moderate and *E. annuus* was low, according to the value of Antioxidant activity index (0.646) and IC_{50} value (123.87 μg/mL). The *U. dioica* methanolic extracts tested in our study contained higher concentrations of total phenolics (50.389 ± 1.686 mg g^{-1}) and total flavonoids (18.28 ± 0.124 mg g^{-1}), in comparison to the total phenolics (26.02 mg g^{-1}) and total flavonoids (10.26 mg g^{-1}) determined in the *U. dioica* leaves methanolic extract determined by Karima et al. (2022). These findings suggest that *E. annuus* possesses a higher phenolic profile, while *U. dioica* has stronger antioxidative potential.

The observed differences in the content of phenolic compounds and antioxidant activity between investigated plant species can be attributed to various factors. Higher values of total phenolics, flavonoids, and total tannins in *E. annuus* compared to *U. dioica* might be attributed to its inherent genetics and biosynthetic pathways that can lead to variations in the quantity and quality of phenolic compounds, influencing the overall antioxidant activity (Kumar et al 2023). Furthermore, environmental factors such as climate, soil conditions, and cultivation methods can significantly impact the phenolic content and antioxidant activity of plants. Different growing conditions can alter the expression of genes involved in the synthesis of phenolic compounds, resulting in variations in their levels and subsequent antioxidant activity (Mykhailenko et al. 2020).

On the other hand, *U. dioica* exhibited greater antioxidant activity, indicating the presence of potent bioactive compounds responsible for neutralizing free radicals. Antioxidants help to neutralize free radicals and protect cells from oxidative damage. The greater antioxidant activity of *U. dioica* may be attributed to its specific composition of bioactive compounds, such as phenolics and flavonoids, which possess strong antioxidant properties. The variations in phenolic profiles and antioxidant potential could be attributed to the different environmental conditions and specific metabolic pathways of each plant species (Kumar et al 2023).

Phenolic compounds, such as flavonoids and tannins, are known for their diverse biological activities and have been reported to possess insect-repellent properties Isman (2014). The repellent activity observed in *E. annuus* may be attributed to these phenolic compounds, which act as natural defense mechanisms against herbivores and pests. The connection between the high phenolic content in *E. annuus* and its repellent activity could be explained by the synergistic effects of phenolic compounds (War et al. 2012). These compounds not only act as repellents but also interfere with the feeding and oviposition behavior of insects, leading to reduced pest infestation. The greater antioxidant activity of *U. dioica*, despite its lower phenolic content compared to *E. annuus*, suggests the presence of additional bioactive compounds with potent antioxidant properties. These compounds may contribute to the plant's ability to repel insects by interfering with their sensory receptors or disrupting their biological processes (Divekar et al., 2022).

Secondary metabolites, although not involved in primary metabolism, still play an important ecological role in plant-insect relationships. According to Isman (2014), more than a thousand of these compounds have shown biological activity against insects, at least in laboratory tests. Some of the secondary metabolites have repellent or deterrent effects on feeding or oviposition. They may also cause acute toxicity, developmental disorders, or growth inhibition. It is not uncommon for a secondary plant compound to have both behavioral and physiological effects in one insect species or different effects in different species (Isman 2014).

The presence of specific phenolic compounds, such as flavonoids and tannins, has been linked to repellent activity against pest insect larvae. These compounds can interfere with feeding behavior, disrupt insect sensory receptors, or act as feeding deterrents. The variation in the levels of these phenolic compounds among different plant species may contribute to differences in their repellent activity against larval pests (Isman 2014; Divekar et al. 2022).

The use of plant extracts derived from weeds, medicinal plants, and invasive plant species as insecticides holds significant importance. These extracts can offer an eco-friendly and sustainable alternative to synthetic insecticides, reducing the environmental impact and potential health risks associated with chemical pesticides. Moreover, using plant extracts allows for the utilization of abundant and often underutilized plant resources.

Repellency test

The results of repellency tests of *U. dioica* and *E. annuus* extracts at three tested concentrations (1, 2, and 5%) against two maturity groups of *P. interpunctella* larvae are shown in Table 2.

Table 2

Repellency classes of different concentrations of *Urtica dioica* extract against two maturity groups of *Plodia interpunctella* larvae

P. interpunctella larval stage	Concentration*	RI		Repellency class (1/3 h average)
	(%)	1 h	3 h	
II-III	1	26.67 ± 6.67[a]	33.33 ± 6.67[a]	II
	2	86.67 ± 6.67[a]	93.33 ± 6.67[a]	**V**
	5	33.33 ± 17.11[a]	40.00 ± 10.55[a]	II
IV-V	1	66.67 ± 30.55[a]	86.67 ± 23.09[b]	III
	2	66.67 ± 24.03[a]	80.00 ± 0.00[b]	III
	5	66.67 ± 13.33[a]	86.67 ± 6.67[b]	IV

*Concentration is expressed as grams of plant extract dissolved in 100 ml of distilled water. Values are mean ± standard error of three replicates.

[a]Horizontal mean values of RI after 1 and 3 h having different letters in superscript are statistically different by Independent Samples Test at $P < 0.05$.

The 2% extract of *U. dioica* was extremely repellent (class V) against the younger *P. interpunctella* larvae, while 1 and 5% extracts showed only a slight repellency (class II). As time passes, the repellent effect becomes only slightly stronger. Older *P. interpunctella* larvae (IV-V stage) responded differently to *U. dioica* extract – 1 and 2% extracts were moderately (class III), but 5% extract was strongly repellent (class IV).

Interestingly, many insect larvae, especially moth larvae, feed on the leaves of *U. dioica*. According to some authors, nettle does not appear to have any other form of chemical defense against caterpillars *Aglais io* L. (Lepidoptera: Nymphalidae) and many other insects (Davis 1983). *Aglais io* feeds on *U. dioica* plants with high nutrient quality. Females lay their eggs on young plants, and immediately after hatching, the larvae feed on the young, growing leaves at the top of the plants (Pullin 1986). The larvae of the moth *Callimorpha dominula* L. (Lepidoptera: Erebidae) feed preferentially on stinging nettles (Cook 1961), while the larvae of *Acronicta menyanthidis* Esper and *Naenia typica* L. (Lepidoptera: Noctuidae) are not specialized, but also feed on stinging nettles (Vyšniauskaitė and Tamutis 2012).

However, some studies confirm a possible insecticidal effect of nettle. El-Aswad et al. (2022) showed that tannins isolated from stinging nettle had a strong antifeedant effect against larvae of *Spodoptera litoralis* Boisduval (Lepidoptera: Noctuidae) during the first week of treatment. Jovanović et al. (2007) reported that a 100% and 30% concentrated *Urtica dioica* extract was effective in repelling and reducing F1 progeny in *Acanthoscelides obtectus* Say (Coleoptera: Curculionidae).

Exposure time did not appear to have a statistically significant effect on the repellent activity of the extracts tested, based on a comparison of the mean RI values after 1 and 3 hours for each concentration, using the Independent Samples T Test (Tables 2 and 3). Based on the results of repeated measures ANOVA, 1 and 5% *U. dioica* extract had significantly higher RI in older larvae when mean values were compared between younger and older groups of larvae, after 1 and 3 hours of exposure ($P < 0.05$). These differences were also significant for the *E. annuus* extract when comparing the mean RI values after 3 hours between the different concentrations of the extract ($P < 0.05$) between younger and older *P. interpunctella* larvae (Table 3). Based on these results, older larvae are generally more sensitive, i.e., extracts are more repellent regardless of concentration and exposure time.

Erigeron annuus 1 and 2% extracts were moderately (class III), while the 5% extract was strongly repellent (class IV) against the younger larvae. 1 and 2% extracts were strongly repellent (class IV), while 5% extract was extremely repellent (class V) against the older larvae. Halloran et al. (2013) tested the attractancy of *E. annuus* and showed that it can be an effective trap plant, able to control pest insect *Lygus rubrosignatus* Knight (Hemiptera: Myridae.) and its natural enemy, the wasp *Peristenus relictus*

(Ruthe) (Hymenoptera: Braconidae). The toxicology of *E. annuus* in humans hasn't been studied (Zhang et al. 2020).

Table 3
Repellency classes of different concentrations of *Erigeron annuus* extract against two maturity groups of *Plodia interpunctella* larvae

P. interpunctella larval stage	Concentration* (%)	RI 1 h	RI 3 h	Repellency class (1/3 h average)
II-III	1	53.33 ± 13.33[a]	53.33 ± 17.64[a]	III
	2	43.33 ± 24.04[a]	46.67 ± 26.67[a]	III
	5	60.00 ± 11.54[a]	66.67 ± 24.04[a]	IV
IV-V	1	53.33 ± 13.33[a]	86.67 ± 6.67[b]	IV
	2	60.00 ± 11.55[a]	66.67 ± 24.04[a]	IV
	5	73.33 ± 6.67[a]	93.33 ± 6.67[b]	V

*Concentration is expressed as grams of plant extract dissolved in 100 ml of distilled water.

Values are mean ± standard error of three replicates. [a]Horizontal mean values of RI after 1 and 3 h having different letter in superscript are statistically different by Independent Samples Test at $P < 0.05$.

Based on the comparison of the mean RI values after 1 and 3 hours for each concentration, using the Independent Samples T Test, we conclude that the exposure time had no statistically significant effect on the repellent activity of the tested extracts (Tables 2 and 3). When means after 1 and 3 hours of exposure ($P < 0.05$) were compared between younger and older groups of larvae, based on the results of repeated measures ANOVA, 1% and 5% extracts of *U. dioica* had a significantly higher RI on older larvae. The differences were also significant for the *E. annuus* extract when comparing the mean RI values after 3 hours between the different concentrations of the extract ($P < 0.05$) between younger and older *P. interpunctella* larvae (Table 3). Older larvae are more sensitive, that is, the extracts are more repellent for them than for younger ones, regardless of the concentration of the extracts and the exposure time.

In this age of mass use of synthetic pesticides that seriously harm human and animal health and pollute the environment, the discovery, testing and application of natural products to protect stored foods from infestation by stored insect pests is an excellent alternative. Going back to the human roots, traditional knowledge, and methods of protecting stored foods can certainly have many benefits, both economically and in terms of key health importance. The concept of "pest against pest" could lead to good results. Instead of removing weeds from agricultural land, treating them chemically and suppressing them, they should be further investigated as a resource and weapon in controlling (storage) insect pests and analyzed with the aim of possible application.

The use of plant extracts derived from weeds, medicinal plants, and invasive plant species as insecticides holds significant importance. These extracts can offer an eco-friendly and sustainable alternative to synthetic insecticides, with less environmental impact and potential health risks associated with chemical pesticides. The application of plant extracts enables the inexpensive use of often underutilized, ubiquitous plant resources against pest insects.

Repellency is certainly an important property of many plants. According to Isman (2000), this property is the phenomenon of the self-defense mechanism of plant leaves, which are toxic to most insects, herbivores, annelids, and other destructive animals. It is possible that because of this property, weeds in particular are very common and difficult to control.

Generally, our results confirm previous observations that *U. dioica* and *E. annuus* have a repellent effect against insects, depending on the extract concentrations and maturity of insects.

Conclusion

According to the results presented here, both *U. dioica* and *E. annuus* have a good repellency potential against *P. interpunctella* larvae. *Urtica dioica* can be cleverly used against younger, while *E. annuus* against the older *P. interpunctella* larvae. The repellent activity exhibited by *E. annuus* and *U. dioica* against *P. interpunctella* larvae highlights the potential use of these plant species as natural alternatives to synthetic insecticides. Further studies are required to isolate and identify the specific compounds responsible for the observed repellent activity and their mechanisms of action. Understanding the relationship between the phenolic content, antioxidant activity, and repellency of these plant extracts can aid in the development of eco-friendly and sustainable pest insect repellents. Additionally, investigations into their safety, stability, and effectiveness against other pests are necessary for practical application in agriculture and food storage.

Since *P. interpunctella* does not occur alone in the warehouse, but together with some other pests, both from the order Lepidoptera and Coleoptera, it is necessary for practical application to test the reaction of other insects to the extracts investigated in this study. In addition to evaluating the efficacy, there is a need to study the effect of botanical pesticides on mammals, the impact on the quality of stored food, the duration of protection from insects, etc.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest.

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