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ORIGINAL RESEARCH ARTICLE

Insecticidal and repellent effects of essential oil *Eugenia uniflora* L. (Myrtaceae) on *Sitophilus zeamais* Mots. (Coleoptera: Curculionidae)

Mayara Devide Altoe[1] · Jackeline Dall Agnol Lima[1] · Michele Potrich[3] · Lucas Battisti[2] · Everton Ricardi Lozano[3]

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Abstract

The objective of this work was to evaluate the insecticidal and repellent effects of *Eugenia uniflora* (Myrtaceae) essential oil (EUEO) on *Sitophilus zeamais* (Coleoptera: Curculionidae) and to identify the chemical compounds of this oil. Three experiments were carried out to evaluate the insecticidal effect (immersion of the insect, volatilization and spraying on corn grains) and one for the repellent effect. Different concentrations of EUEO (0; 0.31; 0.62; 1.25; 2.5; 5; 10%) were prepared. Seven plates (replicates) were prepared per treatment, containing 15 adult insects each. For the immersion of the insect and spraying experiment on corn grain, the evaluations were performed at intervals of 1; 6; 12; 24; 48; 72; 96 h. For the volatilization experiment, the evaluation was done at intervals of 12; 24; 48; 72 and 96 h, quantifying the dead insects. In the repellency experiment, the *E. uniflora* oil was evaluated at 2.5% in an arena consisting of five polyethylene containers. The evaluation was performed after 24 h, quantifying the number of insects in each container. In order to identify the chemical compounds of the EUEO, gas chromatography analysis was performed by mass spectrometer. In the immersion experiment, mortality was found at 10% concentration, differing significantly from the control. In the volatilization experiment, there was no significant mortality within and between the application times in any of the treatments. In the spraying experiment on corn grains, it was found that the concentrations 2.5%, 5% and 10% caused the highest mortality rates, respectively, of 85.71%, 100% and 100%, differing from the control. The 2.5% EUEO has a repellent effect for *S. zeamais* adults. Regarding the identification of the essential oil compounds, the major compounds identified were sesquiterpenes of Calamen-10-one and Silfiperferol-6-in-5-one. The EUEO spraying on corn grain has acute insecticidal and repellent effect on *S. zeamais*, and containing sesquiterpenes as major constituents.

Keywords Alternative control · Botanical insecticide · Corn weevil

Introduction

Sitophilus zeamais Motschulsky, 1885 (Coleoptera: Curculionidae), also known as weevil or corn weevil, is considered one of the main pests of stored grains in Brazil, as both larvae and adults cause qualitative and quantitative losses (Brilinger et al. 2020) before, during and after the harvest, in the transport, industrialization and storage of the grains (Tavares and Vendramim 2005). The control of insect pests of stored grains is often carried out with synthetic chemical insecticides, as they are fast acting and easy to apply. However, as disadvantages, these are flammable and can cause explosions; leave residues; cause toxicity to humans; and select populations of resistant insects (Dias et al. 2020).

Natural plant-based products such as extracts and essential oils are potentially viable alternatives that can be used to control *S. zeamais* since, in most cases, they can be safer than synthetic chemical molecules, a point which has aroused the interest of the scientific community. Research on botanical insecticides has increased since 1980, when the proportion of articles published on the topic corresponded to less than 1.43%, compared to 21.38% in 2012 (Isman 2015). Furthermore, the authors emphasize that there is a positive

✉ Everton Ricardi Lozano
evertonloz@gmail.com; evertonlticardi@utfpr.edu.br

[1] Cordination of the Animal Science Course, Biological Control Laboratory (LABCON), Universidade Tecnológica Federal do Paraná, Campus Dois Vizinhos (UTFPR-DV), Estrada para Boa Esperança, Km 4, Dois Vizinhos, Paraná, Brasil

[2] PHD, Francisco Beltrão, Paraná, Brasil

[3] Cordination of the Biological Sciences Course, LABCON, UTFPR-DV, Dois Vizinhos, Paraná, Brasil

trend in the use of botanical products for insect pest control, estimating that botanical insecticides will account for 7% of the bioinsecticide market by 2025.

Among the potential insecticides of plant origin, essential oils, extracted from certain plants, have received special attention. Essential oils can cause repellency or have an insecticidal effect on pests, which can cause reduced growth and fecundity, cuticle disruption, inhibition of motility and respiration, deterrence and effect on biochemical cycles (Copping and Menn 2000; Enan 2001; Isman 2000).

Some essential oils have shown potential for the control of *S. zeamais*, such as the essential oil of *Elletaria cardamomum* (L.) Maton. (Zingiberaceae) that showed toxicity for adults (Huang et al. 2000); the essential oils of *Piper aduncum* L. and *P. hispidinervum* C.DC. (Piperaceae) with insecticidal effect varying according to concentration and exposure method (Fazolin et al. 2007); the essential oil of *Tanaecium nocturnum* (Barb. Rodr.) Bur. & K. Shum (Bignoneaceae) with toxicity and slight deterrent effect (Fazolin et al. 2007); essential oil of *Tagetes patula* L. (Asteraceae) with insecticidal and repellent effect (Restello et al. 2009) and the insecticidal effect of the essential oil of *Salvia officinalis* L. (Lamiaceae) (Mouna et al. 2021).

The pitangueira, *Eugenia uniflora* L. (Myrtaceae), native to Brazil and found in all regions, is one of the plant species that has been studied in terms of its diverse potential. It produces oil in its leaves, flowers and fruits, and the main chemical component found in essential oils is sesquiterpenes (Sobeh et al. 2016), which have a phagoinhibitory effect, affect development, reduce pupal weight, and can lead to death of the insect (Picman 1986). Several studies have been demonstrated the insecticidal potential of plants from Myrtaceae family on several insect pests (Ebadollahi 2013). However, there are few studies investigating the effects of *E. uniflora* on insect pests. Eight essential oils, obtained from different plants, were evaluated on *S. zeamais*, and the essential oil of *E. uniflora*, applied on corn grains, stood out, causing 100% mortality of the insects (Coitinho et al. 2010), as well as being the second most toxic, when applied by contact and ingestion (Coitinho et al. 2011). In a recent study, the essential oil of *E. uniflora* proved to be efficient for the control of *Thaumastocoris peregrinus* Carpintero and Dellapé 2006 (Hemiptera: Thaumastocoridae) (Stenger et al. 2021).

In this sense, considering the importance of *S. zeamais* in the processing and storage of stored grains, the potential availability of *E. uniflora*, as well as the need to develop new control strategies that are toxicologically safer and environmentally correct in relation to synthetic chemicals, the present work aimed to evaluate the insecticidal and repellent effect of *E. uniflora* essential oil on *S. zeamais* and to identify its chemical compounds.

Materials and methods

The experiments were carried out at the Biological Control Laboratory (LABCON) of the Federal Technological University of Paraná, Campus Dois Vizinhos (UTFPR-DV).

Rearing *Sitophilus zeamais*

The adult insects used in the experiment came from a rearing unit in the laboratory, in an acclimatized environment with temperature of 25 ± 5 °C, humidity of 60 ± 10% and photoperiod of 12 h. For rearing, adults of *S. zeamais* were obtained from infested corn grains and were placed in glass containers with a volume capacity of three litres, together with organic corn grains, the containers being closed with voile type fabric to allow aeration. After 25–30 days, the period for egg laying and larval development, the adults were removed from the corn grains and placed in another container with a new substrate for new laying. The container containing the corn with the larvae was kept under the same conditions already described, for a period of seven days, until the emergence of the adults. This procedure was carried out over continuous generations for conducting the experiments, according to the adapted methodology of Procópio et al. (2003) and Restello et al. (2009).

Obtaining *Eugenia uniflora* essential oil

The essential oil of *E. uniflora* leaves, obtained by steam distillation, was supplied by the company Garden City - São Paulo.

Effect of *Eugenia uniflora* essential oil on *Sitophilus zeamais*

The corn used for all the experiments was left in a freezer for three days, at a temperature of around −2 °C, to eliminate any other type of insect that could possibly occur and all glassware used in the experiments was sterilized. The adult insects used in all experiments were from the same generation, not sexed, and with age of up to 60 days. To evaluate the possible effects of the essential oil, four experiments were carried out, described below.

Insecticidal effect: direct contact by immersion of the insect and spraying on corn grains and indirect contact by volatilization

The possible insecticidal effect was evaluated by direct and indirect contact. By direct contact, the experiment was carried out in two ways: by immersion of the insect in different concentrations of essential oil and by spraying different concentrations of essential oil on the corn grains. Indirect contact was evaluated by volatilization. In all experiments, the *E. uniflora* essential oil was evaluated at concentrations of 0; 0.31; 0.62; 1.25; 2.5; 5; 10% (treatments), diluted in distilled water and Tween 80® (0.01%). The Petri dishes (Ø 150 mm) used (experimental units) were closed and wrapped with plastic film so that the insects could not escape and were placed in an acclimatized chamber at a temperature of 27 ± 2 °C, relative humidity of 60 ± 10% and photoperiod of 12 h. The experimental design was completely randomized, with seven replications per treatment.

In the experiment of direct contact by immersion of the insects in the concentrations, groups of 15 adult insects of *S. zeamais* were immersed for 10 s in a plastic container containing one mL of the different treatments. After immersion, the insects were placed in Petri dishes, containing 15 g of corn grain in each dish. The evaluations were carried out after 1; 6; 12; 24; 48; 72; 96 h, quantifying the number of dead individuals.

For the direct contact experiment by spraying the essential oil on the corn grain, portions of 15 g of corn grain were placed in Petri dishes (150 mm Ø) and one mL of the treatments was sprayed with the aid of an airbrush coupled to a Fanen® vacuum pump, calibrated at 1.2 kgf/cm^2. Then, 15 adults of *S. zeamais* were placed on each plate. The evaluations were carried out after 1; 6; 12; 24; 48; 72; 96 h, quantifying the number of dead individuals.

For the experiment of indirect contact by volatilization, filter paper discs of the same diameter as the plate, containing one mL of the different treatments, were placed at the bottom of each Petri dish (Ø100 mm). On these paper discs were placed glass beads (nº 4) and on these, another disc of filter paper (100 mm Ø), without treatment and on this, 5 g of corn grains, according to the adapted methodology of (Restello et al. 2009). Then, 15 adult *S. zeamais* insects were placed onto the second filter paper. The evaluations were carried out at 12, 24, 48, 72 and 96 h, quantifying the number of dead individuals.

Repelling effect: free-choice roll

To evaluate the possible repellent effect, the free choice test was used. For this purpose, a concentration of 2.5% of *E. uniflora* oil, selected from the results of indirect contact experiments, was used. Seven arenas were made, consisting of five acrylic containers (5.0 cm Ø and 6.5 cm high) interconnected by transparent tubes (10 cm). Two of the external containers received 5 g of corn sprayed with 0.5 mL of distilled water (control) and two received 5 g of corn sprayed with 2.5% essential oil (treatment). The spraying procedures were the same as described for the contact experiment by spraying the essential oil on the grain. Thus 30 adult insects were released into the container at the centre. All containers were closed with a lid and sealed with plastic film to prevent insects from escaping. The arenas were placed in an acclimatized environment at a temperature of 25 ± 5 °C, humidity of 60 ± 10% and a photoperiod of 12 h. The evaluation was performed after 24 h, quantifying the number of insects in each container, according to the methodology adapted from (Procópio et al. 2003).

The Preference Index (P.I.) was also calculated, in which: P.I. = (% of insects on the test plant - % of insects on the control) /(% of insects on the test plant + % of insects on the control), where: P.I.: -1.00 to -0.10, plant repellent test; P.I.: -0.10 to + 0.10, neutral test plant; P.I.: +0.10 to + 1.00, attractive test plant.

Analysis of *E. uniflora* essential oil by gas chromatography in a mass spectrometer (GC-MS)

The chromatographic analysis was performed by the company Garden City – São Paulo, using automatic injection (TripPlus As, Thermo) in a gas chromatograph (Focus GC, Thermo) coupled to an ion trap mass spectrometer (Polaris Q, Thermo). The sample was injected with a 1:50 flow division (Split) (1μL) and separated through a DB-5 chromatographic column (30 m x 0.025 mm, Agilent). Separation of compounds was performed at 230 °C, transfer line 250 °C, with constant flow and vacuum compensation. Oven temperature programming: 40ºC, 6 min isotherm, heating to 300 ºC at a rate of 3 °C.min^{-1}, with a final isotherm of 5 min. The mass spectrometer was operated in positive electron impact ionization mode at 70 eV, with ion source temperature at 200 °C.

Statistical analysis

For all insecticide experiments, data were analyzed for normality distribution, using the Shapiro-Wilk test. As all data were not normal, the non-parametric Kruskal-Wallis test was used. The repellency experiment was submitted to analysis of variance (F test), and the means were compared by Tukey's test at 5% significance ($p < 0.05$). In all experiments, the analyses were carried out with the aid of the statistical program Assistet 7.7 (Silva 2014).

Results

Insecticidal effect of *Eugenia uniflora* essential oil on *Sitophilus zeamais*: direct contact by immersion and spraying and indirect contact by volatilization

In the immersion experiment, it was found that only *E. uniflora* at 10% caused significant accumulated mortality

Table 1 Mean percentage of mortality (± PE) of adults of *S. zeamais* caused after immersion in different concentrations of *E. uniflora* essential oil, over 96 h

% mortality over time					
Treatment					
	0–24 h	**48 h**	**72–96 h**	**p**	**Accumulated**
0%	0.00 ± 0.00bA	0.00 ± 0.00aA	0.00 ± 0.00aA	> 0.05	0.00 ± 0.00b
0.31%	0.00 ± 0.00bA	0.00 ± 0.00aA	0.00 ± 0.00aA	> 0.05	0.00 ± 0.00b
0.62%	0.00 ± 0.00bA	0.00 ± 0.00aA	0.95 ± 0.80aA	> 0.05	0.95 ± 0.80b
1.25%	0.00 ± 0.00bA	0.00 ± 0.00aA	0.00 ± 0.00aA	> 0.05	0.00 ± 0.00b
2.5%	0.00 ± 0.00bA	0.00 ± 0.00aA	0.00 ± 0.00aA	> 0.05	0.00 ± 0.00b
5%	21.90 ± 6.63abA	0.00 ± 0.00aB	0.00 ± 0.00aB	< 0.05	21.90 ± 6.63ab
10%	51.43 ± 4.34aA	0.00 ± 0.00aB	2.86 ± 1.66aB	< 0.05	54.29 ± 3.53a
p	< 0.05	> 0.05	> 0.05		< 0.05

Means (± EP) followed by the same lowercase letter in the column and uppercase in the row, do not differ significantly from each other by the Kruskal-Wallis test ($p < 0.05$). Caption: Treatment = different concentrations of *E. uniflora* essential oil

(54.29%) to *S. zeamais*, differing from the control. The same is observed in the analysis of mortality within the times, and only in the time of 0–24 h, in the concentration at 10%, there was significant mortality (51.43%) in relation to the control. Likewise, in the analysis between times, it was found that only in the time of 0–24 h, concentrations of 5% and 10% caused mortality of *S. zeamais* (21.90% and 51.43%, respectively), differing significantly from the other times. For the other treatments, mortality within and between times did not differ significantly from the control (Table 1).

In the spraying experiment on corn grains it was found that at concentrations of 2.5%, 5% and 10% of *E. uniflora*, the accumulated mortality of *S. zeamais* was higher, respectively, 85.71%, 100% and 100%, differing from the control and the treatment in the concentration of 0.31%. In the analysis within and between times, it is observed that the highest percentages of mortality of *S. zeamais* occurred in the time of 0–24 h, proportionally higher, according to the concentration. In this time interval, the concentrations of *E. uniflora* at 2.5%, 5% and 10% caused mortality of *S. zeamais*, which varied from 66.67 to 100.00%, differing significantly from the control. In the analysis between times, it was found that at concentrations of 0.62%, 1.25%, 5% and 10% the highest percentages of mortality of *S. zeamais* occurred in the time of 0–24 h, differing significantly from the other times (Table 2).

In the indirect contact by volatilization experiment, both in the evaluations within and in the evaluations between the times, there was no significant difference in the mortality of *S. zeamais* between treatments (Table 3).

Repelling effect: free-choice roll

It was found that a concentration of 2.5% of *E. uniflora* essential oil caused repellency for adults of *S. zeamais*, differing significantly from the control (Fig. 1), with a Preference Index (P.I.) of -0.48, demonstrating the repellent effect of *E. uniflora*.

Table 2 Mean percentage of mortality (± PE) of adults of *S. zeamais* in corn grains sprayed with different concentrations of *E. uniflora* essential oil, over 96 h

% mortality over time					
Treatment					
	0–24 h	**48 h**	**72–96 h**	**p**	**Accumulated**
0%	0.00 ± 0.00dA	0.00 ± 0.00aA	0.00 ± 0.00bA	> 0.05	0.00 ± 0.00b
0.31%	7.62 ± 4.78cdA	0.00 ± 0.00aA	0.00 ± 0.00bA	> 0.05	7.62 ± 4.78b
0.62%	20.00 ± 4.04bcdA	0.00 ± 0.00aB	0.00 ± 0.00bB	< 0.05	20.00 ± 4.04ab
1.25%	25.71 ± 3.32abcdA	0.00 ± 0.00aB	4.76 ± 2.01abB	< 0.05	30.48 ± 4.19ab
2.5%	66.67 ± 7.20abcA	2.85 ± 1.13aB	17.78 ± 3.44aAB	< 0.05	85.71 ± 5.76a
5%	94.29 ± 1.90abA	3.81 ± 1.13aB	1.90 ± 1.03bB	< 0.05	100.00 ± 0.00a
10%	100.00 ± 0.00aA	0.00 ± 0.00aB	0.00 ± 0.00bB	< 0.05	100.00 ± 0.00a
P	< 0.05	> 0.05	< 0.05		< 0.05

Means (± EP) followed by the same lowercase letter in the column and uppercase in the row, do not differ significantly from each other by the Kruskal-Wallis test ($p < 0.05$). Caption: Treatment = different concentrations of *E. uniflora* essential oil

Table 3 Mean percentage of mortality (±PE) of adults of *S. zeamais* subjected to volatilization of different concentrations of essential oil of *E. uniflora*, over 96 h

% mortality over time					
Treatment					
	12–24 h	**48 h**	**72–96 h**	**p**	**Accumulated**
0%	0.00 ± 0.00aA	0.95 ± 0.80 aA	0.95 ± 0.80 aA	> 0.05	1.90 ± 1.03a
0.31%	1.90 ± 1.03 aA	0.00 ± 0.00 aA	0.00 ± 0.00 aA	> 0.05	1.90 ± 1.03a
0.62%	1.90 ± 1.59 aA	0.95 ± 0.80 aA	1.90 ± 1.03 aA	> 0.05	4.76 ± 3.15a
1.25%	1.90 ± 1.03 aA	0.00 ± 0.00 aA	0.95 ± 0.80 aA	> 0.05	2.86 ± 1.66a
2.5%	0.95 ± 0.80 aA	0.95 ± 0.80 aA	2.86 ± 1.66 aA	> 0.05	4.76 ± 2.01a
5%	0.00 ± 0.00 aA	0.95 ± 0.80 aA	0.00 ± 0.00 aA	> 0.05	0.95 ± 0.80a
10%	1.90 ± 1.03 aA	0.95 ± 0.80 aA	1.90 ± 1.03 aA	> 0.05	4.76 ± 2.01a
P	> 0.05	> 0.05	> 0.05		> 0.05

Means (±PE) followed by the same lowercase letter in the column and uppercase in the row, do not differ significantly from each other by the Kruskal-Wallis test ($p < 0.05$). Caption: Treatment = different concentrations of *E. uniflora* essential oil

Analysis of essential oil by gas chromatography in a mass spectrometer (GC)

Several compounds were identified in *E. uniflora* essential oil, Calamen-10-one (20.20%), Silfiperferol-6-in-5-one (10.06%) and Germacrone (6.61%) being the most abundant (Table 4).

Discussion

It is important to point out that essential oils from plants of Myrtaceae family have insecticidal effect for several insect pests, including stored grain pests (Ebadollahi 2013). However, studies with the essential oil of *E. uniflora* are scarcer. The insecticidal potential of *E. uniflora* essential oil on *S. zeamais* had already been observed in similar studies in which *E. uniflora* essential oil, applied to corn grains, stood out, causing 100% mortality (Coitinho et al. 2010) and was the second lowest LC_{50} (11.6 µL/40 g corn) among the eight oils when evaluated by contact and ingestion (Coitinho et al. 2011). The insecticidal effect of *E. uniflora* oil was also observed for other insects pests such as on leafcutter ants *Atta laevigata* F. Smith (Hymenoptera: Formicidae) (Jung et al. 2013) and for eggs, third instar nymphs and adults of *Thaumastocoris peregrinus* Carpintero and Dellapé 2006 (Hemiptera: Thaumastocoridae) (Stenger et al. 2021).

Regarding the repellent effect, there are no studies with essential oil from *E. uniflora* on *S. zeamais*. However, extracts from other plants of the Myrtaceae family also showed a repellent effect against *S. zeamais*, such as *E. citriodora* powder (Procópio et al. 2003) and essential oils of *E. globulus* and *E. citriodora*, with respectively 92.2%

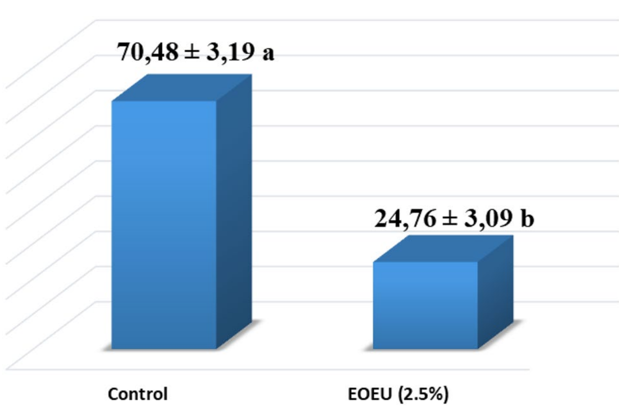

Fig. 1 Percentage of adults of *S. zeamais* (±SE) in the control and *E. uniflora* essential oil treatment, at 2.5%, after 24 h

Table 4 *Eugenia uniflora* essential oil composition according to gas chromatography - mass spectrometer (GC-MS)

Compound	Relative %
calamen-10-ene	20.21
silfiperferol-6-em-5-one	10.06
germacrone	6.61
germacrene B	6.24
curzerene	5.79
s-amorphene	5.46
E-caryophyllene	5.18
a-cubene	3.05
a-gurjunene	2.43
b-elemene	2.16
macrocarpene	1.92
valencene	1.73
amorpha-4,7 (11)-diene	1.67
g-gurjunene	1.66
trans-calamenene	1.47
E-b-cymene	1.22
unidentified	1.44
others	˂ 20

and 71.1% of repellency (Coitinho et al. 2011), which shows the potential of this botanical family as an insect repellent.

In addition to species from the Myrtaceae family, species belonging to other families have shown potential insecticidal effects on *S. zeamais* and other stored grain insect species. In a study with a methodology similar to the one used in this work, the essential oil of marigold *Tagetes patula* L. (Asteraceae) repelled *S. zeamais* (98%), with P.I.-96, proving the repellent effect of this essential oil (Restello et al. 2009). In a study on the repellent effect of different concentrations of essential oils to *Zabrotes subfasciatus* (Coleoptera: Bruchidae), the following essential oils showed a repellency index proportional to the volume of oil of ranging from 62.0 to 74.6% for laurel oil *Laurus nobilis* (Lauraceae), from 63.5 to 96.2% for cinnamon oil *Cinnamomum verum* (Lauraceae) and from 29 0.6–89.4% for neem oil– *Azadirachta indica* (Oliveira and Vendramim 1999). Likewise, the carqueja essential oil, *Baccharis articulata* (Asteraceae), at different volumes and times, caused repellency to *Acanthoscelides obtectus* (Coleoptera: Curculionidae) (Campos et al. 2014).

Regarding the composition of *E. uniflora* essential oil, Brun and Mossi (2010) found 15 compounds, namely: Ocimene, b-Elemene, b-caryophyllene, Selina- 1, 3,7(11)-Trien-8-one, Atractylone, Elemene, Transcaryophyllene, Oxidoseline-1,3,7(11)-trien-8-one, Curzerene, Germacrene B, Spathulenol, Germacrone, Bicyclogermacrene, Furanedione and Cadinene. This variation in chemical composition can occur according to the form of extraction (Brun and Mossi 2010; Cassel and Vargas 2006), with the genetic variability of the plants, the age of the leaves, the environment and the season of the year in which they are collected (Brun and Mossi 2010; Cipriano et al. 2021).

The potential of *E. uniflora* essential oil may be related to the amount of compounds it contains. The action of essential oils against some pests is neurotoxic, with evidence of interference with neuromodular octopamine and/or GABAergic chloride and calcium channels. Octopamine has the function of regulating the heartbeat, metabolism, movements and behaviour of insects, as it acts as a neurotransmitter, neuromodulator and neurohormone (Hikal et al. 2017 Regnault-Roger et al. 2012).

The major compounds in *E. uniflora* essential oil are terpenes, mainly sesquiterpenes, which have a phagoinhibitory effect, affect development, reduce pupal weight, and can lead to insect death (Picman 1986). Still in the terpene group, there are compounds such as 1,2-epoxy-pulegone, which inhibits acetylcholinesterase in insects, rhodojaponine III diterpenes, which have a phagoinhibitory effect, and diterpenes from the labdane group, which are larval growth inhibitors (Cipriano et al. 2021; Hikal et al. 2017; Regnault-Roger et al. 2012).

The insecticidal effect results verified in this work varied according to the methodology (insect immersion, spraying on the corn grain and volatilization), and the insect immersion experiment and spraying on the grain showed significant results, as well as the repellency experiment. When it comes to insecticidal and repellent effects, in a situation of pest control management, when applying the oil to corn grains, it can be verified that these effects are complementary, as it will have both an acute insecticidal effect and a repellency effect on these pests of grains. It is still important to highlight that, in general, the highest percentages of mortality occurred in the first hours of evaluation, which shows that in addition to the insecticidal potential presented by *E. uniflora* oil, its action time can be an important factor in pest control.

In general, considering the results obtained in this study, they indicate that the essential oil of *E. uniflora* can be a potentially viable alternative for the control of *S. zeamais*. However, complementary studies such as the insecticidal effect of the oil on *S. zeamais* larvae, the association of *E. uniflora* oil with other oils that have an insecticidal effect in order to potentiate their insecticidal and/or repellent effect, and studies concerning the residual effect of the essential oil on the grains in view of its volatilization, are fundamental for advancing in the use of this possible technology.

Conclusion

The essential oil of *E. uniflora* had an insecticidal effect on *S. zeamais* with more satisfactory results when applied by spraying on the corn grains. At 2.5%, *E. uniflora* essential oil is repellent to adults of *S. zeamais*. In its composition, sesquiterpenes were the majority, with greater abundance of Calamen-10-one and Silfiperferol-6-in-5-one.

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Author contributions Mayara Devide Altoe: Methodology; Formal analysis; Investigation; Writing - Original Draft. Jackeline Dall Agnol De Lima: Formal analysis; Investigation. Michele Potrich: Formal analysis; Resources; Writing - Review & Editing. Lucas Battisti: Formal analysis; Resources; Writing - Review & Editing. Everton Ricardi Lozano: Conceptualization; Methodology; Formal analysis; Resources; Writing - Review & Editing; Supervision and Project administration.

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Data Availability The data that has been used is confidential.

Declarations

Ethics approval and consent to participate Not applicable.

Competing interests All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

References

Brilinger D, Wille CL, Machado da Rosa J, Franco CR, Carissimi Boff MI (2020) Susceptibility of brazilian maize landraces to the attack of *Sitophilus zeamais* (Coleoptera: Curculionidae). J Stored Prod Res 88. https://doi.org/10.1016/j.jspr.2020.101677

Brun GR, Moss AJ (2010) Chemical characterization and antimicrobial activity of the volatile oil of Pitanga (*Eugenia Uniflora* L.). Perspect Erechim 34:135–142

Campos ACT, Radunz LL, Radünz AL, Mossi AJ, Dionello RG, Ecker SL (2014) Insecticide and repellent activity of the essential oil from carqueja doce on bean weevil. Rev Bras Eng Agric e Ambient 18:861–865. https://doi.org/10.1590/1807-1929/agriambi.v18n08p861-865

Cassel E, Vargas RMF (2006) Experiments and modeling of the *Cymbopogon winterianus* essential oil extraction by steam distillation article. Chem Soc 50:126–129

Cipriano RR, Maia BHLNS, Deschamps C (2021) Chemical variability of essential oils of *Eugenia uniflora* L. genotypes and their antioxidant activity. A acad. https://doi.org/10.1590/0001-3765202120181299. Bras Cienc 93

Coitinho BC, Leandro R, de Oliveira josé V, Guedes M, Gondim Junior C, Câmara CAG (2010) Persistência de óleos essenciais em milho armazenado, submetido à infestação de gorgulho do milho. Ciência Rural 40:1492–1496. https://doi.org/10.1590/S0103-84782010005000109

Coitinho BC, Leandro R, de Oliveira josé V, Guedes M, Gondim Junior C, Câmara CAG (2011) Toxicidade por fumigação, contato e ingestão de óleos essenciais para *Sitophilus zeamais* Motschulsky, 1885 (Coleoptera: Curculionidae). Ciêc Agrotc 35:172–178. https://doi.org/10.1590/S1413-70542011000100022

Copping LG, Menn JJ (2000) Review biopesticides: a review of their action, applications and efficacy †. Pest Manag Sci 56:651–676. https://doi.org/10.1002/1526-4998(200008)56:8

Dias TFV, Arcanjo LL, Costa GL, Souza CS, Lima CAR (2020) Controle de pragas e tratamento de grãos armazenados para uso em rações para animais. Res So Dev 9:1–16. https://doi.org/10.33448/rsd-v9i9.6964

Ebadollahi A (2013) Essential oils isolated from Myrtaceae Family as Natural Insecticides. Ann Rev & Res in Biology 3:148–175

Enan E (2001) Insecticidal activity of essential oils: octopaminergic sites of action. Comp Biochem Physiol Part C 130:325–337. https://doi.org/10.1016/S1532-0456(01)00255-1

Fazolin M, Estrela JLV, Catani V, Lima MS (2007) Atividade inseticida do óleo essencial de *Tanaecium nocturnum* (Barb. Rodr.) Bur. & K. Shum (Bignoneaceae) sobre *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae). Acta Amaz 37:599–603. https://doi.org/10.1590/S0044-59672007000400015s

Hikal WM, Baeshen RS, Said-Al Ahl HAH (2017) Botanical insecticide as simple extractives for pest control. Cogent Biol 3:1–16. https://doi.org/10.1080/23312025.2017.1404274

Huang Y, Lam SL, Ho SH (2000) Bioactivities of essential oil from *Elletaria cardamomum* (L.) Maton. To *Sitophilus zeamais* Motschulsky and *Tribolium castaneum* (Herbst). J Stored Prod Res 36:107–117. https://doi.org/10.1016/S0022-474X(99)00040-5

Isman MB (2015) A renaissance for botanical insecticides? Pest Manag Sci 71:1587–1590. https://doi.org/10.1002/ps.4088

Isman MB (2000) Plant essential oils for pest and disease management. Crop Prot 19:603–608. https://doi.org/10.1016/S0261-2194(00)00079-X

Jung PH, Silveira AC, Nieri EM, Potrich M, Silva ERL, Refatti M (2013) Atividade inseticida de *Eugenia uniflora* L. e *Melia azedarach* L. sobre *Atta laevigata* S. Floresta e Ambient 20:191–196. https://doi.org/10.4322/floram.2013.015

Mouna M, Khadra B, Assia B, Salim L (2021) Insecticidal effect of two aqueous extracts from the leaves of *Salvia officinalis* and *Eucalyptus camaldulensis* against *Aphis fabae*. J Entomol Res 45:268–279. https://doi.org/10.5958/0974-4576.2021.00043.8

Oliveira JV, Vendramim JD (1999) Repelência de óleos essenciais e pós vegetais sobre adultos de *Zabrotes subfasciatus* (Boh.) (Coleoptera: Bruchidae) em sementes de feijoeiro. An. da Soc. Entomológica do Bras 28:549–555. https://doi.org/10.1590/s0301-80591999000300026

Picman AK (1986) Biological activities of sesquiterpene lactones. Biochem Syst Ecol 14:255–281. https://doi.org/10.1016/0305-1978(86)90101-8

Procópio SO, jair Vendramim J, Ivo J, Júnior R, Barbosa J, Santos D (2003) Bioatividade de diversos pós de origem vegetal em relação a *Sitophilus zeamais* Mots. (Coleoptera: Crculionidae) bioactivity of powders from some plants on *Sitophilus zeamais* Mots. (Coleoptera: Curculionidae). Ciênc Agrotec 27:1231–1236. https://doi.org/10.1590/S1413-70542003000600004

Regnault-Roger C, Vincent C, Arnason JT (2012) Essential oils in insect control: low-risk products in a high-stakes world. Annu Rev Entomol 57:405–424. https://doi.org/10.1146/annurev-ento-120710-100554

Restello RM, Menegatt C, Mossi AJ (2009) Efeito do óleo essencial de *Tagetes patula* L. (Asteraceae) sobre S*itophilus zeamais* Motschulsky (Coleoptera, Curculionidae). Rev Bras Entomol 53:304–307. https://doi.org/10.1590/S0085-56262009000200015

Sobeh M, Braun MS, Krstin S, Youssef FS, Ashour ML, Wink M (2016) Chemical profiling of the essential oils of *Syzygium aqueum, Syzygium samarangense* and *Eugenia uniflora* and their discrimination using chemometric analysis. Chem Biodivers 13:1537–1550. https://doi.org/10.1002/cbdv.201600089

Stenger LD, Abati R, Pawlak IG, Varpechoski GO, De Souza Vismara E, Barbosa LR, Wagner Júnior A, Lozano ER, Potrich M (2021) Toxicity of essential oil of *Eugenia uniflora* (L.) to *Thaumastocoris peregrinus* (Hemiptera: Thaumastocoridae) and selectivity to the parasitoid *Cleruchoides noackae* (Lin & Hubert) (Hymenoptera: Mymaridae). https://doi.org/10.1016/j.cropro.2021.105693. Crop Prot 147

Silva F (2014) Assistat 7.7. Software Estatístico. A.S. Campina Grande, Paraíba

Tavares MAGC, Vendramim JD (2005) Bioatividade da erva-de-santamaria, *Chenopodium ambrosioides* L., Sobre *Sitophilus zeamais* mots. (Coleoptera: Curculionidae). Neotrop Entomol 34:319–323. https://doi.org/10.1590/S1519-566X2005000200021