Frontiers in Agronomy

TYPE Original Research
PUBLISHED 10 September 2025
DOI 10.3389/fagro.2025.1648839

Check for updates

OPEN ACCESS

EDITED BY
Cesar Rodriguez-Saona,
Rutgers, The State University of New Jersey, United States

REVIEWED BY
Yahel Ben-Zvi,
Rutgers, The State University of New Jersey, United States
Chase Stratton,
Delaware State University, United States

*CORRESPONDENCE
Carlos Granados-Echegoyen
cgranadose@ipn.mx
Baldomero Hortencio Zárate-Nicolás
bzaraten@ipn.mx

RECEIVED 17 June 2025
ACCEPTED 20 August 2025
PUBLISHED 10 September 2025

CITATION
Gómez-Sosa L, Pérez-Pacheco R, Zárate-Nicolás BH, Ortiz-Hernández YD, Vásquez-López A, Aquino-Bolaños T, Quiroz-González B, Martinez-Tomas SH, Arroyo-Balán F, Fonseca-Muñoz A and Granados-Echegoyen C (2025) *Tridax coronopifolia* var. *alboradiata* (Asteraceae) essential oil: chemical characterization and repellent potential against *Sitophilus zeamais* (Coleoptera: Curculionidae). *Front. Agron.* 7:1648839. doi: 10.3389/fagro.2025.1648839

Tridax coronopifolia var. *alboradiata* (Asteraceae) essential oil: chemical characterization and repellent potential against *Sitophilus zeamais* (Coleoptera: Curculionidae)

Lilibeth Gómez-Sosa[1], Rafael Pérez-Pacheco[1], Baldomero Hortencio Zárate-Nicolás[1]*, Yolanda Donají Ortiz-Hernández[1], Alfonso Vásquez-López[1], Teodulfo Aquino-Bolaños[1], Beatriz Quiroz-González[1], Sabino H. Martinez-Tomas[1], Fabián Arroyo-Balán[2], Alicia Fonseca-Muñoz[3] and Carlos Granados-Echegoyen[4]*

[1]Instituto Politécnico Nacional, Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional (CIIDIR), Unidad Oaxaca, Santa Cruz Xoxocotlan, Oaxaca, Mexico, [2]The Secretariat of Science, Humanities, Technology, and Innovation (SECIHTI), The Center for Studies in Sustainable Development and Wildlife Management (CEDESU), Universidad Autónoma de Campeche, San Francisco de Campeche, Campeche, Mexico, [3]Facultad de Sistemas Biológicos e Innovación Tecnológica, Universidad Autónoma Benito Juárez de Oaxaca, Oaxaca, Mexico, [4]The Secretariat of Science, Humanities, Technology, and Innovation (SECIHTI), Instituto Politécnico Nacional, Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional (CIIDIR), Unidad Oaxaca, Santa Cruz Xoxocotlan Oaxaca, Mexico

Currently, on a global level, there are major difficulties in pest control during the storage of grains and cereals. The most widely used method is the use of synthetic insecticides, a practice that pollutes the environment and causes health problems for consumers. As a result of this problem, this study evaluated the repellent effect of essential oil from *Tridax coronopifolia* var. *alboradiata* against *Sitophilus zeamais*. The oil was extracted via microwave-assisted hydrodistillation and characterized using gas chromatography. Repellency bioassays were conducted at concentrations of 50, 100, 200, 400, 600, and 800 ppm, with both positive and negative controls. The essential oil exhibited significant repellent activity against *S. zeamais*. At 800 ppm, the selection index was 0.27, indicating high repellency and a clear preference of insects for untreated maize grains. Chemical analysis revealed sixteen terpenes, accounting for 98.43% of the total volatile content. The predominant compounds were 2-carene (24.1%), camphene (12.6%), α-pinene (10.23%), and hexadecanal (9.11%). These results confirm the efficacy of *T. coronopifolia* var. *alboradiata* essential oil as a repellent against *S. zeamais* and underscore its potential as a botanical insecticide. The chemical profile provides valuable information to support its development as a sustainable alternative for managing stored grain pests.

KEYWORDS

***Tridax coronopifolia* var. *alboradiata*, essential oils, repellency, maize weevils, IPM (integrated pest management)**

1 Introduction

Due to population growth, securing the global food supply has become a pressing challenge; according to Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) (2024), agricultural production will need to increase by nearly 50% compared with ten years ago. One major threat to crop yields is the damage caused by insect pests, particularly during grain storage, which leads to significant economic losses. Among these pests, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), commonly known as the maize weevil, is considered the most serious pest of maize worldwide (Silva et al., 2003; Bohinc et al., 2018; Khandagale et al., 2019; Tangadi et al., 2021). Infestations can reduce both grain weight and quality (Abdullahi et al., 2014; Mbata et al., 2018), decrease moisture content, and promote fungal colonization, resulting in germ browning, heating, and overall deterioration of stored maize.

Synthetic chemical insecticides remain a common control method because of their effectiveness and rapid action (Oerke, 2006). Products frequently used against *S. zeamais* include malathion, deltamethrin, and fumigants such as methyl bromide, aluminum phosphide, sulfur fluoride, and propylene oxide (Boyer et al., 2012). However, these chemicals present several drawbacks, including grain contamination with residues, insect resistance—which often necessitates higher doses or product mixtures to maintain efficacy (Vilaseca et al., 2008)—as well as risks to the environment, soil, and water (Reyes et al., 2010) and adverse health effects (Hassaan et al., 2020; Schmidt et al., 2023). Their toxicity and persistence have led to increasing demand for safer, more sustainable pest management strategies.

Plant-derived natural products offer a promising alternative to synthetic insecticides (Silva et al., 2002; Ordoñez-Beltrán et al., 2019). Plants produce diverse secondary metabolites that serve as natural defenses against herbivores, insects, and microbial pathogens (Tofel et al., 2017). These compounds fall into three main chemical groups: phenolics (e.g., coumarins, flavonoids, tannins), nitrogen-containing compounds (e.g., alkaloids), and hydrocarbons such as terpenoids (Ferrero et al., 2006; Duplais et al., 2020). Many secondary metabolites affect insect behavior and physiology through multiple mechanisms, including toxicity, inhibition of growth, reproduction, and oviposition, as well as feeding deterrence or repellency (Rioja-Soto, 2020). They may also disrupt nervous system function by targeting essential enzymes, block metabolic pathways, and contribute to long-term pest suppression, while offering reduced environmental impact and greater target selectivity (Rioja-Soto, 2020; Lustre-Sánchez, 2022; Tangadi et al., 2021; Soto-Cáceres et al., 2022).

The push toward sustainable agriculture has driven the search for alternative pest control methods, including the use of biocontrol agents (BCAs) or biopesticides, which provide ecological benefits and reduced reliance on synthetic pesticides (Regnault-Roger, 2020). Essential oils from aromatic plants have shown strong repellent activity against various insect pests (Duplais et al., 2020), including *S. zeamais* in both laboratory and field studies (Granados-Echegoyen et al., 2017; Ferreira et al., 2020; Jayasundara and Arampath, 2021). *Tridax coronopifolia* var. *alboradiata* (A. Gray) B.L. Rob. & Greenm. (Asterales: Asteraceae), commonly known as "rabbit grass" in southeastern Mexico, is an aromatic and edible plant traditionally used to flavor beans, broths, stews, tamales, sauces, and moles (Rosado-Aguilar et al., 2017). It can grow as an annual or perennial and is often found along roadsides and in irrigated areas (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), 2023). Several species of the *Tridax* genus have been reported to possess antiseptic, insecticidal, parasiticidal, and antimicrobial properties (Manzanero-Medina et al., 2020; Gomez et al., 2021).

The present study aimed to (i) evaluate the repellent efficacy of *T. coronopifolia* var. *alboradiata* essential oil against the maize weevil *S. zeamais* using a selection index bioassay, and (ii) identify its chemical constituents through gas chromatography–mass spectrometry (GC–MS).

2 Materials and methods

2.1 Insect rearing

Infested 'Criollo' maize grains were collected from farmers' fields in Villa de Zaachila, Oaxaca, Mexico (16°57′03″ N, 96°44′57″ W) and transported to the Centro de Investigación para el Desarrollo Regional Integral (CIIDIR-OAX). Insects were identified using the taxonomic keys of Haines (1991) and Munyaneza and Henne (2013). To establish a laboratory colony, 100 pairs of adult *S. zeamais* were placed into 20 L plastic containers, each containing 2,500 g of maize grains. Containers were kept in a well-ventilated area and covered with anti-aphid mesh to ensure adequate gas exchange and insect respiration. After a 14-day oviposition period, all adult insects were removed using a fine sieve. The containers were maintained under controlled laboratory conditions (25 ± 2 °C; 70 ± 10% RH) until the F_1 generation emerged. Individuals from this generation were used in experimental bioassays (Juárez-Flores et al., 2010).

2.2 Essential oil extraction

Mature leaves of *T. coronopifolia* var. *alboradiata* were collected during the flowering stage in Villa de Zaachila, Oaxaca, Mexico. Plants were selected based on their aromatic properties, local availability, and traditional use in the region (Haines, 1991; Juárez-Flores et al., 2010). Taxonomic identification was confirmed by staff at the CIIDIR Oaxaca herbarium, where voucher specimens were deposited under reference number OAX-FLO-129–0402 to ensure traceability for future studies. Collected leaves were thoroughly washed and prepared for essential oil extraction.

Essential oil was obtained via microwave-assisted hydrodistillation with saturated steam at atmospheric pressure, following Dezfooli et al. (2012). An adapted Clevenger-type apparatus was used in conjunction with a standard household

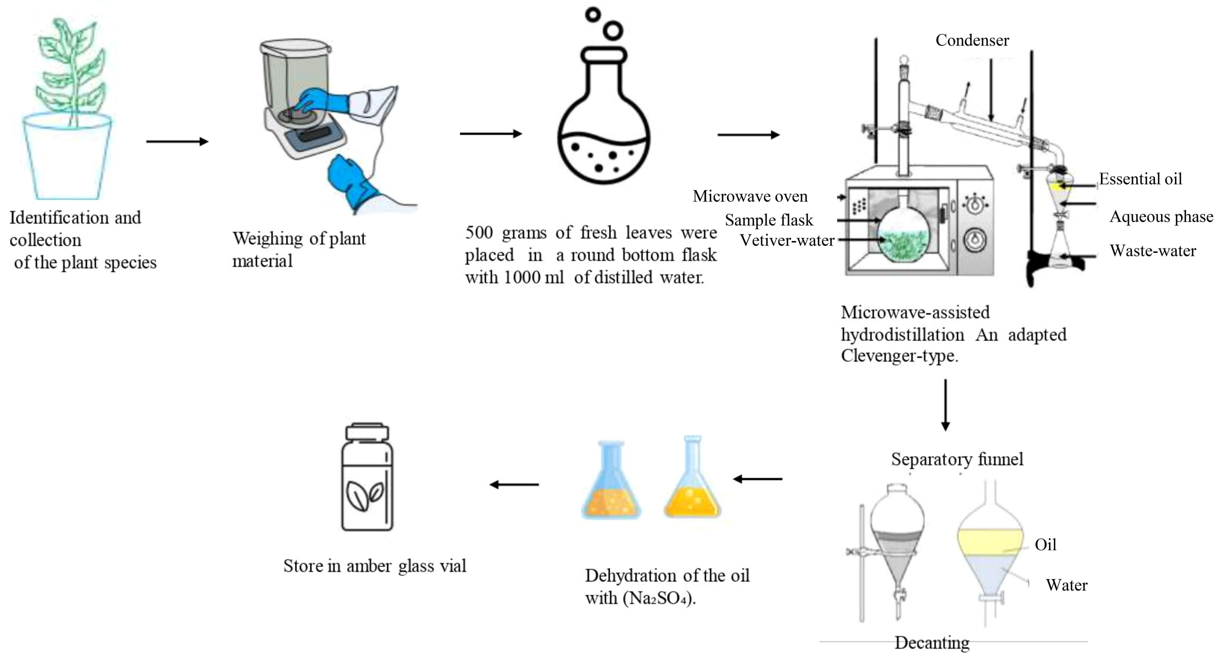

FIGURE 1
Essential oil extraction process.

microwave oven (Samsung MW1235WB, 2450 MHz) set at 70% power. A weight-to-volume ratio of 1:2 was applied, with 500 g of fresh leaves placed in a round-bottom flask containing 1,000 ml of distilled water. The extraction was carried out for 120 min, yielding 0.0095% (w/w). The oil was separated by decantation, dehydrated with anhydrous sodium sulfate (Na_2SO_4), and stored in amber glass vials at 4 °C until further analysis (Figure 1).

2.3 Volatile compound identification

Chemical analysis of the essential oil was performed using gas chromatography–mass spectrometry (GC–MS) on a Model 7890B gas chromatograph coupled to a Model 5977B quadrupole mass selective detector (electron impact ionization, EI) and a Model 7697A headspace sampler. Volatile compounds were separated on an HP-5MS UI capillary column (30 m × 0.25 mm × 0.25 μm). A 1 μL aliquot of the essential oil, diluted in isopropanol, was injected for compound identification. The oven temperature was programmed from 80°C to 300°C at a rate of 10°C/min, with a total run time of ~10 min. Helium was used as the carrier gas at a constant flow rate of 1 mL/min. Compounds were identified by comparing retention times and mass spectra with those in the NIST HP-5MS library (Keffeous and Lynda, 2022). The relative abundance of each component was expressed as a percentage of the total ion current.

2.4 Selection index test

Repellent activity of *T. coronopifolia* var. *alboradiata* essential oil was assessed using maize grains as the substrate. Fifty grams of maize were placed in 20 cm porcelain plates, and the essential oil was diluted in 10 mL ethanol to prepare solutions of 50, 100, 200, 400, 600, and 800 ppm. One milliliter of each solution was applied to the maize using a micropipette to ensure uniform coverage. Plates were left for 20 min to allow complete ethanol evaporation before testing.

The bioassay apparatus consisted of three plastic containers connected by tubes (10 cm long × 1 cm diameter). The two side containers each contained 50 g of maize: one treated with essential oil and one untreated. The central container housed 20 unsexed adult *S. zeamais* that had been starved for 24 h. Piperonyl butoxide with commercial deltamethrin (K-Obiol 2.5, Bayer Mexico) at 10 $\mu L/cm^2$ served as the positive control. After 24 h, the number of insects in each container was recorded, and the selection index (Si) was calculated following Mazzonetto and Vendramin (2003):

$$Si = (2 \times G)/(G + C)$$

where G is the percentage of insects in the treated container and C is the percentage in the untreated container. The repellent/attractant effect of the essential oil was classified according to Arivoli and Tennyson (2013) as follows: neutral (Si = 1.00), non-repellent (Si > 1.00), low repellency (0.75–0.99), medium repellency

TABLE 1 Compounds from the essential oil of *Tridax coronopifolia* var. *alboradiata* analyzed by gas chromatography–mass spectrometry (GC-MS).

Peak	Compounds	(%)	Retention Time	Kovats Retention Index	Formula
1	1-hexanol	2.73	4.82	867	$C_6H_{14}O$
2	γ-terpinene	0.62	6.55	1060	$C_{10}H_{16}$
3	Hexyl butanoate	0.05	8.07	1184	$C_{10}H_{20}O$
4	Nerolidol (*E*)	0.34	9.65	1562	$C_{15}H_{26}O$
5	Calarenepoxide	0.87	11.40	1592	$C_{15}H_{24}O$
6	Iso-sphatulenol	6.06	12.29	1631	$C_{15}H_{24}O$
7	α-pinene	10.23	13.30	917	$C_{10}H_{16}$
8	2-carene	24.10	13.70	1001	$C_{10}H_{16}$
9	Camphene	12.60	14.01	933	$C_{10}H_{16}$
10	Hexadecanal	9.11	14.50	1822	$C_{16}H_{32}O$
11	2-bornanone	6.29	16.31	1145	$C_{10}H_{16}O$
12	Phytol	5.57	16.39	2122	$C_{20}H_{40}O$
13	β-caryophyllene	8.42	19.05	1598	$C_{15}H_{24}4$
14	Safrole	1.62	20.62	1291.4	$C_{10}H_{10}O_2$
15	Caryophyllene oxide	2.80	22.73	1578	$C_{15}H_{24}O$
16	*iso*-methone	2.64	25.18	1164	$C_{10}H_{18}O$
17	Cyclosativene	1.68	26.77	1373.6	$C_{15}H_{24}$
Total		**98.43**			

Peak: Highest retention point. Compounds: Identified compounds. (%): Presence of the compound in the essential oil. Retention time: Time each analyte needs to travel from the injector to the detector. Kovats retention index: Quantification of the relative elution times of the identified compounds. Formula: Chemical representation of the identified compound.

(0.50–0.74), high repellency (0.25–0.49), and very high repellency (0.00–0.24).

2.5 Experimental design and data analysis

Bioassays were conducted individually in a completely randomized design. G*Power software was used to calculate statistical power, determine sample size, and ensure result reliability. Data were analyzed by one-way ANOVA, and treatment means were compared using Tukey's test at $p < 0.05$. Statistical analyses were performed in Minitab (version 20.3). Selection index results are presented as means ± standard deviation. All experiments were replicated four times to ensure statistical robustness (Alonso-Hernández et al., 2023; Pérez-Hernández et al., 2023).

3 Results

3.1 Identification of volatile compounds

Gas chromatography–mass spectrometry analysis of *T. coronopifolia* var. *alboradiata* essential oil identified 16 terpenes, representing 98.43% of the total composition (Table 1). The extraction yielded 800 µL of oil. The predominant constituents were 2-carene (24.1%), camphene (12.6%), α-pinene (10.23%), hexadecanal (9.11%), β-caryophyllene (8.42%), 2-bornanone (6.29%), iso-sphatulenol (6.06%), phytol (5.57%), and caryophyllene oxide (2.80%) (Figure 2).

3.2 Selection index test

Repellency increased with oil concentration, as indicated by the decreasing number of weevils in treated maize containers. At the highest concentration (800 ppm), the SI was 0.27 ($F = 197.64$, df = 7.24, $p < 0.001$, $r^2 = 0.9829$), with 86.25% of weevils found in untreated maize. Concentrations of 600 and 800 ppm (SI = 0.37 and 0.27, respectively) were classified as having high repellent activity ($0.25 \leq SI \leq 0.49$). At the lowest concentration (50 ppm), the SI was 0.90, indicating low repellency ($0.75 \leq SI \leq 0.99$), with 55.00% of weevils in untreated maize. All concentrations of *T. coronopifolia* var. *alboradiata* essential oil exhibited repellency against *S. zeamais*, whereas the positive control (commercial chemical repellent) demonstrated very high repellency (Table 2; Figure 3).

4 Discussion

This study is the first to report the chemical characterization of the essential oil extracted from *T. coronopifolia* var. *alboradiata*.

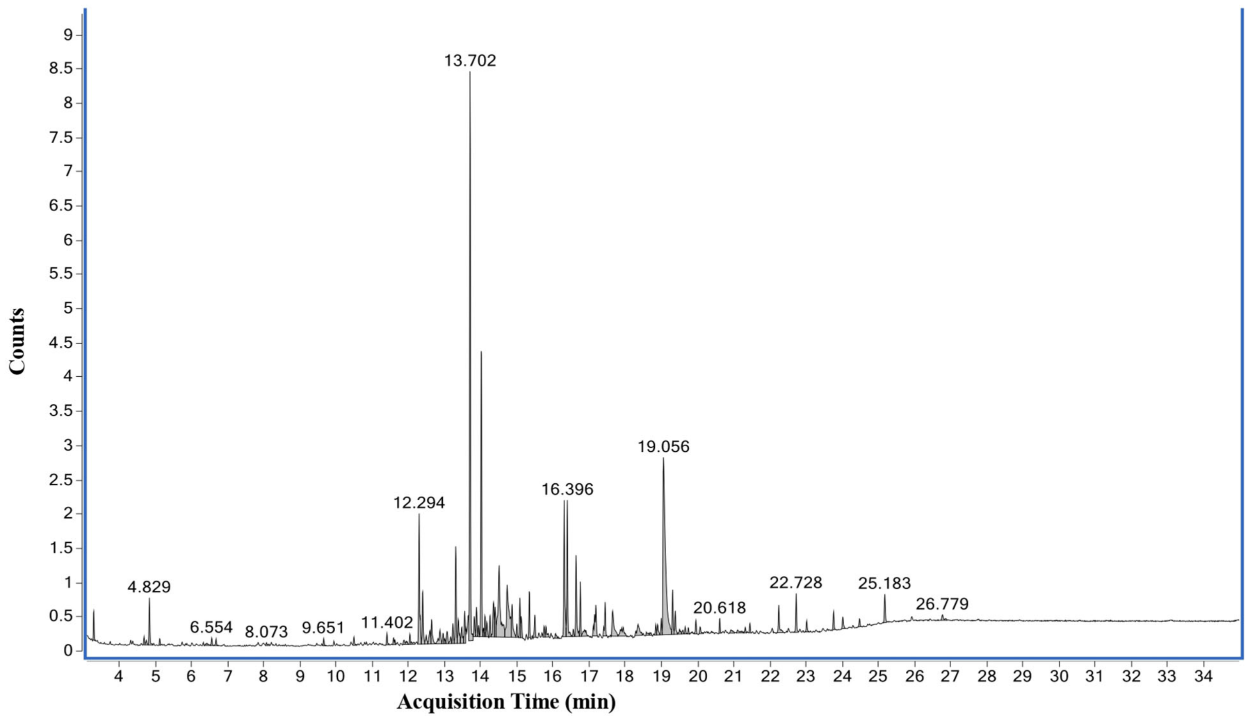

FIGURE 2
Chromatogram of the essential oil of *Tridax coronopifolia* var. *alboradiata* obtained by gas chromatography–mass spectrometry (GC-MS).

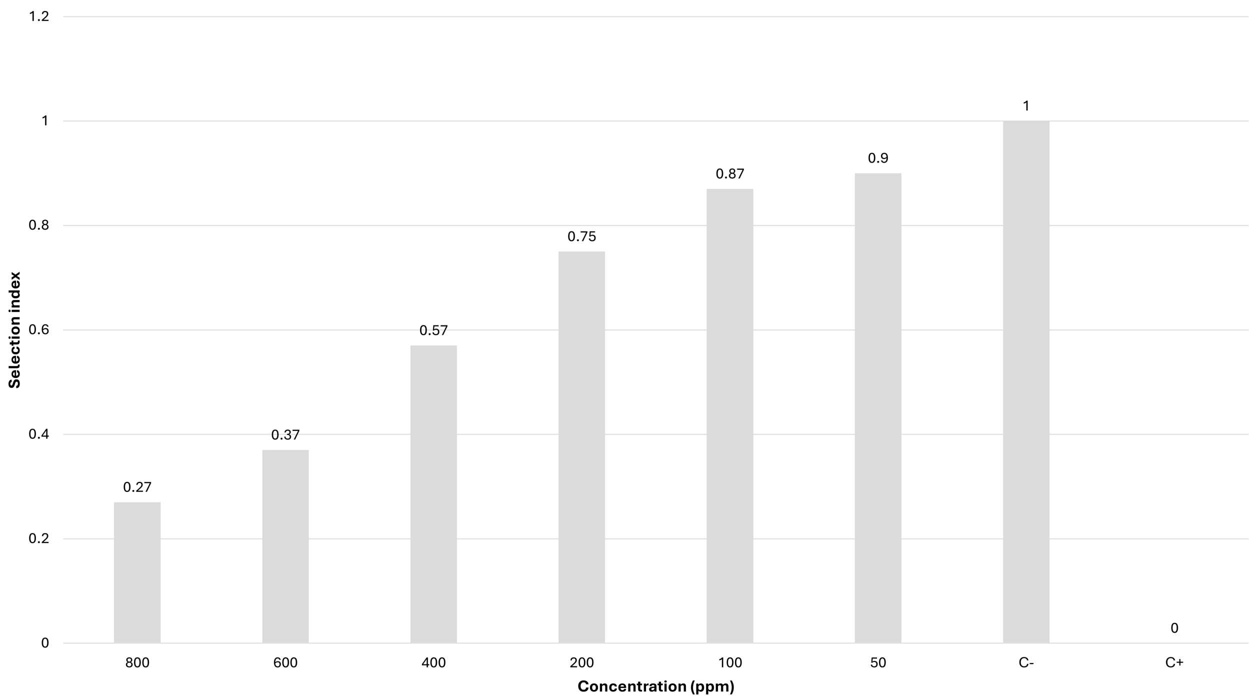

FIGURE 3
Repellency index of the essential oil of *Tridax coronopifolia* var. *alboradiata* on *Sitophilus zeamais.* C-: negative control, without the addition of essential oil; C+: is the positive control, in which piperonyl butoxide with deltamethrin was used as a pyrethroid insecticide, applying 10 µL per cm^2 (K-Obiol 2.5, Bayer Mexico).

TABLE 2 Selection (preference) index of the grain maize weevil (*Sitophilus zeamais*) exposed to *Tridax coronopifolia* var. *alboradiata* essential oil.

Concentration (ppm)	Treated grain	Untreated grain	Selection index	Rating
800	13.75 ± 2.50 e	86.25 ± 2.50 b	0.27 ± 0.05 e	+++
600	18.75 ± 2.50 e	81.25± 2.50 b	0.37 ± 0.05 e	+++
400	28.75 ± 4.79 d	71.25 ± 4.79 c	0.57 ± 0.09 d	++
200	37.50 ± 2.89 c	62.50 ± 2.89 d	0.75 ± 0.05 c	+
100	43.75 ± 2.50 b	56.25 ± 2.50 e	0.87 ± 0.05 b	+
50	45.00 ± 0.00 ab	55.00 ± 0.00 ef	0.90 ± 0.00 ab	+
C-	50.00 ± 0.00 a	50.00 ± 0.00 f	1.00 ± 0.00 a	0
C+	0.00 ± 0.00 f	100 ± 0.00 a	0.00 ± 0.00 f	++++

Data in columns with different letters are significantly different $p< 0.05$. Neutral activity (Si = 1; rating '0'), non-repellent activity (Si > 1.00), low repellent activity (0.75 ≥ Si ≥ 0.99; category '+'), medium repellent activity (0.50 ≥ Si ≥ 0.74; rating '++'), high repellent activity (0.25 ≥ Si ≥ 0.49; rating '+++'), very high repellent activity (0.00 ≥ Si ≥ 0.24; rating '++++'). Data in columns with different letters are significantly different $p<0.05$; C- is the negative control, without the addition of essential oil; C+ is the positive control, in which piperonyl butoxide with deltamethrin was used as a pyrethroid insecticide, applying 10 µL per cm² (K-Obiol 2.5, Bayer Mexico).

Analysis identified several metabolites with known biological activities, with 2-carene being the most abundant compound (24.1%). This bicyclic monoterpene occurs naturally in the essential oils of several Lamiaceae species, including oregano (*Origanum vulgare* L.) and rosemary (*Rosmarinus officinalis* L.), both of which have demonstrated 100% mortality against *S. zeamais* in pest management studies (Costa-Becheleni et al., 2020). Camphene, another major compound, possesses a pungent camphor-like aroma and is present in plants such as citronella (*Cymbopogon nardus* (L.) Rendle), ginger (*Zingiber officinale* Roscoe), and several Lamiales species, with documented insecticidal, antifungal, antibacterial, and antioxidant properties (Wang et al., 2008; Flores-Villa et al., 2020). Additionally, α-pinene, found in thyme (*Thymus vulgaris* L.) and various *Salvia* species, has shown insecticidal activity against the bean weevil (*Sitophilus oryzae* L.), achieving up to 98.9% efficacy (Tapia-Borja et al., 2020). Hexadecanal, a fatty aldehyde identified as a major compound in the oil, is known for its distinctive odor and may function as a chemical signal to attract or repel specific insects, enhancing the plant's defense against herbivores and pathogens. Since these identifications are based solely on HP-5MS library matches, further confirmation using retention indices or authentic standards is recommended.

The quality and efficacy of essential oils can be influenced by multiple factors, including the timing of leaf harvest, the plant part used, extraction method, plant origin, and variability in chemical composition. Genetic, environmental, and phenological factors, as well as post-harvest handling, can affect concentrations of bioactive compounds. Storage conditions also influence the stability of essential oil constituents. Such variability can lead to different chemotypes, which may affect the efficacy of oils in integrated pest management strategies (Granados-Echegoyen et al., 2017; Ferreira et al., 2020; Jayasundara and Arampath, 2021). Similar patterns have been observed in *Porophyllum linaria* Cav., where higher concentrations of active compounds correlated with enhanced bioactivity (Hernández-Cruz et al., 2019; Landero-Valenzuela et al., 2022). These observations support our finding that pest repellency improves with increasing essential oil concentration and prolonged exposure.

Previous studies have evaluated the repellent effectiveness of other essential oils against *S. zeamais*, including oils from boldo (*Peumus boldus* Molina), Chilean laurel (*Laurelia sempervirens* (Ruiz & Pav.) Tul.), and tepa (*Laureliopsis philippiana* (Looser) R. Schodde), which contain safrole, a terpene also present in *T. coronopifolia* var. *alboradiata* (Bustos et al., 2017). Other natural products, such as powders and extracts of neem (*Azadirachta indica* A. Juss), have demonstrated low biocidal activity but higher repellent effects (Palomino-Reyes et al., 2022). Preliminary studies on phytol and humulene I and II indicate that these compounds contribute to insecticidal activity (Arceo-Medina et al., 2016; Rizvi et al., 2018; Perdomo-Cedeño, 2020). In the present study, the observed repellent effect (SI = 0.27) at concentrations of 600 and 800 ppm qualifies as high repellency (0.25 ≤ SI ≤ 0.49) according to Mazzonetto and Vendramin (2003), with all tested concentrations showing repellency compared to the negative control. Similar results have been reported for *Chenopodium ambrosioides* L. (SI = 0.31) and *Schinus molle* L. (SI = 0.20) (Aros et al., 2019; Arias et al., 2017). The mode of action of terpenoids includes repellency and deterrence, interference with juvenile hormone and molting hormone, inhibition of chitin synthesis and digestive enzymes, reduced feeding, and prevention of oviposition (Pavela et al., 2020). The repellent properties of essential oils are strongly associated with the presence of monoterpenes and sesquiterpenes in their volatile profiles (Albarracin-Gomez et al., 2022; Opiyo et al., 2022).

Essential oils represent a sustainable and environmentally friendly alternative to synthetic insecticides. They reduce exposure to toxic chemicals, protect human health, minimize soil and water contamination, and are biodegradable, avoiding long-term ecological damage (Opiyo et al., 2022). Although synthetic insecticides act rapidly, essential oils offer a viable option when environmental safety, human health, and sustainability are priorities. Cost-effectiveness depends on factors such as equipment type, extraction parameters, and plant material. Hydrodistillation is both efficient and economical, ensuring optimal utilization of natural resources (Albarracín-Montoyo and Gallo-Palma, 2003). Advances in sustainable production technologies are reducing costs while maintaining or improving essential oil quality, which is particularly relevant for stored grain preservation. The organic origin of essential oils also enhances marketability and supports food safety and security objectives (González-Puetate et al., 2023).

5 Conclusions and future directions

The results confirm that *T. coronopifolia* var. *alboradiata* essential oil is an effective repellent against the maize weevil (*S. zeamais*) in stored grain. These findings indicate that this essential oil is a promising natural alternative to conventional synthetic insecticides and could be integrated into pest management strategies for stored products. As a natural repellent, it provides an environmentally friendly and efficient option for crop protection. Future research should evaluate the oil's effects on seed viability, ensuring that concentrations up to 800 ppm do not compromise maize germination, sensory quality, or increase the risk of mycotoxin contamination.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

Author contributions

LG-S: Investigation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing. RP-P: Funding acquisition, Methodology, Writing – original draft, Supervision, Resources, Conceptualization, Writing – review & editing. BH: Project administration, Software, Writing – original draft, Methodology, Resources, Writing – review & editing. YO-H: Formal Analysis, Data curation, Writing – original draft, Writing – review & editing, Funding acquisition. AV-L: Methodology, Project administration, Investigation, Writing – original draft, Writing – review & editing. TA-B: Validation, Writing – review & editing, Writing – original draft, Software, Supervision. BQ-G: Resources, Investigation, Project administration, Writing – review & editing, Methodology, Writing – original draft. SM-T: Funding acquisition, Writing – original draft, Formal Analysis, Writing – review & editing, Data curation. FA-B: Writing – review & editing, Software, Writing – original draft, Supervision, Visualization, Validation. AF-B: Project administration, Resources, Writing – review & editing, Writing – original draft, Methodology. CG-E: Writing – original draft, Formal Analysis, Supervision, Software, Conceptualization, Resources, Methodology, Validation, Writing – review & editing, Data curation, Investigation, Visualization.

Funding

The author(s) declare financial support was received for the research and/or publication of this article. The first author gratefully acknowledges the Science, Humanities, Technology and Innovation Secretariat (SECIHTI, México) for the scholarship provided (CVU: 791859).

Acknowledgments

We also thank the Instituto Politécnico Nacional (IPN), particularly the CIIDIR-Oaxaca unit, for providing the facilities and institutional support essential for the first author's doctoral studies.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

References

Abdullahi, N., Umar, I., Tukur, Z., and Babura, S. R. (2014). Comparative efficacy of the bark and root powders of *Acacia nilotica* against maize weevil *Sitophilus zeamais* (Motsculsky) (Coleoptera: Curculionidae) in Kano State of Nigeria. *Afr. J. Agric. Res.* 9, 588–592. doi: 10.5897/AJAR2012.1131

Albarracin-Gomez, L. D., Hortua-Gamboa, S. D., and Acero-Godoy, J. (2022). Efecto inhibitorio del aceite esencial de *Lippia graveolens* sobre *Fusarium oxysporum* en la familia Solanaceae. Una revisión. *Rev. Tecn. En March.* 36, 54–65. doi: 10.18845/tm.v36i1.5877

Alonso-Hernández, N., Granados-Echegoyen, C., Vera-Reyes, I., Pérez-Pacheco, R., Arroyo-Balán, F., Valdez-Calderón, A., et al. (2023). Evaluación de las propiedades larvicidas de la planta endémica de Campeche, México *Piper cordoncillo* var. *apazoteanum* (Piperaceae) contra mosquitos *Aedes aEgypti* (Diptera: Culicidae). *Insec.* 14, 312. doi: 10.3390/insects14040312

Arceo-Medina, G. N., Rosado-Aguilar, J. A., Rodríguez-Vivas, R. I., and Borgez-Argaez, R. (2016). Synergistic action of fatty acids, sulphides and stilbene against acaricide-resistant *Rhipicephalus microplus* ticks. *Vet. Parasitol.* 228, 121–125. doi: 10.1016/j.vetpar.2016.08.023

Arias, P. J., Silva, A. G., Fischer, G. S., Robles-Bermudez., A., Rodriguez-Maciel, C., and Lagunes-Tededa, A. (2017). Actividad insecticida, repelente y antialimentaria del polvo y aceite esencial de frutos de *Schinus molle* L. para el control de *Sitophilus zeamais* (Motschulsky). *Chil. J. Agricul. Anim. Scien.* 33, 93–104. doi: 10.4067/S0719-38902017005000301

Arivoli, S., and Tennyson, S. (2013). Ovicidal activity of plant extract against *Spodoptera litura* (Fab.) (Lepidoptera: Noctuidae). *Bull. Environ. Pharm. L. Sci.* 2, 140–145.

Aros, J., Silva-Aguayo, G., Fischer, G. S., Rodriguez-Maciel, C., Lagunes-Tededa, A., Castañeda-Ramirez, G. S., et al. (2019). Actividad insecticida del aceite esencial del paico *Chenopodium ambrosioides* L. sobre *Sitophilus zeamais* (Motschulsky). *Agrocien.* 35, 282-292. doi: 10.4067/S0719-38902019005000504

Bohinc, T., Horvat, A., Andric, G., Prazic Golic, M., Kljajic, P., and Trdan, S. (2018). Comparison of three different wood ashes and diatomaceous earth in controlling the maize weevil under laboratory conditions. *J. Stored Prod. Res.* 79, 1–8. doi: 10.1016/j.jspr.2018.06.007

Boyer, S., Zhang, H., and Lemperier, G. (2012). A review of control methods and resistance mechanisms in stored-product insects. *Bull. Entomol. Resear.* 102, 213–229. doi: 10.1017/S0007485311000654

Bustos, G., Silva, G., Fisher, S., Figueroa, I., Urbina, A., and Rodríguez, J. C. (2017). Repelencia de mezclas de aceites esenciales de boldo, laurel chileno, y tepa contra el gorgojo del maíz. *Southw. Entomol.* 42 (2), 551–562. doi: 10.3958/059.042.0224

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) (2023). Available online at: http://www.conabio.gob.mx/malezasdeMexico/asteraceae/tridaxcoronopifolia/fichas/ficha.htm (Accessed January 15, 2025).

Costa-Becheleni, F. R., Toro-Sánchez, C. L. D., Wong-Corral, F. J., Robles-Burgueño, M. D. R., Cárdenas-López, J. L., and Borboa-Flores, J. (2020). Aceites esenciales para el control de *Sitophilus zeamais Motschulsky* (Coleoptera: Curculionidae) y efecto sobre la calidad del grano de maíz *Zea mays Linnaeus* (Poales: Poaceae). *Rev. Chil. Entomol.* 46, 639–652. doi: 10.35249/rche.46.4.20.10

Dezfooli, N. A., Hasanzadeh, N., Bagher, M., and Ghasemi, A. (2012). Antibacterial activity and chemical compositions of *Chamaemelum nobile* essential oil/extracts against *Pseudomonas tolaasii*, the causative agent of mushroom brown blotch. *Annals. Biol. Res.* 3, 2602–2608.

Duplais, C., Papon, N., and Courdavault, V. (2020). Tracking the origin and evolution of plant metabolites. *Tren. Plant Sci.* 25, 1182–1184. doi: 10.1016/j.tplants.2020.08.010

Ferreira, D. F., Lucas, B. N., Voss, M., Santos, D., Mello, P. A., Wagner, R., et al. (2020). Solvent free simultaneous extraction of volatile and non-volatile antioxidants from rosemary (*Rosmarinus officinalis* L.) by microwave hydrodiffusion and gravity. *Ind. Crop Prod.* 145, 1–8. doi: 10.22201/fesz.23958723e.2020.0.266

Ferrero, A. A., Werdin- González, J. O., and Sánchez- Chopa, C. (2006). Biological activity of *Schinus molle* on *Triatoma infestans*. *Fitoterapia.* 77, 381–383. doi: 10.1016/j.fitote.2006.03.004

Flores-Villa, E., Sáenz-Galindo, A., Castañeda-Facio, A. O., and Narro-Céspedes, R. I. (2020). Romero (*Rosmarinus officinalis* L.): su origen, importancia y generalidades de sus metabolitos secundarios. *TIP. Rev. Espec. Cienc. Quím-biol.* 23, 1-17. doi: 10.22201/fesz.23958723e.2020.0.266

Gomez, A. C., Tschinkel, P. S., De Araújo Medeiros, C. S., de Souza, I. D., and Do Nascimento, V. A. (2021). Dados elementares da folha de *Tridax Procumbens* L. (Erva Touro). *J. Dev.* 7, 36838–36853. doi: 10.34117/bjdv7n4-241

González-Puetate, I., Arévalo-Bozada, M. M., Vélez-León, M. F., and Acosta-Prócel, J. M. (2023). Aceites esenciales, alternativa frente a plagas y enfermedades en apicultura: Essential oils, alternative against pests and diseases in beekeeping. *LATAM Latin. Cienc. Soc Y Hum.* 4, 30–44. doi: 10.56712/latam.v4i5.1300

Granados-Echegoyen, C. A., Alonso-Hernández, N., Ortega-Morales, B., Reyes-Estébanez, M., Chan-Bacab, M., and Camacho-Chab, J. C. (2017). Polvos botánicos de *Senecio salignus* (Asteraceae) y *Solanum Diversifolium* (Solanaceae) como alternativa ecológica de control de *Sitophilus zeamais* (Coleoptera: Curculionidae). *Entomol. Agríc.* 4, 403–408.

Haines, C. P. (1991). "Insects and arachnids of tropical stored products: Their biology and identification," in *A* Training Manual, *2nd ed.* Ed. C. P. Haines (Natal University Press, Pietermaritzburg, South Africa). Natural Resources Institute: Kent, UK.

Hassaan, M. A., Khandagale, B. M., Tangadi, R. R., Yankanchi, S. R., and Nemr, A. E. (2020). Pesticides pollution: Classifications, human health impact, extraction and treatment techniques. *Egypt. J. Aquat. Res.* 46, 207–220. doi: 10.1016/j.ejar.2020.08.007

Hernández-Cruz, J., Luna-Cruz, A., Loera-Alvarado, E., Villanueva-Sánchez, E., Landero-Valenzuela, N., Zárate-Nicolás, B. H., et al. (2019). Efficiency of the essential oil of *Porophyllum linaria* (Asteraceae) a Mexican endemic plant against *Sitophilus zeamais* (Coleoptera: Curculionidae). *Insec.* 6, 1-19. doi: 10.1093/jisesa/iez079

Jayasundara, N. D. B., and Arampath, P. (2021). Effect of variety, location & maturity stage at harvesting, on essential oil chemical composition, and weight yield of *Zingiber officinale* roscoe grown in Sri Lanka. *J. Heli.* 7, 1-8. doi: 10.1016/j.heliyon.2021.e06560

Juárez-Flores, B. I., Jasso-Pineda., Y., Aguirre-Rivera, J., and Jasso-Pineda, I. (2010). Efecto de polvos de Asteráceas sobre el gorgojo del maíz (*Sitophilus zeamais* Motsch). *Polibot.* 30, 123–135.

Keffeous, B., and Lynda, A. (2022). Determination of chemical characterization of *Foeniculum vulgare* Mill essential oil composition and its toxicological effects against mosquito (*Aedes caspius*, Pallas 1771). *Uttar prades. J. Zool.* 43, 66–73. doi: 10.9734/bpi/cerb/v3/4117B

Khandagale, B., Tangadi, R. R., and Yankanchi, S. R. (2019). Toxic efficacy of essential oils against rice weevil *Sitophilus oryzae* (L). *L. Sci. Bioinf. Pharma. Chem. Sci.* 5, 139–144.

Landero-Valenzuela, N., Alonso-Hernández, N., Lara-Viveros, F., Gómez-Dominguez, N. S., Juárez-Pelcastre, J., Aguado-Rodriguez, J., et al. (2022). Efficiency of *Schinus molle* essential oil against *Bactericera cockerelli* (Hemiptera: Triozidae) and *Sitophilus zeamais* (Coleoptera: Dryophthoridae). *Agriculture.* 12, 554. doi: 10.3390/agriculture12040554

Lustre-Sánchez, H. (2022). Los superpoderes de las plantas: los metabolitos secundarios en su adaptación y defensa. *Rev. Dig. Univer.* 23, 2–8. doi: 10.22201/cuaieed.16076079e.2022.23.2.10

Manzanero-Medina, G. I., Vásquez-Dávila, M. A., Lustre-Sánchez, H., and Pérez-Herrer, A. (2020). Ethnobotany of food plants (quelites) sold in two traditional markets of Oaxaca, Mexico. *South Afric. J. Bot.* 130, 215–223. doi: 10.1016/j.sajb.2020.01.002

Mazzonetto, F., and Vendramin, J. D. (2003). Efeito de pos de origem vegetal sobre *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) em feijao armazenado. *Neot. Entomol.* 31, 145–149. doi: 10.1590/S1519-566X2003000100022

Mbata, G. N., Ivey, C., and Shapiro-Ilan, D. (2018). The potential for using entomopathogenic nematodes and fungi in the management of the maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae). *Biol. Cont.* 125, 39–43. doi: 10.1016/j.biocontrol.2018.06.008

Munyaneza, J. E., and Henne, D. C. (2013). "Chapter 4- Leafhopper and psyllid pests of potato," in *Insect Pests of Potato: Global Perspectives on Biology and Management*. Eds. P. Giordanengo, C. Vincent and A. Alyokhin (Academic Press, San Diego, CA, USA), 65–102. doi: 10.1016/B978-0-12-386895-4.00004-1

Oerke, E. (2006). Crop losses to pests. *J. Agric. Sci.* 144, 31–43. doi: 10.1017/S0021859605005708

Opiyo, S. A., Njoroge, P. W., and Ndirangu, E. G. (2022). A review pesticidal activity of essential oils against *Sitophilus oryzae*, *Sitophilus granaries* and *Sitophilus zeamais*. *J. Appl. Chem.* 15, 39–51. doi: 10.9790/5736-1504013951

Ordoñez-Beltrán, V., Frías-Moreno, M. N., Parra-Acosta, H., and Martínez-Tapia, M. E. (2019). Estudio sobre el uso de plaguicidas y su posible relación con daños a la salud. *Toxi.* 36, 148–153.

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) (2024). *Cereal supply and demand brief*. Available online at: http://www.fao.org/worldfoodsituation/csdb/en/.

Palomino-Reyes, D. Y., Lozano-Lévano, C., and de la Cruz-Leytón, C. (2022). Evaluación del efecto repelente y biocida del extracto y polvo de hojas de *Azadirachta Indica* A. Juss., (neem) sobre *Ulomoides dermestoides* (Fairmare 1893) (Coleoptera: Tenebrionidae. *Biotempo* 19, 251–258. doi: 10.31381/biotempo.v19i2.5141

Pavela, R., Maggi, F., Giordani, C., Cappellacci, L., Petrelli, R., and Canale, A. (2020). Insecticidal activity of two essential oils used in perfumery (ylang ylang and frankincense). *Nat. Prod.* 35, 4746–4752. doi: 10.1080/14786419.2020.1715403

Perdomo-Cedeño, L. F. (2020). *Determinación del potencial insecticida y repelente de mezclas de constituyentes químicos bioactivos presentes en aceites esenciales para el control de* Tribolium castaneum (Colombia National University). Available online at: https://bffrepositorio.unal.edu.com.

Pérez-Hernández, R. G., Reyes-García, C., Grijalva-Arango, R., Chávez-Pesqueira, M., Espadas-Manrique, C., and Hernández-Guzmán, M. (2023). Usos tradicionales y prácticas de manejo de *Piper auritum* en comunidades maya rurales de Yucatán. *Bot. Sci.* 101, 1049–1069. doi: 10.17129/botsci.3305

Regnault-Roger, C. (2020). "Tendencias para la comercialización de agentes de biocontrol (Bioplaguicida)," in *En Defensa vegetal: Control biológico* (Sprin. Inter. Publish, Cham), 445–471.

Reyes, G., Chaparro-Giraldo, A., and Ávila, K. (2010). Efecto ambiental de agroquímicos y maquinaria agrícola en cultivos transgénicos y convencionales de algodón. *Biotecnol.* 12, 151–162.

Rioja-Soto, T. C. (2020). Los metabolitos secundarios de las plantas y potencial uso en el manejo de plagas agrícolas en agroecosistemas desérticos. *Ides. J. (Arica).* 38, 3–5. doi: 10.4067/S0718-34292020000100003

Rizvi, S. A. H., Ling, S., Tian, F., Xie, F., and Zeng, X. (2018). Toxicity and enzyme inhibition activities of the essential oil and dominant constituents derived from *Artemisia absinthium* L. against adult Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae). *Ind. Crop Prod.* 121, 468–475. doi: 10.1016/j.indcrop.2018.05.031

Rosado-Aguilar, J. A., Arjona-Cambranes, K., Torres-Acosta, J. F. J., Rodríguez-Vivas, R. I., Bolio-González, M. E., Ortega-Pacheco, A., et al. (2017). Plant products and secondary metabolites with acaricide activity against ticks. *Vet. Parasitol.* 238, 66–76. doi: 10.1016/j.vetpar.2017.03.023

Schmidt, M., Tobías, M., Merlinsky, M. G., and Toledo López, V. (2023). Conflicts over water and the use of agrochemicals in Salta and Santiago del Estero, Argentina: a political ecology analysis. *Rev. A. Y Territ./Wat. Landsc.* 21, 85–102. doi: 10.17561/at.21.5889

Silva, A. G., Lagunes, T. A., Rodríguez, J. C., and Rodríguez., L. D. (2002). Insecticidas vegetales: Una vieja y nueva alternativa para el manejo de plagas. *M.I P. y Agroecol.* 66, 4–12.

Silva, G., Lagunes, A., and Rodríguez-Sánchez, J. (2003). Control de *Sitophilus zeamais* (Coleoptera: Curculionidae) con polvos vegetales solos y en mezcla con carbonato de calcio en maíz almacenado. *Cien. Investig. Agrar.* 30, 153–160. doi: 10.7764/rcia.v30i3.271

Soto-Cáceres, V. A., Díaz-Vélez, C., Becerra-Gutiérrez, L. K., Arriaga-Deza, E. V., Meoño-Asalde, C. N., Reyes-Damián, J. R., et al. (2022). Repellent effect and protection time of essential oils against the adult stage of *Aedes aEgypti*. *J. Invest. Veterin. del Perú.* 33, 8-28. doi: 10.15381/rivep.v33i6.21018

Tangadi, R., Jadhav, G., Devarsh, A., and Yankanchi, S. (2021). Efficacy of plant essential oils against rice weevil, *Sitophilus oryzae* L. *J. Biopestic.* 14, 22–26. doi: 10.57182/jbiopestic.14.1.22-26

Tapia-Borja, A. I., Castillo De La Guerra, C. G., Pullutasig-López, D. J., and Sanches, M. E.B. (2024). Extracto de jengibre (*Zingiber officinale*) y falso tabaco (*Nicotiana glauca*), Para el control de mosca blanca (*Bemisia tabaci*) en condiciones de laboratorio. *Nat. Prod. y Sosten.* 3, 20–34. doi: 10.61236/renpys.v3i1.590

Tofel, K. H., Kosma, P., Stahler, M., Adler, C., and Nukenine, E. N. (2017). Insecticidal products from *Azadirachta indica* and *Plectranthus glandulosus* growing in Cameroon for the protection of stored cowpea and maize against their major insect pests. *Ind. Crop Prod.* 110, 58–64. doi: 10.1016/j.indcrop.2017.09.051

Vilaseca, J. C., Font, M. I., and Jordá, C. (2008). Biofumigación y biosolarización en el control del ToMV: una buena alternativa al bromuro de metilo. *Agroecol.* 1, 1–11. Available online at: https://revistas.um.es/agroecologia/article/view/172.

Wang, W., Wu, N., Zu, Y. G., and Fu, Y. J. (2008). Antioxidative activity of *Rosmarinus officinalis* L. essential oil compared to its main components. *J. Agric. F. Chem.* 108, 1019–1022. doi: 10.1016/j.foodchem.2007.11.046