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ORIGINAL ARTICLE

Antifeedant and insecticidal activity of four medicinal plants from arid regions on adults of the red flour beetle *Tribolium castaneum* (*Coleoptera, Tenebrionidae*)

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Abstract

Considering the importance of sustainable pest control, this study evaluated the insecticidal and antifeedant properties of medicinal plants from arid regions against *Tribolium castaneum*. The methodology involved extracting bioactive compounds from four selected plant species: *Atriplex halimus* L. (saltbush), *Sonchus oleraceus* L. (sowthistle), *Lavandula multifida* L. (fernleaf lavender) and *Globularia alypum* L. (globe daisy), and conducting antifeedant and insecticidal bioassays, along with phytochemical screening tests, to assess their effects on adult beetles. The primary findings indicated that *Lavandula multifida* and *Sonchus oleraceus* manifested notable insecticidal activity, underscoring their promise as efficacious natural pest management agents, despite their modest antifeedant activities. Notably, Atriplex halimus demonstrated remarkable antifeedant activity, achieving a 31.37% effect, though its insecticidal activity was somewhat modest. Globularia alypum showed minimal insecticidal and antifeedant activity. However, the utilization of Lavandula multifida as a bioinsecticide may be limited by the plant's small size, which necessitates the production of a considerable quantity of plant material to produce a sufficient extract. Phytochemical analysis indicated that these plants are rich in bioactive compounds, including flavonoids, terpenoids, and tannins. The observed differences between insecticidal and antifeedant activities suggest the presence of different underlying mechanisms. This study underscores the potential of these plant extracts as environmentally friendly alternatives to synthetic pesticides and lays the groundwork for future research into their role in sustainable pest management strategies.

Key words: antifeedant activity, arid regions, insecticidal activity, medicinal plants, sustainable pest control, *Tribolium castaneum*

Introduction

Insect pests pose a considerable menace to global food security, with the greatest risk to agricultural ecosystems. These pests inflict considerable damage to crops and stored food products, resulting in significant disruptions to global food production and availability. The primary damage caused by insects to stored foodstuffs is through direct consumption (Manandhar *et al.* 2018). Also, they are vectors for fungal infections, which can increase the risk of contamination with mycotoxins and reduce the quality of stored grains (Eigenbrode *et al.* 2018; Yun *et al.* 2018). The red flour beetle, *Tribolium castaneum* (Herbst 1797) (Coleoptera: Tenebrionidae), is of particular concern because it is a common stored grain pest, affecting processed cereals, oilseeds, nuts, and dried fruits. Despite the implementation of various preventive and control measures, *T. castaneum* continues to pose a persistent problem in storage depots (Swamy *et al.* 2020). Furthermore, this species has developed resistance to chemical insecticides, which makes its management more complex (Astuti *et al.* 2020).

Approximately, two million tons of pesticides are applied globally each year for insect damage control (Sharma *et al.* 2019). However, the massive use of chemical pesticides has serious consequences for the environment and human health. These substances are toxic, accumulate in the environment, and resist degradation, which leads to their prolonged presence in ecosystems. In addition, unreasonable pesticide use has led to a number of complications, including the development of insecticide resistance, the appearance of secondary pests, damage to beneficial insects, and the presence of pesticide residues in food products (Bass *et al.* 2014; Pathak *et al.* 2022). It is recommended that pest control methods prioritize environmental and ecological considerations, giving preference to the use of biological and physical control methods over other strategies. Chemical treatments should be used only as a last resort. Despite the speed and cost-effectiveness of chemical methods, which involve the use of insecticides in stored produce, they also present risks, including grain contamination and toxicity to humans and animals (Arora *et al.* 2021).

Scientific research has recently shown interest in the potential use of medicinal plants as a source of bioactive compounds with insecticidal properties. The field of ethnopharmacology has strongly captured the attention of the pharmaceutical and medical communities due to the growing recognition of the potential of these natural compounds, which are often unlikely to have adverse effects (Gacem *et al.* 2019). In this context, medicinal plants from arid and semi-arid regions, such as those found in Algeria, where these climates cover over 87% of the land surface, are of particular interest. Despite the harsh environmental conditions, these regions are home to over 2,800 plant species, many of which have unique phytochemical profiles and have been traditionally used in medicine (Halla *et al.* 2018; Behaz *et al.* 2024).

The bioactive molecules present in these plants often have complementary or synergistic therapeutic effects, and their potential as natural insecticides is increasingly recognized. Furthermore, the antioxidant properties of these plants reinforce their value in combating pests and maintaining food quality and safety (Chaouche *et al.* 2020; Haddouchi *et al.* 2021).

Despite the numerous studies about the bioactivity of medicinal plants, there is still limited information about their application in agricultural sciences, specifically in the protection of stored food products against insect pests. Plant-derived products, including crude extracts, have promise as biological alternatives for controlling storage pests like *T. castaneum* (Herbest) reducing chemical residues in food products, and minimizing environmental impact. However, research on plants from arid and semi-arid regions remains limited, particularly concerning their insecticidal and antifeedant effects under storage conditions.

In this context, the present study aimed to evaluate the insecticidal and antifeedant effects of four medicinal plants: *Atriplex halimus* L. (Mediterranean saltbush; Amaranthaceae), *Sonchus oleraceus* L. (Common sowthistle; Asteraceae), *Lavandula multifida* L. (Fernleaf lavender; Lamiaceae), and *Globularia alypum* L. (Globe daisy; Plantaginaceae), which are found in the arid regions of Algeria, against *Tribolium castaneum* (Herbest) a major stored-product pest. The goal was to identify natural alternatives for managing insect infestations in storage environments, contributing to food preservation and environmentally friendly pest control practices.

Materials and Methods

Insect breeding

Colonies of *T. castaneum* were reared in glass jars containing semolina as a substrate. The jars, covered with fine mesh for ventilation, were placed in an incubator at 30 ± 3°C and about 70% relative humidity. Breeding took place at the Laboratory of Ecosystems Diversity and Agricultural Production Systems Dynamics in Arid Zones (DEDSPAZA) located at the University of Biskra. This species was selected due to its significant economic impact on stored products and for its suitability for mass rearing under laboratory conditions, allowing for the collection of large numbers of individuals for bioassays.

Plant material

The aerial parts of four plant species, *A. halimus* L., *S. oleraceus* L., *L. multifida* L., and *G. alypum* L., were collected during the spring season from various arid regions in Algeria (Table 1). The collected specimens were identified and taxonomically authenticated by Dr. Abdelkader Nabil Benghanem, lecturer and researcher in botany at the National Higher School of Agronomy, Algiers. Identification was confirmed using standard botanical keys and regional floras, including Nouvelle Flore de l'Algérie et des Régions Désertiques

Table 1. Botanical identity, common names, and collection site details of the studied plants

Family	Species	Common name	Bioclimatic floor, geographic coordinates
Amaranthaceae	*Atriplex halimus* L	mediterranean saltbush	Arid, 34°45′33″N, 5°53′34″E
Asteraceae	*Sonchus oleraceus* L	common sowthistle	Arid, 34°45′32″N, 5°53′40″E
Lamiaceae	*Lavandula multifida* L	fernleaf lavender	Arid, 34°56′10″N, 5°59′08″E
Plantaginaceae	*Globularia alypum* L	globe daisy	Arid, 34°59′47.3″N, 6°3′0.75″E

Méridionales (Quézel and Santa 1962, 1963) and Flore d'Afrique du Nord Maire (1964).

The plant materials were air-dried for three to four weeks in a well-ventilated area, and away from direct light from direct light. Each dried sample was ground into a fine powder using an electric grinder and stored at room temperature until further use.

Preparation of the extract

For extraction, 50 g of each powder was mixed with 500 ml of ethanol solvent, and 100 ml of distilled water was added to an Erlenmeyer flask covered with aluminum foil. The mixture was stirred for two hours using a magnetic stirrer. During this step, it was ensured that the mixture was homogeneously agitated before proceeding to maceration. The solutions were macerated in the shade at room temperature for 48 hours. After filtration, each extracted solution underwent pressure evaporation at 45°C in a rotary evaporator to eliminate a significant amount of the solvent. The resultant plant concentrates were then kept in glass vials, safeguarded from light at 4°C for future use.

Phytochemical screening analysis

Phytochemical screening was carried out using qualitative methods as described by Shaikh and Patil (2020). The following tests were performed to detect various phytochemicals:

- **Alkaloids** were detected by using the tannic acid test. Buff precipitate indicates their presence;
- **Flavonoids** were detected by using the alkaline reagent test. The appearance of an intense yellow color that disappears with HCl confirms the presence of flavonoids;
- **Total polyphenols** were identified using the potassium dichromate test. A dark color indicates their presence;
- **Tannins** were detected by using the test; emulsion formation indicates the presence of hydrolysable tannins;
- **Saponins** were detected using the foam test. The appearance of foam that persists more than 10 minutes means there are saponins in the extract;
- **Terpenoids** were detected by testing with chloroform and concentrated H_2SO_4. Their presence was indicated with the formation of a dense golden--yellow layer;
- **Quinones** were detected with the concentrated HCl test. A green color indicates the presence of quinones;
- **Coumarins** were determined by using the NaOH test (10% NaOH). The appearence of yellow color confirms coumarins;
- **Anthraquinones** were detected with the Borntrager's test. After shaking, a violet to red solution indicates their presence.

Toxicity tests (contact/inhalation)

For each plant, the crude extract obtained through solvent extraction was used in these tests. Different doses (D1 = 10%, D2 = 30%, and D3 = 50%) were applied to the surface of Petri dishes containing 10 adults of *T. castaneum* and 2 grams of wheat semolina. Each dose was repeated three times, and the control was treated with distilled water only. The dishes were preserved under the same rearing conditions, and dead individuals were counted every day for 21 days.

Antifeedant test

The evaluation of antifeedant activity and the applied protocol were inspired by methodologies commonly used in recent studies on insect–plant interactions (Mayanglambam et *al.* 2022; Ajaha *et al.* 2023; Tine *et al.* 2023).

Prepared disks containing 2 g of semolina, treated with 5 µl of plant extract (treated group with 30% dose) or distilled water (control group), were weighed after a brief evaporation period. Ten adult *T. castaneum* insects, fasted for 2 hours, were introduced to each disk. Each test was conducted with three replications (Fig. 1).

Choice Test

In this test, insects were given a choice between 2 g of treated semolina and 2 g of untreated semolina (Fig. 1).

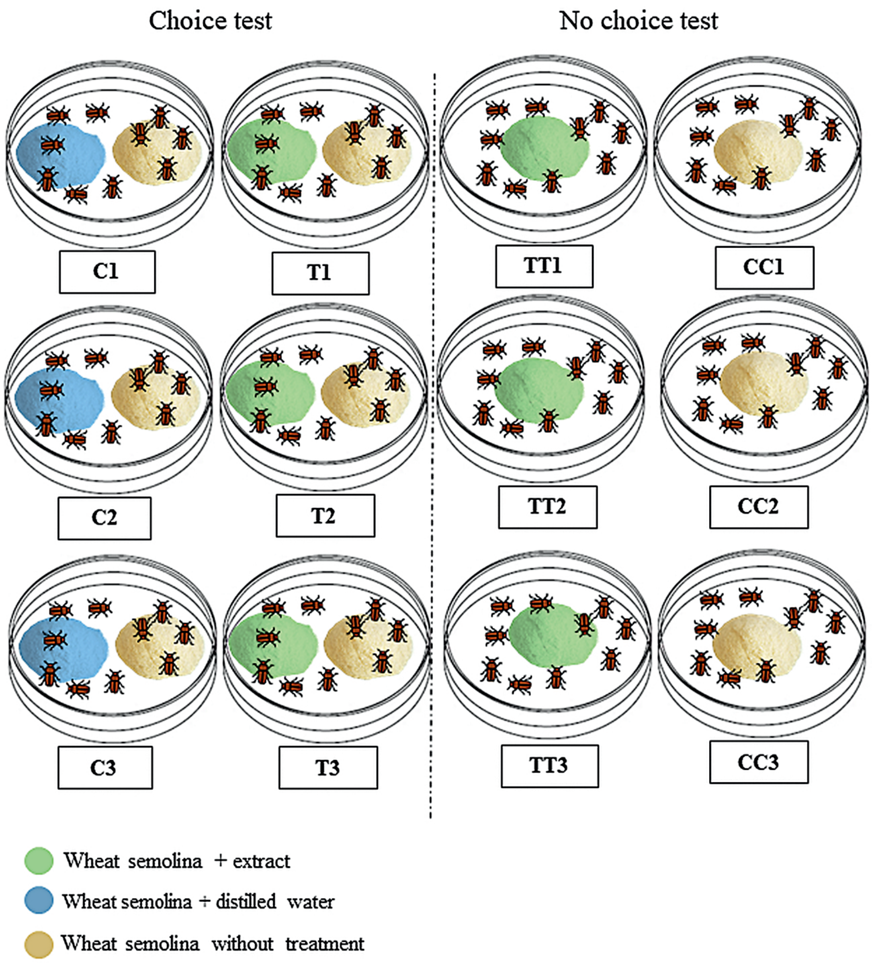

Fig. 1. Antifeedant test: choice and no choice test protocol (Original 2024)

No-Choice Test

In this test, insects were presented with a single 2 g semolina disk, either treated with the plant extract or untreated, with three replications for each condition (Fig. 1).

The weight of the semolina in each test was recorded daily over 7 days. Food consumption by the insects was calculated by subtracting the weight recorded each day from that of the previous day.

- Discs without treatment (CC).
- Discs where there was a choice between a treated disc (with distilled water) and a non-treated disc (C).
- Treated discs where there was no choice (TT).
- Discs where there was a choice between a treated disc (with extract) and a non-treated disc (T).

The use of the formula by Nawrot *et al.* (1986):

Choice Test

$$\%R = \frac{C - T}{C + T} \times 100,$$

where:
C – weight of consumed semolina for the control group (mg);
T – weight of consumed semolina for the treated group (mg);
R – relative antifeedant activity (%).

No-choice Test

$$\%A = \frac{CC - TT}{CC + TT} \times 100,$$

where:
CC – weight of consumed semolina for the control group (mg);
TT – weight of semolina for the treated group (mg);
A – absolute antifeedant activity (%).

These equations serve to quantify the anti-appetence activity of the treatments in comparison to the control group, both in a choice test and in a no-choice test.
The total:

$$T = A + R,$$

where:
T – total inhibition coefficient value;
A – absolute anti-appetence activity (%);
R – relative anti-appetence activity (%).

The categories of anti-appetence activity based on Gabrys *et al.* (2006) are as follows:

Table 2. Groups of antifeedant activity based on the total value of the inhibition coefficient

N°	T value	Category of antifeedant activity
1	< 50	weak deterrents
2	51–100	medium deterrents
3	101–150	good deterrents
4	151–200	very good deterrents
5	negative	attractant properties

Data analysis

Mortality correction

Mortality rates were corrected using Schneider-Orelli's (1947) formula

$$\text{Corrected mortality (CM) (\%)} =$$

$$= \frac{\text{Mt (\%)} - \text{M0 (\%)}}{100 - \text{M0 (\%)}} \times 100\,,$$

where:
CM – Corrected mortality (%);
Mt – Mortality of treated sample (%);
M0 – Mortality of untreated sample (%).

Regression lines were constructed by linking the corrected mortality rates expressed in Probits to the extract doses.

Statistical analysis

All results are presented as mean ± standard deviation (SD). Statistical analyses were performed using IBM SPSS Statistics version 26. One-way ANOVA followed by chi-square test was used to compare differences between groups. Probit analysis was applied to calculate lethal doses (LD_{50} and LD_{90}) with 95% confidence limits. Differences were considered statistically significant at $p < 0.05$.

Results

Toxicity effect of plant extracts

The results showed an increase in the percentage mortality of *T. castaneum* adults as a function of time and plant extract dose (Fig. 2). In general, no mortality was observed in the control groups during

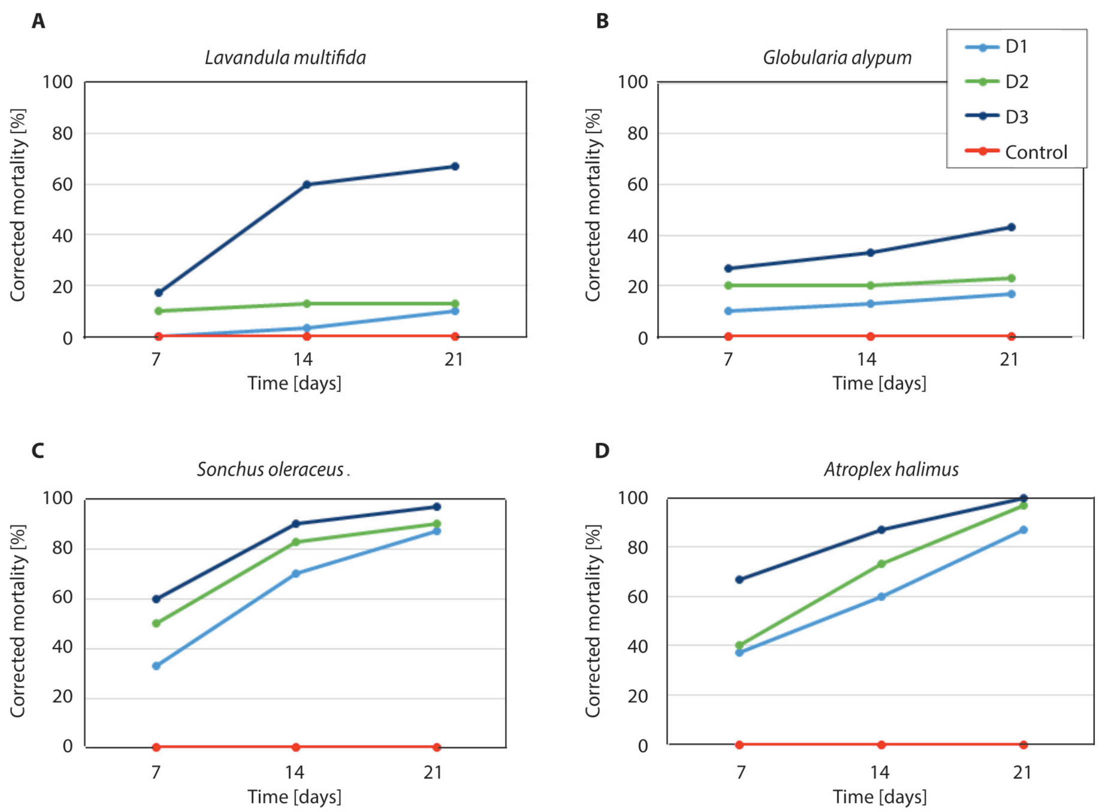

Fig. 2. Percentage change in corrected mortality of *Tribolium castaneum* adults as a function of time and the dose of the studied Saharan plant extracts

the exposure period. As illustrated in Figure 2B, for *G. alypum*, mortality increased with dose, reaching approximately 40% after 21 days for D3, in comparison to the dose of 30% (D2), and 10% (D1), respectively (around 10 to 20%). The effects observed for *L. multifida* (Fig. 2A) were more moderate, with maximum mortality of approximately 60% for D3, while D2 and D1 showed lower rates, at around 20%. In contrast, *A. halimus* (Fig. 2D) and *S. oleraceus* (Fig. 2C) exhibited a more rapid and significant effect, with mortality rates exceeding around 70 to 85% as early as 14 days for D2 and D3, reaching approximately 100% at 21 days. In comparison, D1 demonstrated less efficacy, with mortality rates ranging between 60% and 65% in 14 days. Based on results in Figure 2, comparing the mortality in the highest dose D3, the results showed that *A. halimus* extract exhibited the highest mortality percentage, ranging from 67% to 100%, with highly significant P-values (<0.001) (Table 3). This was followed by *S. oleraceus* extract (60% to 97%), *L. multifida* extract (17% to 67%), and *Globularia alypum* extract (27% to 43%) (Fig. 2).

The LD50, LD90, LT50, and LT90 values represent the lethal doses and times for extracts from four plants (*G. alypum, L. multifida, A. halimus*, and *S. oleraceus*) (Table 3).

The efficacy of *S. oleraceus* was consistently the highest, requiring the lowest doses and shortest times to achieve significant mortality rates. This was indicated by the LD50 (3.76 mg · ml^{-1}), LT50 (2.91 hours), and LT90 (6.89 hours) values. Furthermore, the LT50 (2.91 hours) and LT90 (6.89 hours) values are noteworthy (Table 3). This suggests that *S. oleraceus* contained bioactive compounds that were both rapid and effective in their action against target pests. In contrast, *L. multifida* was the least effective, with the highest LT90 (35.95 hours) (Table 3), indicating the necessity for higher concentrations and longer exposure times to achieve comparable results. This may restrict its practical application without further improvement. The efficacy of *A. halimus* and *G. alypum* was moderate, with *A. halimus* demonstrating greater efficacy at lower doses, while *G. alypum* required the longest time for complete pest mortality (LT90: 445.29 hours) (Table 3).

Overall, *S. oleraceus* was the most promising candidate for developing rapid and efficient plant-based insecticides, while *L. multifida* may require further refinement to enhance its effectiveness. The moderate efficacy of *A. halimus* and *G. alypum* suggests potential for use in specific contexts, depending on the required balance between dose and action time.

The extremely low *P*-values (<0.05) across all lethal doses and times suggest that there are highly significant differences between the effects of the four plant extracts (Table 3).

Antifeedant activity

All extracts provided low antifeedant activity, with indices below 50% (Fig. 3). The *G. alypum* extract showed minimal activity with an index value of 2%. However, *L. multifida* and *S. oleraceus* extracts were slightly attractive, with negative index values of –3% and –0.5%, respectively. The highest antifeedant activity was observed in *A. halimus* with a value of 31.37%.

A chi-square test was performed and revealed a statistically significant association between antifeedant indices and the extracts studied ($\chi^2 = 68.405$, df = 3, $p < 0.001$). The high value of the chi-square statistic and the very low probability suggest that the differences observed were not due to chance. No contingency cell had a theoretical frequency of less than five, confirming the reliability of the results. This association indicates that plant type had a significant influence on antifeedant indices, which should be taken into consideration when managing insect populations.

Preliminary phytochemical screening

Phytochemical screening of the four medicinal plants (*L. multifida, G. alypum, A. halimus and S. oleraceus*) revealed the presence of various bioactive compounds including flavonoids, phenolic compounds, terpenoids and alkaloids known for their insecticidal and antifeedant properties (Table 4). The consistent presence

Table. 3. Lethal dose and time analysis for selected plant extracts

Measure [mg · ml^{-1}]	Plant extracts				Average ± Sd	Variation coefficient	*P*- value
	G. alypum	*L. multifida*	*A. halimus*	*S. oleraceus*			
LD50	7.71	18.77	13.81	3.76	11.01 ± 6.62	0.60	.000
LD90	60.77	48.14	31.33	30.11	42.59 ±14.65	0.34	.000
LT50	23.93	13.59	6.40	2.91	11.71 ± 9.28	0.79	.000
LT90	445.29	35.95	11.27	6.89	124.85 ± 214.01	1.71	.000

LD and LT values are presented with their corresponding 95% confidence limits (CL)

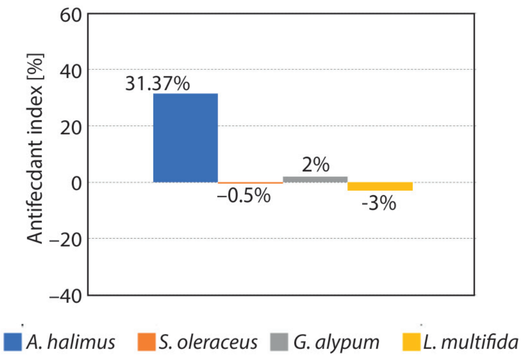

Fig. 3 Antifeedant effects of four different medicinal plant extracts against *Tribolium castaneum* adults

Table 4. Preliminary phytochemical screening results of tested plant extracts

Phytochemical classe	*L. multifida*	*G. alypum*	*A. halimus*	*S. oleraceus*
Alkaloids	–	++++	+	+
Flavonoids	+++	+++	+	++++
Phenolic compounds	+++	++++	++	++
Tannins	+++	++	+	++
Saponins	+	+++	++	–
Terpinoides	+	++++	++	++++
Quinones	++	+++	+++	+
Couramins	++++	++++	++	+
Anthraquinones	++++	+++	++++	++

Very hight – (++++), hight – (+++), moderate – (++), low – (+) and absent – (–)

of these compounds in all plants suggests a potential synergy in their bioactivity against *T. castaneum*. Notably, *A. halimus*, which showed the most significant antifeedant activity (31.37%), was rich in several phytochemicals, such as flavonoids and terpenoids, which may contribute to its strong deterrent effect. Conversely, the weaker antifeedant effects observed in *L. multifida* and *S. oleraceus* (with negative or minimal activity) could be related to the lower or absent concentrations of certain key compounds such as alkaloids.

However, the preliminary screening results indicate that flavonoids, phenolic compounds, and tannins were the predominant phytochemical groups in most of the tested plants. These groups are commonly associated with biological activities such as antioxidant, antimicrobial, and insecticidal effects. Their relative abundance in *G. alypum* and *L. multifida* suggests that they may play a significant role in the observed insecticidal properties. Further detailed chemical analysis would be necessary to identify the specific active compounds responsible for these effects.

The intensity of phytochemical presence was determined using a semi-quantitative scale [(–) – absent, (+) – present in low amount, (++) – moderate, (+++) – high, (++++) – very high], following the visual evaluation method described in previous works (Haddouchi *et al.* 2021; Madike *et al.* 2017).

Discussion

Naboulsi *et al.* (2022) demonstrated that the aqueous extract of *Atriplex halimus* exhibited strong insecticidal activity against *Dactylopius opuntiae Cockerell* (*Dactylopiidae*). This effect was attributed to the high content of triterpenoid saponins according to their LC-MS analysis. Although LC-MS was not carried out in the present study, phytochemical screening confirmed the presence of these compounds, as the bioactive constituents of *A. halimus*, which could contribute to the insecticidal effects observed in these experiments against *T. castaneum*. Similarly, the aqueous extract of *Carica papaya L.* (*Caricaceae*) leaves showed a notable repellent effect against *T. castaneum*, with efficacy rates ranging from 82% to 97%. This effect was attributed to the presence of 2-methoxy-4-vinylphenol (Mangang *et al.* 2020).

Aissani *et al.* (2022) indicated that *S. oleraceus* L. is a rich source of various phytochemicals, such as polyphenols, flavonoids, sterols, triterpenes, and anthraquinone glycosides. These compounds exist in both hydro-methanolic and hot aqueous extracts. This phytochemical profile suggests that this plant may contain important bioactive properties, consistent with the insecticidal activity observed against *T. castaneum* (El-Kamali 2009). The same author, El-Kamali (2009), confirmed that the alcoholic extract of *S. oleraceus* had a high insecticidal effect on *T. castaneum*, with an LC50 value of 20 mg · ml^{-1} after 36 hours. This validates the efficacy of plant extracts in pest control. Furthermore, *S. oleraceus* leaf extracts have shown a certain degree of repellency against cotton mealybugs in the laboratory (Roonjho *et al.* 2013). Although this repellent activity has not been directly tested on *T. castaneum*, it reveals the potential of *S. oleraceus* extracts as a tool for controlling pests, including stored product insects such as *T. castaneum*.

Lavandula multifida revealed significant insecticidal properties. The LC50 value of its essential oil against *Spodoptera littoralis Boisduval (Noctuidae)* was 2.350 mg · ml^{-1}, while it reached 2.91 mg · ml^{-1} 96 hours after treatment for *Agrotis ipsilon* Hufnagel (Noctuidae) larvae. These results, along with the shorter development periods observed in *S. littoralis* larvae and pupae, suggest that *L. multifida* could serve as an effective pest control agent. However, these findings contrast with the absence of a repellent effect of *L. mairei var.*

antiatlantica essential oil against *T. castaneum* (Kanda *et al.* 2017), highlighting the variability of efficacy between different *Lavandula* species.

In comparison, essential oils of *Eucalyptus globulus* Labill. (Myrtaceae) and *Lavandula stoechas* L. (Lamiaceae) showed significant antifeedant effects on *T. castaneum* adults, suggesting that essential oils extracted from different plant species can be used as effective deterrents against this pest (Ebadollahi 2011). However, Kanda *et al.* (2017) reported that the essential oil of *L. mairei var. antiatlantica* showed no deterrent effect on *T. castaneum*, underscoring that the efficacy depends on the plant species and its specific composition. These results align with those observed in the present study. The coefficient of variation further highlights the consistency of LD50 and LD90 values, while differences observed in LT50 and LT90 values suggest that the time required to achieve 50% and 90% mortality may be influenced by other environmental or biological factors.

G. alypum leaves contain high concentrations of polyphenols and flavonoids. Although the extracts showed antioxidant activity, this was less intense than that of the positive control, ascorbic acid (Yahya *et al.* 2023). This suggests that *G. alypum* may possess additional bioactive compounds, although further research is required to determine its insecticidal and repellent activities. Additionally, the elevated mean LT90 observed for *G. alypum* indicates that, despite its rich phytochemical composition, its insecticidal activity may act very slowly, highlighting the complex interactions between phytochemicals and insecticidal efficacy.

Chi-squared test results indicated a significant relationship between plant antifeedant indices and insect feeding behavior.

In the present study, *A. halimus* showed the highest antifeedant index (31.37%), suggesting some deterrent effect. This could be linked to its phytochemical richness, especially phenolic compounds. In contrast, *G. alypum* showed a very low antifeedant index (2%), while *S. oleraceus* and *L. multifida* exhibited negative values (−0.5% and −3%, respectively), indicating slight attractiveness. These variations can be explained by differences in the type and concentration of secondary metabolites, confirming that not all bioactive compounds exert antifeedant effects in the same way. Futhermore, the applied dose and quantity may have an effect. More specific tests are recommended to determine the chemical compounds and their concentrations in the different plant extracts.

This suggests that plant species and the extract doses choice play an important role in regulating plant-insect interactions and acting as a natural deterrent against pests. The absence of theoretical frequency cells of less than five in the chi-square test further validates these results, giving a strong interpretation to the observed results. This could influence insect population management strategies by encouraging the use of specific natural plant species to minimize pest impact and reduce the use of chemical pesticides in crop protection.

These results indicate the possibility of integrating plants' natural antifeedant properties in crop management strategies, serving to promote more sustainable, eco-friendly agricultural practices. However, a direct correlation between antifeedant activity and insecticidal efficacy has yet to be demonstrated, highlighting the necessity for further research in this field.

In summary, the literature supports the efficacy of certain plant extracts, including those derived from *S. oleraceus*, *A. halimus*, and *L. multifida*, in managing insect pests such as *T. castaneum*. However, consistent with the results obtained in the present study, the effectiveness of these extracts can vary depending on the plant species, the type of extract, the target insect, and the applied dose. This highlights the importance of selecting the appropriate plant species and extract type when developing botanical insecticides.

Conclusions

This research underscored the potential of medicinal plant extracts from arid regions to act as natural insecticides against *T. castaneum*. Phytochemical analysis revealed that these plants are rich in bioactive compounds such as flavonoids, terpenoids, and tannins, which may contribute to their insecticidal and antifeedant activities. Among the extracts, *A. halimus* showed the highest antifeedant activity at 31.37%, consistent with its diverse phytochemical profile. In contrast, *L. multifida* and *Sonchus oleraceus* showed lower antifeedant indices of −3% and −0.5%, respectively, but significant insecticidal activity. *G. alypum* had minimal antifeedant activity (2%) and lower insecticidal activity. However, *L. multifida*, despite its insecticidal potential, may not be practical for use as a bioinsecticide due to its small size, which requires a large number of plants to produce a usable amount of extract. Importantly, the study found no direct correlation between antifeedant activity and insecticidal efficacy, suggesting different underlying mechanisms. Overall, these findings highlight the potential of these plant extracts as viable, ecofriendly alternatives to conventional chemical pesticides and support further research into their use in sustainable pest management.

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