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Evaluating the attractiveness of different bait formulations for monitoring *Liriomyza sativae* (Diptera: Agromyzidae) adults

Avaliação da atratividade de diferentes formulações de iscas para monitoramento de adultos de *Liriomyza sativae* (Diptera: Agromyzidae)

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ABSTRACT

The growing need for sustainable agricultural practices drives the search for effective alternatives in pest management. Insects like *Liriomyza sativae* cause significant damage to crops, requiring monitoring and control methods that minimize the use of chemical pesticides. In this context, the use of natural and synthetic attractants for pest capture offers a promising solution while contributing to the preservation of ecological balance. The objective of this work was to study the attractive effect of different formulations for *L. sativae* adults. The formulations were divided into two groups according to their composition. For group 1, they were based on vinegar and sugar, and for group 2, formulations were based on molasses, invert sugar, hydrolyzed protein, and eugenold. The attractiveness of the formulations was evaluated based on free choice. They were placed in tube-shaped plastic containers and randomly arranged in TNT cages. Evaluations were performed every 48 hours by counting the number of adults in the containers until there was a low capture rate. Data were subjected to analysis of variance testing and means were compared using the Scott-Knott test at 5% significance level. All formulations tested were attractive to adults of *L. sativae*, with groups 1 and 2 reaching their maximum averages of 55.60 and 68.00 adults, respectively. Both occurred during the second evaluation. Over time, all formulations showed a reduction in capture rate. The use of effective attractants promotes traps that monitor and even control the pest population in a more sustainable way, benefiting the agroecosystem with sustainable agricultural practices. Furthermore, the research expands knowledge about the chemical ecology of insect pests, providing a basis for the chemical communication of these organisms.

Keywords: miner fly; attractant substances; integrated management; leafminer.

RESUMO

A crescente necessidade de práticas agrícolas sustentáveis impulsiona a busca por alternativas eficazes no manejo de pragas. Insetos como *Liriomyza sativae* causam sérios prejuízos à agricultura, demandando métodos de monitoramento e controle que minimizem o uso de pesticidas químicos. Nesse contexto, a utilização de atrativos naturais e sintéticos para captura de pragas oferece uma solução promissora, ao mesmo tempo em que contribui para a preservação do equilíbrio ecológico. O objetivo deste trabalho foi estudar o efeito atrativo de diferentes formulações para adultos de *L. sativae*. As formulações foram divididas em dois grupos conforme suas composições. Para o grupo 1 foram usadas formulações à base de vinagre e açúcar, e para o grupo 2 foram usadas formulações à base de melaço, açúcar invertido, proteína hidrolisada e eugenol. A atratividade das formulações foi avaliada com base na livre escolha. Elas foram acondicionadas em recipientes plásticos em formato de tubo, dispostas aleatoriamente em gaiolas de TNT. As avaliações foram realizadas a cada 48 horas, contando o número de adultos nos recipientes até que houvesse baixa taxa de captura. Os dados foram submetidos ao teste de análise de variância e as médias comparadas pelo teste de Scott-Knott ao nível de 5% de significância. Todas as formulações testadas foram atrativas para adultos de *L. sativae*, com os grupos 1 e 2 atingindo médias máximas de 55,60 e 68,00 adultos, respectivamente. Ambos ocorreram durante a segunda avaliação. Com o tempo, todas as formulações apresentaram redução na taxa de captura. A utilização de atrativos eficazes promove armadilhas que monitoram e até controlam a população de pragas de maneira mais sustentável, beneficiando o agroecossistema com práticas agrícolas sustentáveis. Além disso, a pesquisa amplia o conhecimento sobre a ecologia química de insetos pragas, oferecendo base na comunicação química desses organismos.

Palavras-chave: mosca minadora; substâncias atrativas; manejo integrado; minadora de folhas.

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Introduction

The leafminer fly *Liriomyza sativae* (Blanchard, 1938) (Diptera: Agromyzidae) is a polyphagous pest that feeds and develops between the upper and lower epidermis of leaves (Liu et al., 2015). The larvae reduce leaf area, impairing photosynthesis and causing losses in production and product quality (Araujo et al., 2013; Fernandes et al., 2019). Its severe damage causes significant losses, especially in vegetable and ornamental crops (Anorbayev et al., 2019; Bragard et al., 2020; Ridland et al., 2020; Supartha et al., 2023). Thus, *L. sativae* is considered a pest of great economic importance in various crops and regions around the world, reducing production by up to 100% (Sadiq et al., 2020).

Synthetic insecticides have been the primary management tactic for this species; however, their effectiveness has decreased due to resistant genotypes and the reduction in natural enemies of *L. sativae* (Fenoglio et al., 2019; Ridland et al., 2020; Supartha et al., 2023). Thus, implementing an integrated management program that includes strategies to reduce synthetic insecticide applications is economically and environmentally important for preserving the agroecosystem (Weddle et al., 2009; Takeda et al., 2020; Paspati et al., 2023).

The use of food stimulants, such as traps containing attractants to capture adult insects, has been applied in pest management (França et al., 2009; Cloonan et al., 2019). The substances in the attractants stimulate chemoreceptors located mainly on the insects' antennae and tarsi, inducing them to change their behavior and move toward these substances for oviposition and feeding (Nation, 2002; Giang et al., 2017). As a result, adult insects are attracted and remain trapped, which have longevity depending on environmental conditions and the type of attractant chosen, lasting from 1–6 weeks without the need for replacement (Navarro-Llopis et al., 2015; Shelly et al., 2020).

Various products have been used as attractants to capture insects, generally derived from secondary metabolism and nitrogenous substances (Kong et al., 2020). Fermented substances such as vinegar, wine, fermenting fruits, and yeasts are used as attractants for various groups, including dipterans (Cha et al., 2015). Sugar solutions based on white and brown sugar are also used to catch dipteran species such as fruit flies. Molasses is another sugary substance used to catch adult insects (Upakut et al., 2017; Stupp et al., 2021). These substances can be used individually or in combination (Candia et al., 2019).

However, the validity of the attractant's effectiveness needs to be studied, as baits become less effective over time (Siegel et al., 2024). Thus, the aim of this study was to evaluate the attractiveness of formulations containing substances that attract *L. sativae* adults and their effect over time.

Materials and methods

The bioassays were performed in the Entomology Laboratory of the Center for Scientific and Technological Development in Plant Health Management of Pests and Diseases at the Campus of Agricultural Sciences and Engineering of the Federal University of Espírito Santo (CCA-UFES), in Alegre, Espírito Santo, Brazil.

Insect acquisition

The *L. sativae* adults were collected from commercial tomato plantations in Piaçu, a district in Muniz Freire, ES, Brazil. The specimens were identified using morphological and molecular techniques by Dr. Viviane Rodrigues de Sousa from the Graduate Program in Biological Sciences (Zoology) at the National Museum of the Federal University of Rio de Janeiro, Brazil.

The creation in the laboratory was carried out according to the methodology of Araujo et al. (2007), using 15-day-old jack bean plants (*Canavalia ensiformis*) grown in plastic cups (200 mL) containing planting substrate. The plants were placed in wooden cages (50 × 40 × 30 cm) containing *L. sativae* adults and a 10% v/v honey solution for 24 hours. After this period, the plants were removed from the cages and placed in plastic trays for five days until the larvae developed. Subsequently, the leaves were cut and hung on wires attached to the iron shelf under the plastic trays for six days, until most of the larvae had turned into pupae. The pupae were collected from the trays using a brush, placed in Petri dishes (9 cm Ø), and sealed with polyvinyl chloride film until the adults emerged, which took an average of eight days. The insects were maintained throughout the cycle at a temperature of 25°C, standard deviation ±2°C, a photoperiod of 12 hours, and a relative humidity (RH) of 60±10%.

Attractiveness of substances by choice

The formulations used to attract *L. sativae* adults were separated into two groups according to the components present in different concentrations in each attractant. Group 1 was comprised of formulations based on banana vinegar, molasses, and citric acid, and group 2 constituted of formulations based on molasses, invert sugar, citric acid, hydrolyzed proteins, and a fruit polyalcohol (sorbitol) added to give the formulation stability. A choice test was conducted for each group of attractants.

The concentrations in % v/v of the substances present in each formulation for each group were as follows:

Group 1

T1: 100% distilled water
F1: 10% banana vinegar+10% molasses+0.5% citric acid
F2: 10% banana vinegar+10% crystal sugar+0.5% citric acid
F3: 10% banana vinegar+10% brown sugar+0.5% citric acid
F4: 10% rice vinegar+10% molasses+0.5% citric acid
F5: 10% apple cider vinegar+10% molasses+0.5% citric acid

Group 2

T1: 100% distilled water
F1: 3% invert sugar+5% molasses+0.5% eugenol+0.5% hydrolyzed protein+0.5% citric acid+0.5% sorbitol
F2: 3% invert sugar+5% molasses+0.5% eugenol+0.5% citric acid+0.5% sorbitol
F3: 3% invert sugar+5% molasses+0.5% hydrolyzed protein+0.5% citric acid
F4: 3% invert sugar+5% molasses+0.5% citric acid

The substances were chosen according to the literature based on tests with other groups of insects, mainly dipterans. The components and concentrations incorporated in each formulation were based on preliminary tests carried out separately with each product.

To evaluate attractiveness by choice, the methodology adopted was based on that of Niogret and Epsky (2018) with adaptations. Briefly, 14 mL of each formulation were placed in plastic tube-shaped containers (8.5 × 3.0 cm) with a 0.5 cm hole for the adults to enter. Subsequently, the tubes containing the treatments were randomly arranged, forming an arena in cylindrical cages (1.0 × 0.5 m) made of breathable non-woven fabric (TNT), without openings and wireframes, with a cardboard base (Figure 1). The *L. sativae* adults used in the experiment were separated beforehand by counting 200 pupae from the same generation for each repetition. After emergence, the adults were released into the center of the cages containing a lima bean plant at a temperature of 25±2°C, a photoperiod of 12 hours, and an RH of 60±10%.

Evaluations were carried out every 48 hours, counting the number of adults in each plastic containers (Figure 2) and replenishing the number of adults captured by the food attractant, so that at the end of each 48-hour evaluation, there would once again be 200 adults in the cage.

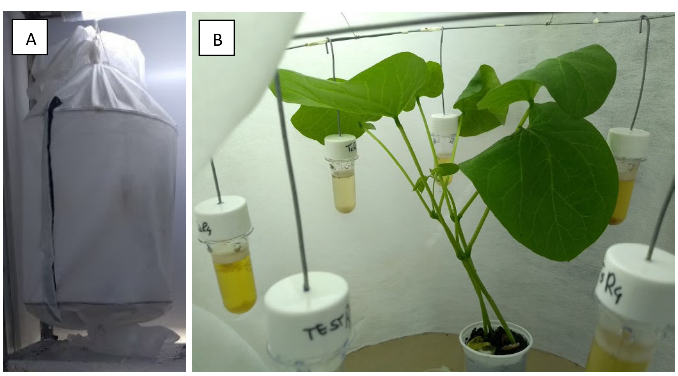

Figure 1 – Bioassay of the attractiveness of substances in *Liriomyza sativae* adults. View of the arena (A) formed internally by plastic tubes containing attractive substances (B).

Figure 2 – Adults of *Liriomyza sativae* captured in plastic tubes containing attractive substances.

By the end of the experiment, approximately 6,250 adults had been used in each formulation group. The 48-hour period was chosen for the evaluation to ensure adequate time for the *L. sativae* adults to take their first flights after emerging. The experiment was conducted over time, with evaluations performed until a minimum adult capture rate was identified, based on the observation of free adults in the cages.

The experiments were conducted in plots subdivided by time using a completely randomized design and ten replicates. Two repetitions of each group were conducted simultaneously to diversify the insects as much as possible and to achieve proper randomization of the adults. For group 1, a factorial design (6 × 6) was used; the group comprised five formulations and a control (water) and was analyzed in six evaluations (I, II, III, IV, V, and VI). For group 2, a factorial (5 × 7) was used; the group comprised four formulations and a control (water) and was analyzed in seven evaluations (I, II, III, IV, V, VI, and VII). The data was evaluated through analysis of variance, and the means were compared employing the Scott-Knott test at a 5% probability in R statistical software (R Development Core Team, 2019).

Comparison of the most attractive formulations in each group

The treatments that proved to be the most attractive from groups 1 and 2 were selected and compared with each other.

The experiment was based on the methodology by Candia et al. (2019), used for the chance attraction tests, with 120 *L. sativae* adults released in the center of each cage.

The assays were conducted in plots subdivided by time with a completely randomized design and ten replications. They were performed using a factorial design (3 × 8), with two formulations, a control, and eight evaluations (I, II, III, IV, V, VI, VII, and VIII). The data was subjected to analysis of variance (F-test), and the means were compared using the Scott-Knott test at 5% probability in R statistical software (R Development Core Team, 2019).

Results

Attractiveness choice experiment

Attraction group 1

For the choice experiment of the formulations in group 1 ($p<0.001$) (Table 1), F1 presented the highest values for the number of insects in evaluations I and II, with 47.00±6.83 and 55.60±5.56, respectively, compared to the other formulations. F1 and F3 showed the highest numbers of insects captured with 38.10±9.80 and 34.20±7.11 in evaluation III, and 24.80±3.01 and 23.50±6.65 in evaluation IV. In evaluation V, P1 and P5 caught the greatest average number of insects, with values of 12.50±2.27 and 14.00±2.26, respectively. In the last evaluation (VI), the highest values were observed for P5, with an average of 11.80±2.44 insects captured. When comparing the formulations in group 1, F1 had a statistically higher number of adults caught than that of the other formulations and the control in all five evaluations, ranging from 12.50 to 55.60 (Figure 3) on average. The lowest capture rates, regardless of evaluation, were recorded with the F4, which ranged on an average from 0.87 to 21.10.

The highest catch rates for each formulation were observed in the first two evaluations, which were statistically superior to the others, except for the control and F5, wherein the catches were similar in all evaluations. Moreover, the catch rates decreased over the course of the evaluations (Figure 3).

Thus, as per these findings, we designated F1 as the most likely to be used in a pest management program.

Table 1 – Average number of *Liriomyza sativae* adults caught every 48 hours in attractant formulations (group 1) in a laboratory with a choice of options at a temperature of 25±2°C and relative humidity of 60±10%.

Formulations						
Evaluation[1]	T[2]	F1[3]	F2[4]	F3[5]	F4[6]	F5[7]
Average number of insects						
I	0.00±0.00Fa*	47.00±6.83Ab	34.10±4.20Ca	42.90±6.24Ba	21.10±5.34Da	16.80±4.05Ea
II	0.10±0.32Ea	55.60±5.56Aa	37.10±4.04Ca	44.70±7.45Ba	16.10±6.28Db	15.50±3.98Da
III	0.10±0.32Ea	38.10±9.80Ac	29.30±5.93Bb	34.20±7.11Ab	8.70±6.55Dc	13.40±3.24Ca
IV	0.10±0.32Ca	24.80±3.01Ad	13.30±3.56Bc	23.50±6.65Ac	2.89±2.09Cd	14.40±2.01Ba
V	0.30±0.67Ca	12.50±2.27Ae	7.90±4.47Bd	7.20±5.90Bd	2.30±1.33Cd	14.00±2.26Aa
VI	0.30±0.95Ca	7.40±3.17Bf	3.30±4.29Ce	2.40±1.58Ce	0.87±1.12Cd	11.80±2.44Aa

*Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ significantly at a 5% probability using the Scott-Knott test; [1]: evaluations every 48 hours; [2]T: witness; [3]F1: 10% banana vinegar+10% molasses+0.5% citric acid; [4]F2: 10% banana vinegar+10% white sugar+0.5% citric acid; [5]F3: 10% banana vinegar+10% brown sugar+0.5% citric acid; [6]F4: 10% rice vinegar+10% molasses+0.5% citric acid; [7]F5: 10% apple cider vinegar+10% molasses+0.5% citric acid.

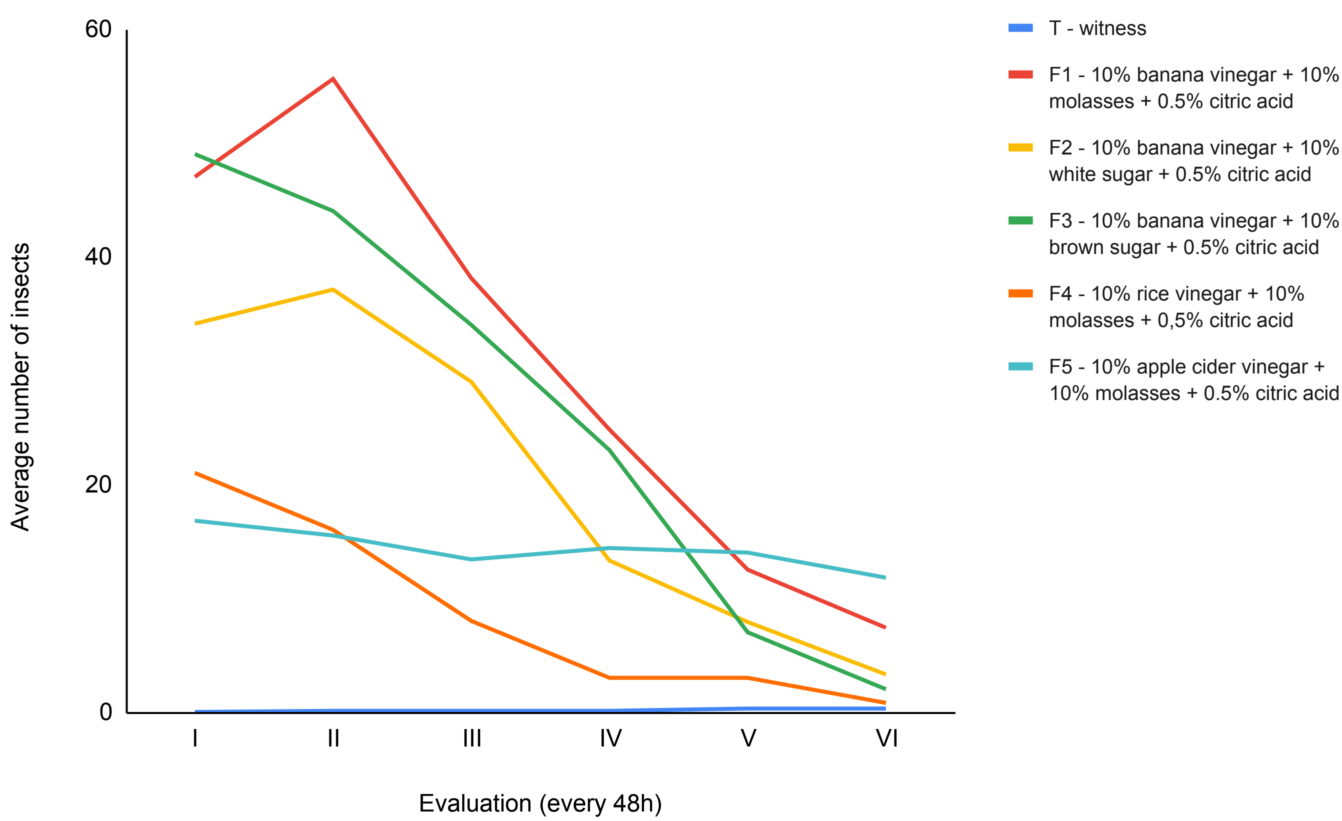

Figure 3 – Average number of adults of *Liriomyza sativae* caught every 48 hours in attractant formulations (group 1) in a laboratory with a choice of options at a temperature of 25±2°C and relative humidity of 60±10%.

Attraction group 2

Regardless of the evaluation, F3 had the highest catch rates in group 2 ($p<0.001$), ranging on an average from 7.90±2.99 to 68.00±4.14 adults; these rates were statistically higher than those of the other formulations and the control (Figure 4). Except for the control, the other formulations in group 2 exhibited the highest catch rates between the II and IV evaluations. The lowest rates were observed in the I, V, VI, and VII evaluations (Table 2; Figure 4).

In this group, the F3 had the highest performance compared to other formulations and the control and could also be used in pest management programs.

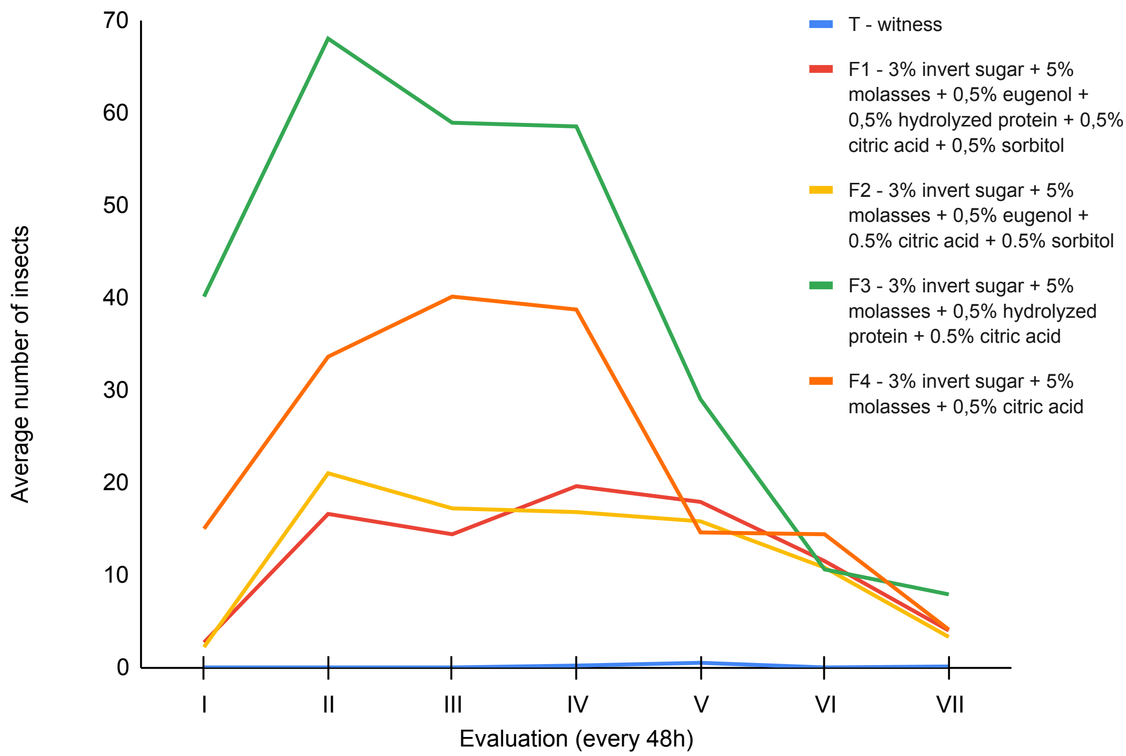

Figure 4 – Average number of adults of *Liriomyza sativae* captured every 48 hours in attractant formulations (group 2) in a laboratory with a choice at a temperature of 25±2°C and relative humidity of 60±10%.

Table 2 - Average number of *Liriomyza sativae* adults captured every 48 hours in attractant formulations (group 2) in a laboratory with a choice at a temperature of 25±2°C and relative humidity of 60±10%.

	Formulations				
Evaluation[1]	T[2]	F1[3]	F2[4]	F3[5]	F4[6]
	Average number of insects				
I	0.00±0.00 Ca*	2.70±1.72 Cc	2.20±1.14 Cd	40.10±7.39 Ac	15.00±4.52 Bc
II	0.00±0.00 Ea	16.60±3.37 Da	21.00±3.20 Ca	68.00±4.14 Aa	33.60±5.62 Bb
III	0.20±0.42 Da	14.40±3.20 Cb	17.20±3.94 Cb	58.90±7.68 Ab	40.10±6.35 Ba
IV	0.20±0.42 Da	19.60±3.69 Ca	16.80±2.28 Cb	58.50±7.91 Ab	38.72±6.80 Ba
V	0.50±0.85 Ca	17.90±2.69 Ba	15.80±4.57 Bb	29.00±6.32 Ad	14.63±4.02 Bc
VI	0.00±0.00 Ba	11.50±4.58 Ab	10.80±4.71 Ac	10.60±3.57 Ae	14.41±4.30 Ac
VII	0.10±0.32 Ba	4.00±3.09 Bc	3.30±2.79 Bd	7.92±2.99 Ae	4.10±2.51 Bd

*Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ significantly at 5% probability using the Scott-Knott test; [1]: evaluations every 48 h; [2]T: witness; [3]F2: 3% invert sugar+5% molasses+0.5% eugenol+0.5% hydrolyzed protein+0.5% citric acid+0.5% sorbitol; [4]F3: 3% invert sugar+5% molasses+0.5% eugenol+0.5% citric acid+0.5% sorbitol; [5]F4: 3% invert sugar+5% molasses+0.5% hydrolyzed protein+0.5% citric acid; [6]F5: 3% invert sugar+5% molasses+0.5% citric acid.

Comparison between selected formulations of each group of attractions

Based on the results of the previous experiments, F1 was selected for attractant group 1 (10% v/v banana vinegar+10% v/v molasses+0.5% v/v citric acid), and compared with F3 of attractant group 2 (3% v/v invert sugar+5% v/v molasses+0.5% v/v hydrolyzed protein+0.5% v/v citric acid) due to their superior attractiveness for *L. sativae* adults (Table 3).The average number of adults caught using the two formulations (F1 and F3) were significantly higher than that using the control formulation (Figure 5).

About the catch rate during the evaluations, there was no predominance of any formulation, but the highest catch rates were found in the first three evaluations for F1, and only in the first evaluation for F3 (Figure 5).

Discussion

According to the results obtained in the experiments and on comparing each formulation with the respective control, all the formulations were found to be attractive to *L. sativae* adults. This attractiveness of adults to the tested formulations may be related to the perception of the volatiles emitted by the substances and the consequent change in behavior towards them, which stimulated the insect's nervous system through valence reversal (Chapman, 1998; Cheng et al., 2019).

Species belonging to the genus *Liriomyza* use various resources of the sensory system to perform different functions that work simultaneously and in sequence. Among these resources, olfaction is considered the most important due to the use of kairomones to locate hosts and sexual partners (Kang et al. 2009), in addition to inhibiting certain behaviors to protect the insect itself (Cheng et al., 2019).

Table 3 – Average number of *Liriomyza sativae* adults caught in attractant formulations in the laboratory every 48 hours at a temperature of 25±2°C and relative humidity of 60±10%.

	Formulations		
Evaluation	T[0]	F1[1]	F3[2]
	Number of adults		
I	1.33±1.93Ca*	18.67±3.39Ba	22.22±4.49Aa
II	0.71±0.71Ba	18.55±4.58Aa	15.66±5.15Ab
III	1.00±0.73Ca	20.00±3.46Aa	13.55±4.09Bb
IV	1.62±1.68Ba	15.11±4.04Ab	16.00±4.47Ab
V	0.55±0.52Ba	13.44±4.18Ac	11.44±3.50Ac
VI	0.88±1.05Ba	13.00±5.42Ac	10.44±2.40Ac
VII	0.88±1.05Ca	9.11±2.93Ad	4.55±3.94Bd
VIII	0.77±0.66Ba	8.66±4.63Ad	2.66±2.06Bd

*Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ significantly at 5% probability using the Scott-Knott test; [0]T: witness; [1]F1: 10% banana vinegar+10% molasses+0.5% citric acid (group 1); [2]F3: 3% invert sugar+5% molasses+0.5% hydrolyzed protein+0.5% citric acid (group 2).

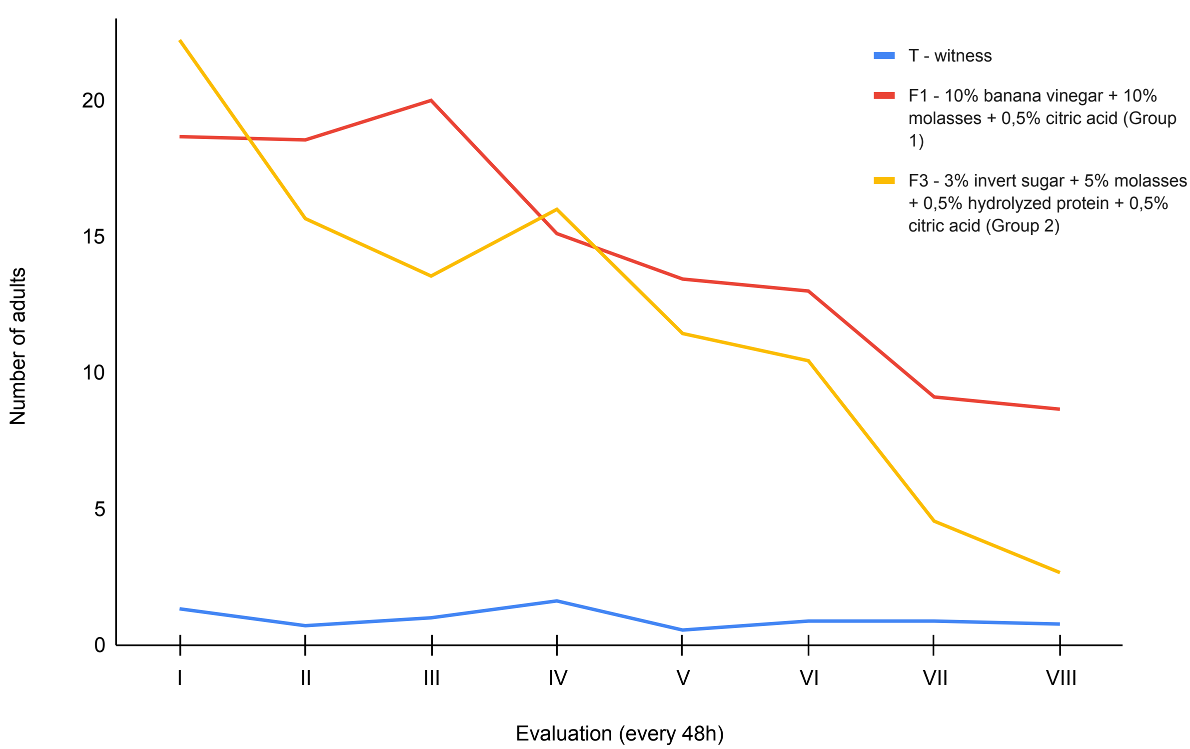

Figure 5 – Average number of *Liriomyza sativae* adults caught in attractant formulations in the laboratory every 48 hours at a temperature of 25±2°C and relative humidity of 60±10%.

This specialization of the olfactory system is a consequence of a structure present in the antennae of males and females, whose function is to increase the receptive capacity and concentrate olfactory stimuli (Zhao and Kang, 2002); it is also found in other dipteran species such as *Ceratitis capitata* (Wiedemann, 1824) (Diptera: Tephritidae) (Mayo et al., 1987) and *Drosophila* adults (Cheng et al., 2019). Therefore, the positive response of *L. sativae* adults to the odors emitted by the attractive substances may be associated with this specialization and efficiency of the olfactory system.

The strongest attractiveness in group 1 was observed with the presence of banana vinegar combined with molasses compared to that with the use of apple cider vinegar and rice vinegar. The strong attractiveness of *L. sativae* adults to this formulation may be because of their attraction to the compounds released during banana fermentation. This was found by Arios-Caro et al. (2024) when testing different baits for the dipterans *Drosophila suzukii* and *Zaprionus indianus* in figs. They described that the fermentation of yeast present in a formula in natural baits was the only that obtained satisfactory capture rate results, indicating that vinegar is not the main attraction. This result was verified by Cruz (1988), who stated that attractants containing mashed banana with molasses were more efficient than apple cider vinegar and grape vinegar for *Liriomyza huidobrensis*. The mixture of banana and molasses also proved attractive to other insect species such as *Rhynchophorus palmarum* (Linnaeus, 1764) (Coleoptera: Curculionidae) compared to other attractants containing pineapple and was similar to traps containing pheromones (Murguía-Gonzales et al., 2018). According to Plata-Rueda et al. (2016), the fermentation of attractants containing banana in their composition produces a greater quantity of compounds such as ethanol, pentane, and ethyl acetate, which are attractive to some groups of insects, than the fermentation of attractants that do not contain banana.

The presence of molasses in group 1 formulations favored the capture of *L. sativae* adults compared to other formulations containing other sugar sources. Although the sugars originate from the same raw material as molasses, the substances present in the volatiles emitted differ by quantity and chemical group (El-Sayed et al., 2005). Molasses contains compounds formed by the decomposition and microbial degradation of the fermentation products, including acetaldehyde and ethanol, which are considered attractive to dipterans (Quinn et al., 2007) and other groups of insects (Brezolin et al., 2018), and differ from compounds found in fermented sugar or unfermented molasses (Verhulst et al., 2023). Other compounds present in the chemical composition of molasses aroma are esters, such as ethyl acetate produced by the species *C. capitata*, that are attractive and present in the pheromones of various insect groups (El-Sayed et al., 2005). Therefore, due to the characteristics of the odors emitted by molasses, this substance was significantly effective in attracting *L. sativae* adults.

The attractiveness of the formulations containing eugenol was lower than that of the other formulations. Similar results were found in smell tests carried out in olfactometers, in which the adults of *L. sativae* responded non-significantly to this isolated compound, despite it being present in the leaves of tomato plants; by contrast, the adults responded significantly to the smells coming from the plants. Therefore, attractiveness to odors is often associated with a set of substances, as in tomato plants, and not just an isolated compound (Zhao and Kang, 2002). In addition, the concentration of the compound can interfere with attractiveness, because when insects encounter an attractive odor source, the response is usually a function of a group of volatiles emitted simultaneously, since a certain compound may only be indirectly related to attractiveness (Cha et al., 2015; Devescovi et al., 2024). Therefore, although eugenol is a compound present in tomato plants, it alone does not confer attractiveness to *L. sativae* adults, and the choice of tomato plants as hosts may be associated with the mixture of volatile compounds present in the plant.

The presence of hydrolyzed protein in the attractant formulations that did not contain eugenol favored the attractiveness of *L. sativae* adults (F3 of group 2: 3% v/v invert sugar+5% v/v molasses+0.5% v/v hydrolyzed proteins+0.5% v/v citric acid). This activity may have resulted from the necessity of ingesting protein substances for ovarian development, sexual maturation, increased egg production, and increased mating rate and longevity that occurs in several insect species, especially in the pre-oviposition period (Guimarães et al., 2009); these species include dipterans (Biasazin et al., 2018; Lasa and Williams, 2021) and *Liriomyza* sp. In addition, newly emerged adults concentrate their activities on dispersing and locating food sources (Epsky et al., 2014), and their response pattern to attractive odors is related to physiological factors such as age, sex, and nutritional status (Lasa and Williams, 2021). The *L. sativae* adults used in the experiments were newly emerged; so, their demand to feed prioritized the search for food resources and, consequently, the attraction to formulations containing these resources. Although hydrolyzed proteins were unable to attract *L. sativae* adults in studies by Rocha et al. (2010), mixing it with other components such as molasses and invert sugar favored the capture of adults; this discrepancy in the responses could be due to the different smells emitted. However, in the experiments carried out by Rocha et al. (2010), hydrolyzed corn protein was used, whereas in the present study, hydrolyzed whey protein was used. Therefore, the type of product may alter the attractant responses of *L. sativae* adults.

Over time, all the formulations reduced their attractiveness due to the presence of contaminants and the consequent deterioration of the compounds. For group 1, evaluations were carried out over 12 days, whereas for group 2, the evaluations were carried out over 14 days. Similarly, protein-based attractants were assessed for an average of ten days by Raga and Vieira (2015), which resulted in a reduction in their attractiveness to fruit flies (*C. capitata*) due to the deterioration processes. According to Mazor et al. (2002), ammoniacal nitrogen is the main component in the decomposition of attractants based on molasses and proteins. Some fruit fly species such as *Anastrepha obliqua* (Macquart, 1971) (Diptera: Tephritidae) are attracted to this compound at high concentrations, whereas other species are attracted at low concentrations (Lasa et al., 2020). Although some species of Diptera are attracted to this decomposition product, the rejection range is extremely wide (Mazor, 2018). Therefore, the low attractiveness to *L. sativae* adults at the end of the evaluations may have resulted from the high rate of ammoniacal nitrogen release. In addition, substances with a lower pH have a faster decomposition rate (Heath et al., 2009). The formulations used in the experiment had citric acid as a preservative. As it is an acid, this may have been the factor that reduced the pH, thereby favoring the decomposition of the substances.

As a determining factor, the attraction time of the baits must be considered for effective use in pest control, as it directly influences how often the baits need to be replaced (Raga and Souza Filho, 2021). The experiment indicates that for use as pest control traps, careful management with periodic replacement of the baits would be necessary. However, the strong initial attractiveness of the baits, especially those containing banana and molasses, suggests that they could be a promising tool for controlling *L. sativae*, capturing many adults in the first days and reducing the population. The use of these baits as sentinel traps would also be a viable strategy for monitoring agricultural areas, allowing early detection and rapid intervention in pest control (Raga and Souza Filho, 2021).

Conclusion

All tested formulations proved effective in attracting *L. sativae* adults and reducing the damage caused by these insects. Although all formulations showed a decrease in attractiveness over time, the best formulations should be tested in the field to evaluate their effectiveness in capturing *L. sativae* adults and other species. This would expand the potential of the formulations for both monitoring and effective pest control under agricultural conditions.

Authors' contributions

Oliveira, A.C.L.F.: investigation; methodology,; validation; writing — original draft; visualization. **Pratissoli**, D: conceptualization; funding acquisition; supervision; resources; validation. **Tamashiro**, L.A.G.: investigation; methodology; data curation; validation. **Oliveira**, R: conceptualization; project administration; writing - original draft. **Piffer**, A.B.M.: software; ; writing — review & editing.

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