

## Efficacy of various attractants to the Mediterranean fruit fly *Ceratitidis capitata* (Diptera: Tephritidae) under laboratory condition

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### ABSTRACT

The Mediterranean fruit fly *Ceratitidis capitata* (Diptera: Tephritidae) causes substantial economic losses worldwide. The attractiveness of protein hydrolysates (mainly corn, fish, wheat, wheat gluten, and yeast), commercial fruit juices (apple, pomegranate, grape, mango, orange, cherry), and chemical additives (mainly ammonium acetate, ammonium bicarbonate, sodium benzoate, sodium metabisulfite, citric acid) was evaluated. Bioassays were conducted under controlled laboratory conditions ( $28 \pm 1$  °C,  $55 \pm 5\%$  RH, 16:8 h L:D) using a six-arm olfactometer with five independent replicates. Attraction was measured as the mean number of adults per trap (APT). Among protein hydrolysates, corn hydrolysate exhibited the highest attraction of  $14.6 \pm 0.99$  APT, significantly greater than all others, while yeast autolysate was least attractive ( $0.9 \pm 0.23$  APT). Among fruit juices, apple juice was significantly the most effective ( $7.73 \pm 0.49$  APT), while orange juice showed the weakest response ( $3.5 \pm 0.5$  APT). Among chemical additives, 5% ammonium acetate was most significantly attractive ( $10.2 \pm 1.4$  APT). For all treatments, females responded significantly more strongly than males ( $P < 0.05$ ). Females responded significantly more strongly than males across all treatments. Combined treatments showed enhanced attraction exceeding individual attractants. In the final comparative experiment, the selected formulations from the preceding optimization stages containing 2% ammonium acetate, 6% corn hydrolysate, and 2% apple juice showed the highest attraction response ( $12.6 \pm 0.63$  APT) and was selected as the final optimal formulation. These findings demonstrate that integrating attractants can substantially enhance bait attractiveness and offer a potentially sustainable strategy for *C. capitata* management. However, these results are from laboratory assays, and field validation is required.

**Keywords:** Attractants, Integrated pest management, Olfactometer, Protein hydrolysate, Trap.

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## INTRODUCTION

The Mediterranean fruit fly, *Ceratitidis capitata* (Diptera: Tephritidae), is a major agricultural pest worldwide (Papadopoulos *et al.*, 2001). This polyphagous, highly mobile species (Mcquate and Liquido, 2017) affects international fruit trade. As an aggressive invasive species, it threatens fresh fruit production outside its current distribution (Papadopoulos *et al.*, 2013; Tay and Gordon, 2019). *C. capitata* has spread from East Africa to South and Central America via Mediterranean countries and is now frequently detected in California and Central Europe (Giunti *et al.*, 2023). This pest was first recorded in Iran in 1975 in Mashhad (Gholamian *et al.*, 2013), and subsequently spread to other regions, particularly the northern provinces, where it causes both quantitative and qualitative economic losses to a wide range of fruits (Mirsardoo *et al.*, 2010; Ahmadi *et al.*, 2021; Samadaei *et al.*, 2024).

Control methods include visual and olfactory attractants. Fluorescent yellow traps exploit positive phototaxis (Lasa *et al.*, 2015). Combined methods, including Sterile Insect Technique (SIT) (Plá *et al.*, 2021), baits (Medina *et al.*, 2004), hygiene practices, and conservation management (Messing, 1999), significantly reduce populations. Chemical pesticides, including toxic baits applied via ground or aerial spraying (Raga and Sato, 2005; Raga and Sato, 2011), remain the primary control method. These baits combine food-based ingredients with insecticides (Medina *et al.*, 2004). Protein hydrolysate-based baits are important tools for managing fruit flies on farms, particularly for female-targeted monitoring and control (Messing, 1999). Yeast extract is widely used because of its low cost and nutritional value (Tao *et al.*, 2022). Field studies show variation among trap-bait systems: Jackson traps with Tri-Medlor capture more males, while Tephritrap with Ceratrap attracts more females (Mafi Pashakolaei, 2021). Combining Diptrex with Iranian protein hydrolysate or Ceratrap improves attraction (Soleymani *et al.*, 2022). Fruit juice-based baits show seasonal variation, with juice-based traps reducing costs and nontarget impacts (Suárez *et al.*, 2023).

Although previous studies have examined various attractants for *C. capitata*, significant gaps remain. First, most prior work has focused on field evaluations of commercial traps, which are subject to confounding environmental variables and do not allow for controlled comparison of attractant components (Pezhman *et al.*, 2011). Second, no systematic investigation has simultaneously optimized combined formulations with specific ratios under controlled laboratory conditions. Third, quantitative data on the efficacy of locally available formulations in Iran remain

limited (Soleymani et al., 2022). Therefore, the primary objective of this study was to systematically evaluate and optimize attractants for *C. capitata* under controlled laboratory conditions. The specific aims were to: (1) compare the relative attractiveness of individual components (six protein hydrolysates, six fruit juices, and seven chemical additives); (2) quantify sex-specific responses to these attractants; and (3) determine the optimal mixing ratios for combinations. We hypothesized that combined attractants at specific ratios produce enhanced attraction surpassing individual components. Testing individual components establishes baseline activity, while combinations identify higher interactions crucial for cost-effective formulations.

## MATERIAL AND METHODS

### Mediterranean fruit fly

Adult flies were obtained from the insectary of the Agricultural Research Institute of Nuclear Sciences and Technologies, Karaj. The colony was maintained at 25 °C, 70% RH, 12:12 h L:D photoperiod. Age-matched adults (3-day-old) were starved for 24 h before experiments. Sixty flies (30 males, 30 females) were released into the olfactometer central chamber.

### Olfactometer device

The olfactometer used in this study was a cube measuring 50 × 35 × 50 cm, with circular openings (15 cm in diameter) on both sides for introducing flies into the chamber. The apparatus consisted of two main sections: an upper and a lower part. The upper section contained six chambers designed to hold different protein hydrolysate treatments; these chambers were laser-cut and served as odor chambers inside the device. Each chamber also had two lateral openings to facilitate odor diffusion throughout the system. The chambers were removable, allowing independent evaluation of different treatments. The cube included four side arms, each about 20 cm wide and 50 cm long. In the lower section, a fixed central chamber (14 cm × 14 cm × 14 cm) was connected to a central Plexiglas rod. As illustrated in Fig. 1, the system operated by pumping air into the six chambers, allowing attractant odors to disperse throughout the device and attract starved flies toward the treatment sources. Equipment was cleaned with 70% ethanol between replicates to prevent odor contamination.

## Attractant materials used

Materials were classified into four groups: protein hydrolysates (corn, fish, wheat, wheat gluten, yeast extract, yeast autolysate), commercial fruit juices (apple, pomegranate, grape, mango, orange, cherry), chemicals additives (ammonium acetate, ammonium bicarbonate, sodium benzoate, sodium metabisulfite, citric acid, sorbic acid, ascorbic acid), and water (Table 1). Formulations were combined at predetermined concentrations and evaluated.

## Experimental approaches

For experiments, conditions were adjusted to  $28 \pm 1$  °C,  $55 \pm 5\%$  RH, and a 16:8 h L:D to simulate optimal foraging conditions and maximize fly activity. Protein hydrolysates with a distilled water control were tested at 1% (w/v). Corn and yeast extracts, showing the highest attraction, were selected for further testing. Six commercial fruit juices were evaluated; apple juice was the most attractive. Chemical additives were tested at 1%, 3%, 5%, 7%, and 10% (w/v); ammonium acetate and sodium benzoate were chosen for combination trials. Combined formulations were prepared by blending ammonium acetate, corn protein hydrolysate, and apple juice in 100 mL of distilled water. The specific concentrations and ratios of all formulations tested are detailed in Table 2. The optimization was performed sequentially, with the best-performing formulations from each preceding experiment carried forward to the final comparative experiment. The final experiment was therefore used to compare the selected candidate formulations from the preceding optimization stages under identical experimental conditions and to identify the final optimal formulation. For each bioassay, 35 mL of the prepared formulation was placed in sterilized chambers. A Boyu® pump supplied air through activated charcoal to distribute odors for 3-4 h. For each bioassay, 30 male and 30 female flies (3-day-old, starved for 24 h) were released. After odor dispersion, airflow was discontinued, and the apparatus was maintained under laboratory conditions for 24 h, after which captured flies were counted (Fig. 1). The 6-arm olfactometer enables simultaneous comparison of up to six attractants, reducing variability (Asadi Ahangarkolai, 2022). Dimensions allow full expression of tephritid zigzag flight patterns during odor orientation (Landolt *et al.*, 1992). The 24-h exposure period was based on preliminary trials showing maximum capture within 12-18 h.

## Statistical analysis

The experiment used a randomized complete block design (RCBD) with five independent replicates (blocks). The experimental unit was a single olfactometer run containing 60 adult flies (30 males and 30 females). Within each block, treatments were randomly assigned to positions within the olfactometer to minimize positional bias. The block factor accounted for temporal variation across experimental runs. Prior to analysis, data were tested for normality using the Shapiro-Wilk test and homogeneity of variances using Levene's test. When assumptions were violated, data were transformed using  $\log_{10}(x+1)$ . A mixed-design repeated-measures general linear model (GLM) was conducted using SPSS. The two repeated measures, Male and Female, served as the two levels of a within-subject factor named sex. Polynomial contrasts were specified for this within-subject factor. Treatment was included as a between-subjects factor. Block was declared as a covariate but was not entered into the between-subjects design, so it did not adjust the treatment effect. Type III sums of squares were used, and the significance level was set at  $\alpha = 0.05$ . The model tested the within-subject main effect of sex, the between-subjects main effect of treatment, and the sex  $\times$  treatment interaction. Treatment means were separated using Tukey's HSD test at  $\alpha = 0.05$ . All analyses were performed using IBM SPSS Statistics version 27.0.0.

## RESULTS

### Protein hydrolysate attractiveness

Corn protein hydrolysate showed the highest attractiveness ( $14.6 \pm 0.99$  APT), while yeast autolysate was the lowest ( $0.9 \pm 0.23$  APT) (Fig. 2). There was a significant effect of treatment and sex on fly attraction ( $P < 0.001$ ; see Fig. 3 caption for full statistical details). Females showed greater attraction than males (Fig. 3), with corn hydrolysate attracting  $17 \pm 1.04$  APT females vs.  $12.2 \pm 0.66$  APT males. Yeast autolysate attracted only  $1.4 \pm 0.24$  APT females and  $0.4 \pm 0.24$  APT males.

### Fruit juice attractiveness

Apple juice was most attractive ( $7.73 \pm 0.49$  APT); orange juice was least ( $3.5 \pm 0.5$  APT) (Fig. 4). Female response was stronger ( $9.33 \pm 0.63$  APT) than males ( $6.13 \pm 0.48$  APT). Orange juice had the lowest female ( $4.6 \pm 0.67$  APT) and male ( $2.4 \pm 0.24$  APT) attraction (Fig. 5).

**Chemical additive attractiveness**

At varying concentrations (1%, 3%, 5%, 7%, 10% w/v), 5% ammonium acetate was most attractive ( $10.2 \pm 1.4$  APT), while 10% sodium metabisulfite was least attractive ( $1 \pm 0.21$  APT) (Fig. 6). Females showed greater attraction than males (Fig. 7).

**Optimization of combined formulations**

The optimization procedure was conducted sequentially. At each stage, the best-performing formulation were selected and carried forward to the final experiment. The combination of corn protein hydrolysate, ammonium acetate, sodium benzoate, and apple juice significantly increased attraction. The formulation with corn hydrolysate, 1% ammonium acetate, and 1% sodium benzoate showed the highest capture:  $15.8 \pm 1.01$  APT (males) and  $18.6 \pm 0.81$  APT (females) (Fig. 8).

Corn protein hydrolysate concentration optimization showed 1% was most effective ( $12 \pm 0.77$  APT), with females ( $13.6 \pm 0.92$  APT) outperforming males ( $10.4 \pm 0.74$  APT) (Figs. 9a, b). Corn hydrolysate + ammonium acetate optimization identified 9% corn hydrolysate + 1% ammonium acetate (F1; Table 2) as the most attractive ( $8.2 \pm 0.53$  APT). Females ( $9.2 \pm 0.58$  APT) showed higher attraction than males ( $7.2 \pm 0.66$  APT) (Figs. 10a, b). Adding apple juice at varying concentrations identified 2% ammonium acetate, 6% corn hydrolysate, and 2% apple juice (F8; Table 2) as most effective ( $7.3 \pm 0.65$  APT), with females at  $8.2 \pm 0.8$  APT and males at  $6.4 \pm 0.92$  APT (Figs. 11a, b).

In the final comparative experiment, the formulations selected as the best-performing treatments from the preceding optimization stages were compared under the same experimental conditions. Among these final candidate formulations, F8 (2% ammonium acetate, 6% corn protein hydrolysate, and 2% apple juice) showed the highest attraction response ( $12.6 \pm 0.63$  APT) and was therefore selected as the final optimal formulation. Females ( $14.0 \pm 0.83$  APT) showed greater attraction than males ( $11.2 \pm 0.37$  APT) (Figs. 12a, b).

**DISCUSSION**

*C. capitata* is among the most important invasive agricultural pests (Giunti *et al.*, 2023). Developing effective, sustainable attractants is a major focus of IPM programs. In the present study, three-day-old flies starved for 24 hours before the experiment showed the strongest

attraction, indicating responsiveness to food-derived volatiles. Under favorable conditions, the insects moved from the bottom of the chamber toward the top. They approached the protein hydrolysate source in a horizontal zigzag pattern, indicating odor-mediated orientation and active olfactory searching behavior. This behavioral pattern is consistent with previous reports describing the orientation responses of tephritid flies to food-derived odor cues (Wakabayashi and Cunningham, 1991). The observed behavioral responses provided a reliable basis for comparing the attractiveness of the tested bait formulations under controlled laboratory conditions.

#### Effectiveness of protein-based attractants

The consistent female-biased attraction observed across all experiments aligns with the reproductive biology of *C. capitata*. Females require protein for egg maturation and are therefore more responsive to nitrogen-rich food sources (Chapman *et al.*, 1998). This finding supports the development of female-targeted control strategies, which are particularly valuable for population suppression (Vargas *et al.*, 2010). Corn protein hydrolysate was most attractive; yeast autolysate was the weakest, likely due to differences in amino acid composition, nitrogen content, and peptide profile. Similar trends were observed, with corn and fish hydrolysates consistently eliciting stronger responses. Previous studies reported strong attraction to plant proteins like corn and soybean, depending on pH, additives, and stability (Casaña-Giner *et al.*, 2001). Soybean protein alone shows limited attraction without auxiliary attractants (Mazor *et al.*, 1987). Yeast hydrolysates are unstable under humid conditions (Netto *et al.*, 1998). Combining proteins with ammonium compounds is essential for stronger attraction (El-Afify *et al.*, 2024; El-Kareim *et al.*, 2008). Field and laboratory studies showed Ceratrap was more effective than yeast extract (Asadi Ahangarkolai, 2022). Corn and fish hydrolysates also outperformed yeast in this study.

Superior corn hydrolysate performance may be attributed to: (1) higher proportions of nitrogen-rich amino acids (glutamine, proline, leucine) serving as precursors for volatile nitrogenous compounds (El-Afify *et al.*, 2024); (2) peptide size distribution facilitating controlled volatile release (Wang *et al.*, 2021); (3) superior fermentation stability (Piñero *et al.*, 2020); (4) Maillard reaction products contributing additional attractive volatile compounds (Kouloussis *et al.*, 2022). However, these mechanistic explanations remain speculative, as this study did not include detailed chemical analysis. We hypothesize that corn protein hydrolysate contains specific free amino acids serving as volatile precursors, requiring verification through future chemical analyses. Protein

source and nitrogen content appear to be major determinants of bait attractiveness (El-Metwally, 2018; Piñero *et al.*, 2020). The most effective formulation combined corn protein hydrolysate, ammonium acetate, and sodium benzoate, with females responding more strongly.

### Effectiveness of fruit juice-based attractants

This section evaluated the attractiveness of six industrial fruit juices. Apple juice showed high attractiveness, and grape, pomegranate, and mango showed moderate effects. Although grape juice can act as an attractant due to its sugars and volatile phenolics, its effect is generally weaker and less stable than other fruit juices (Herrera *et al.*, 2016). Differences in effectiveness among juices are mainly related to variations in chemical composition and fermentation products. Apple juice is particularly attractive due to its sugars and malic acid, which stimulate feeding behavior, and its volatile compounds—such as esters, aldehydes, and alcohols—are known to elicit olfactory responses in *C. apitata* (Antonatos *et al.*, 2023). Previous studies have confirmed the effectiveness of fruit juice-based attractants, with orange juice being particularly effective (Guillemain *et al.*, 2021; Suárez *et al.*, 2023). In addition, fruit juices provide simple sugars that stimulate feeding and enhance bait attractiveness, especially when combined with proteins or chemical additives (Piñero *et al.*, 2020). Overall, fruit type and processing method strongly affect attractant performance, and selecting suitable fruit juices can improve bait effectiveness in combination with other components.

### Role of chemical additives as attractants

Ammonium compounds act as potent behavioral stimuli for nitrogen-seeking insects (Leblanc *et al.*, 2010; El-Afify *et al.*, 2024), particularly ovipositing females (Delgado *et al.*, 2022). The strong response to ammonium acetate is consistent with established roles (Mazor *et al.*, 1987; Suárez *et al.*, 2023; Piñero *et al.*, 2015). However, optimal attraction requires a delicate balance—sufficient ammonia to signal nitrogen availability without overwhelming olfactory receptors (Delgado *et al.*, 2022). Ammonium acetate outperformed ammonium bicarbonate at all concentrations, suggesting the acetate counter-ion contributes additional attractive properties (Piñero *et al.*, 2020). Reduced effectiveness at 10% reflects receptor saturation or aversive effects at excessive concentrations (Mazor *et al.*, 1987).

**Positive effects of attractant combinations**

Combined formulations showed substantially enhanced attraction, attributable to multimodal sensory integration: ammonia cues (ammonium acetate), feeding stimulants (Antonatos *et al.*, 2023), and gustatory/olfactory cues (protein hydrolysates) converge to produce enhanced attraction responses (Vargas *et al.*, 2010; Giunti *et al.*, 2023). Formulations missing any key component performed worse, confirming single attractants are insufficient (Vargas *et al.*, 1997). The optimal balanced formulation maximizes complementary effects (Navarro-Llopis *et al.*, 2013; El-Metwally, 2018). The consistent female-biased attraction observed across all experiments in this study supports the development of female-targeted control strategies, which are particularly valuable for population suppression (Vargas *et al.*, 2010). Field application faces degradation challenges; sodium benzoate improves stability by inhibiting microbial growth (Vargas *et al.*, 2010), though natural preservatives warrant investigation. Multi-component baits at optimal ratios offer superior performance for pest management, but field validation remains essential.

**Conclusions**

This study demonstrated that the attractiveness of baits for *C. capitata* can be significantly enhanced by optimizing combinations of protein hydrolysates, ammonia derivatives, and fruit juices under laboratory conditions. Corn protein hydrolysate proved more effective than yeast-based products, and its combination with ammonium acetate was particularly attractive to females. The addition of sodium benzoate may improve bait stability, though this requires further testing. The findings suggest that a multi-component formulation has potential for use in integrated pest management (IPM) programs. However, the claims of population reduction and effectiveness are limited to the laboratory setting. Future research must prioritize field-scale validation to assess the performance of these formulations under variable environmental conditions, their long-term stability, and their efficacy in reducing fruit fly populations in agricultural settings. Only then can their true potential as an environmentally sound control method be fully evaluated. Therefore, several limitations should be acknowledged: (1) laboratory conditions do not replicate field variability (temperature, wind, UV, competing stimuli); (2) the laboratory colony may have undergone adaptation; (3) the olfactometer measures short-range responses, not long-range field attraction; (4) industrial fruit juices may not fully represent fresh fruit volatile profiles.

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**Table 1.** Materials tested in this study and their categories for *Ceratitis capitata* attraction.

| Material classification | Types used in this study                                                                                                           |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| Protein hydrolysates    | Soy<br>Wheat<br>Corn<br>Fish<br>Yeast autolyzed<br>Yeast extract                                                                   |
| Fruit juice             | Orange<br>Apple<br>Mango<br>Pomegranate<br>Grape<br>Cherry                                                                         |
| Chemicals               | Ammonium acetate<br>Ammonium bicarbonate<br>Ascorbic acid<br>Citric acid<br>Sodium benzoate<br>Sodium metabisulfite<br>Sorbic acid |
| Water                   | Distilled water                                                                                                                    |

**Table 2.** Composition of combined attractant formulations tested against *Ceratitis capitata* adults under laboratory conditions.

| Formulation ID | Formulation code | Ammonium acetate (A) (% w/v) | Corn hydrolysate (C) (% w/v) | Apple juice (E) (% v/v) | Distilled water (to 100 mL) |
|----------------|------------------|------------------------------|------------------------------|-------------------------|-----------------------------|
| F1             | A1C9             | 1.0                          | 9                            | 0                       | ✓                           |
| F2             | A2C8             | 2.0                          | 8                            | 0                       | ✓                           |
| F3             | A3C7             | 3.0                          | 7                            | 0                       | ✓                           |
| F4             | A4C6             | 4.0                          | 6                            | 0                       | ✓                           |
| F5             | A5C5             | 5.0                          | 5                            | 0                       | ✓                           |
| F6             | A1C8E1           | 1.0                          | 8                            | 1.0                     | ✓                           |
| F7             | A1.5C7E1.5       | 1.5                          | 7                            | 1.5                     | ✓                           |
| F8             | A2C6E2           | 2.0                          | 6                            | 2.0                     | ✓                           |
| F9             | A2.5C5E2.5       | 2.5                          | 5                            | 2.5                     | ✓                           |
| F10            | A3C4E3           | 3.0                          | 4                            | 3.0                     | ✓                           |

Note: All concentrations are expressed as weight/volume (w/v) for solids and volume/volume (v/v) for liquids.

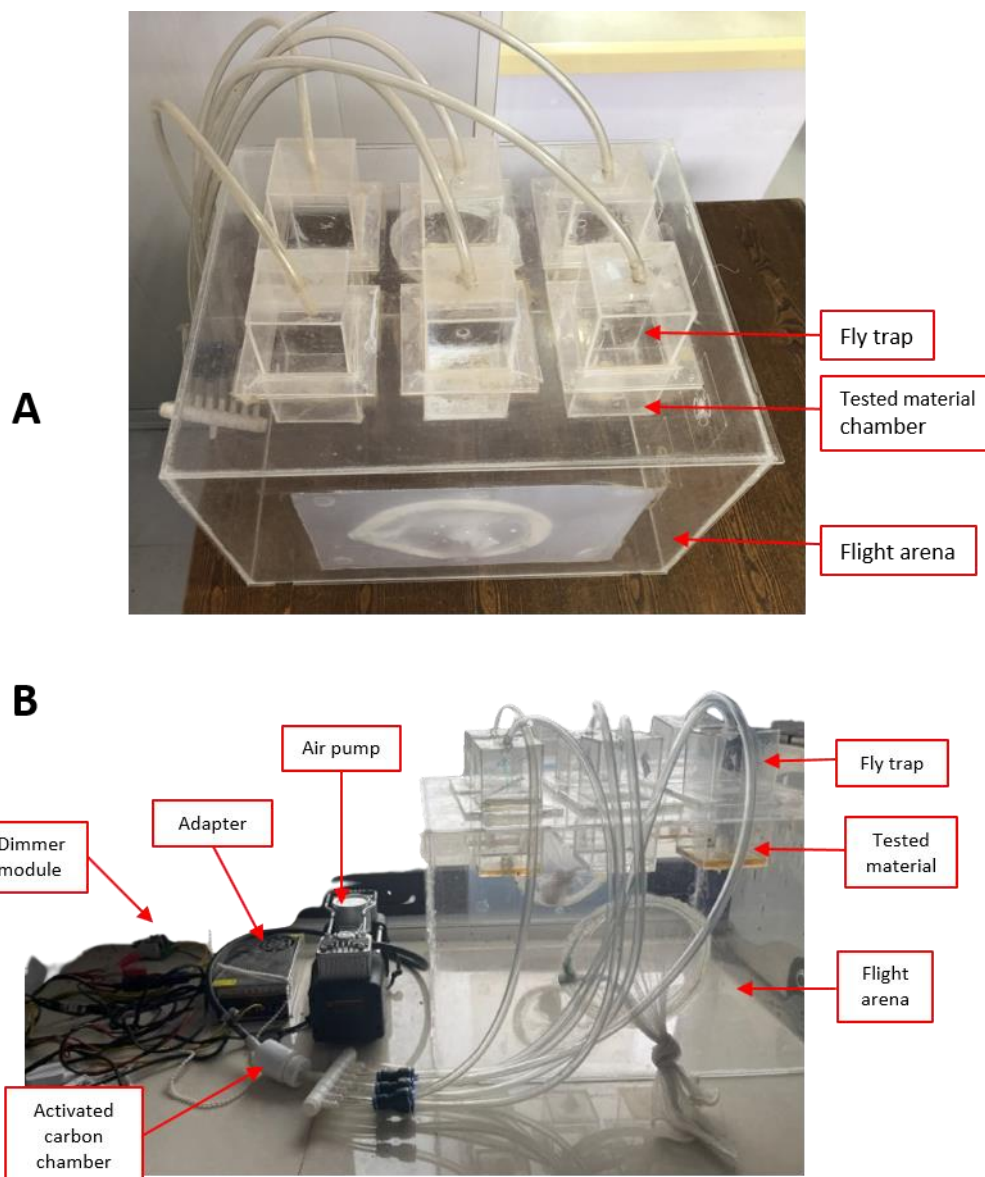


**Figure 1.** Schematic representation of the six-unit olfactometer: (A) top view and (B) side view used for evaluating *Ceratitis capitata* attractants. The vacuum pump draws air through the exposure chamber equally from six volatile sources, and it flows toward the center of the chamber and out through the central hole.

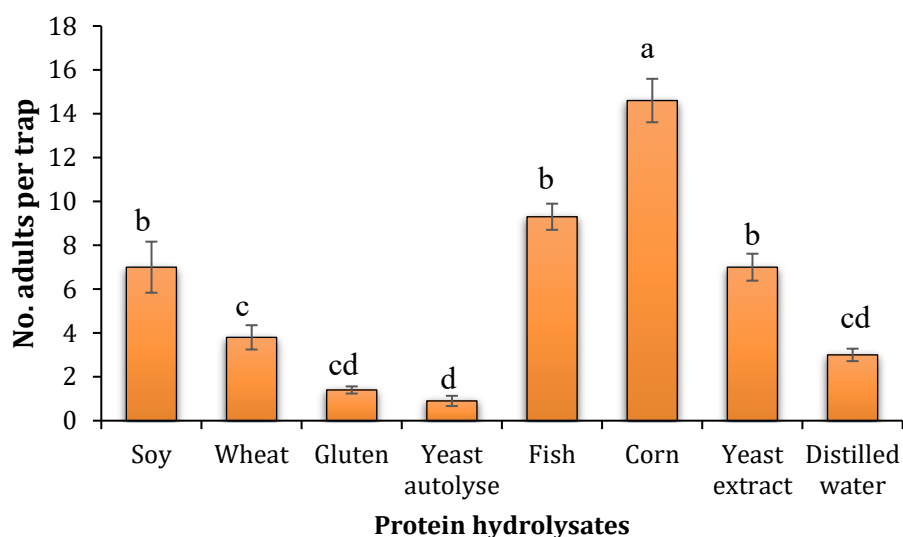


**Figure 2.** Attraction of *Ceratitis capitata* to various protein hydrolysates. Each ingredient was used at 1% (w/v) in distilled water. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). GLM Repeated Measures: Treatment  $F(7,41) = 30.787$ ,  $P < 0.001$ .

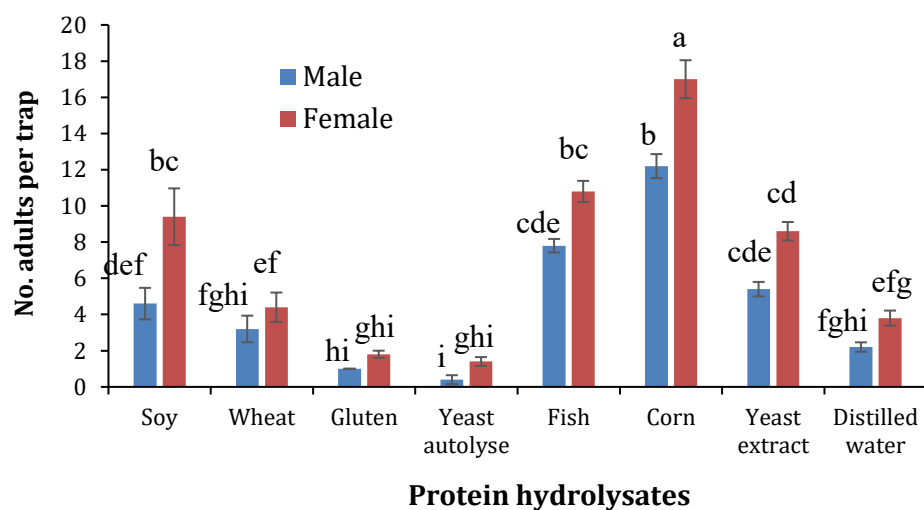


**Figure 3.** Comparative attraction of male and female *Ceratitis capitata* to protein hydrolysates. Each ingredient was used at 1% (w/v) in distilled water. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). GLM Repeated Measures: Treatment  $F(7,41) = 30.787$ ,  $P < 0.001$ ; Sex  $F(1,41) = 10.44$ ,  $P = 0.002$ ; Interaction  $F(7,41) = 1.71$ ,  $P = 0.133$ .

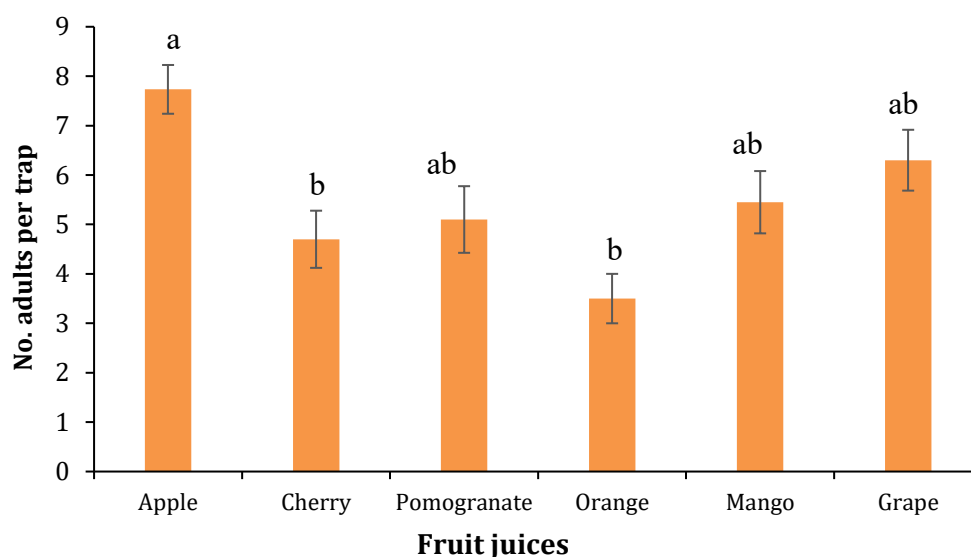


**Figure 4.** Attraction of *Ceratitits capitata* to various fruit juices. Each ingredient was 10 mL. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). GLM Repeated Measures: Treatment  $F(5,38) = 4.802$ ,  $P = 0.002$ .

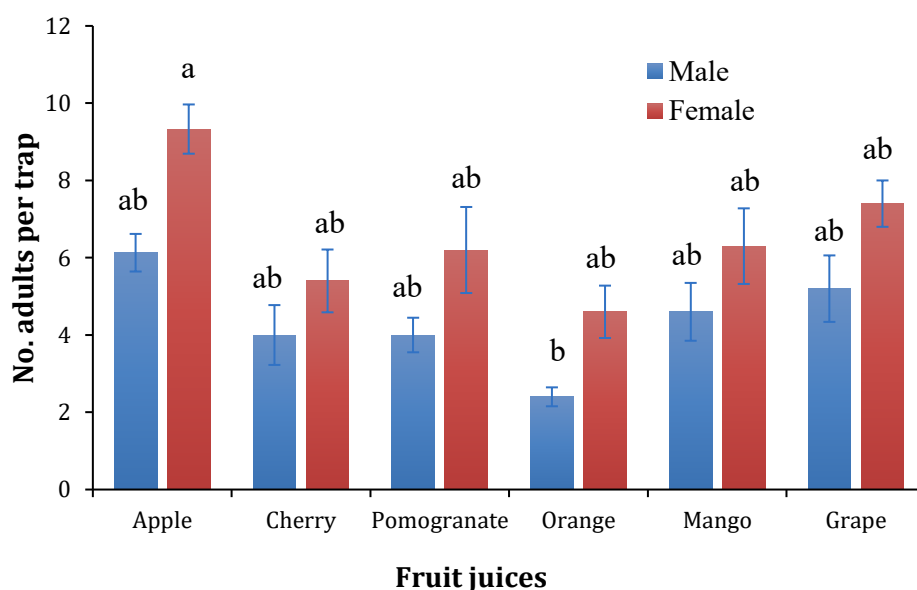


**Figure 5.** Comparative attraction of male and female *Ceratitits capitata* to various fruit juices. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). GLM Repeated Measures: Treatment  $F(5,38) = 4.802$ ,  $P = 0.002$ ; Sex  $F(1,38) = 6.106$ ,  $P = 0.018$ ; Interaction  $F(5,38) = 0.345$ ,  $P = 0.882$ .

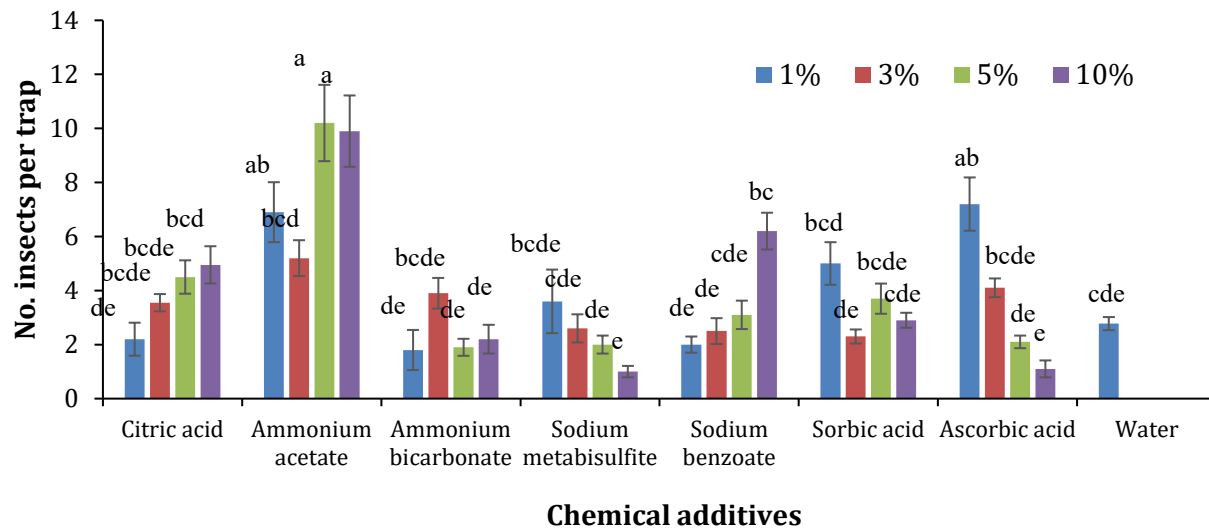


**Figure 6.** Attraction of *Ceratitits capitata* to various chemical additives. Each ingredient was used at 1%, 3%, 5%, 7%, and 10% (w/v) in distilled water. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). GLM Repeated Measures: Treatment  $F(28,170) = 5.771$ ,  $P < 0.001$ .

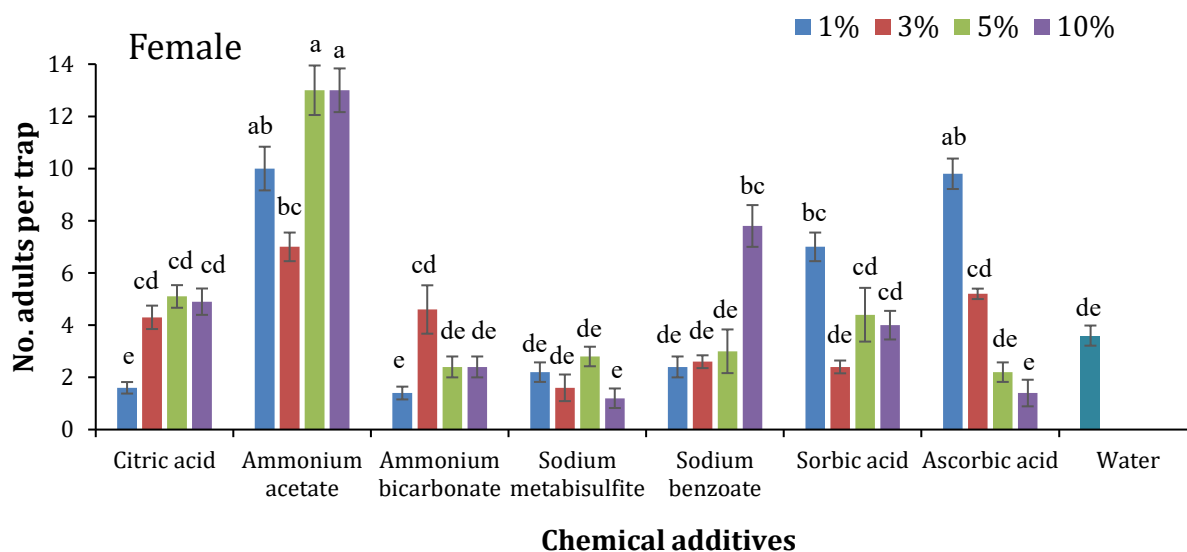
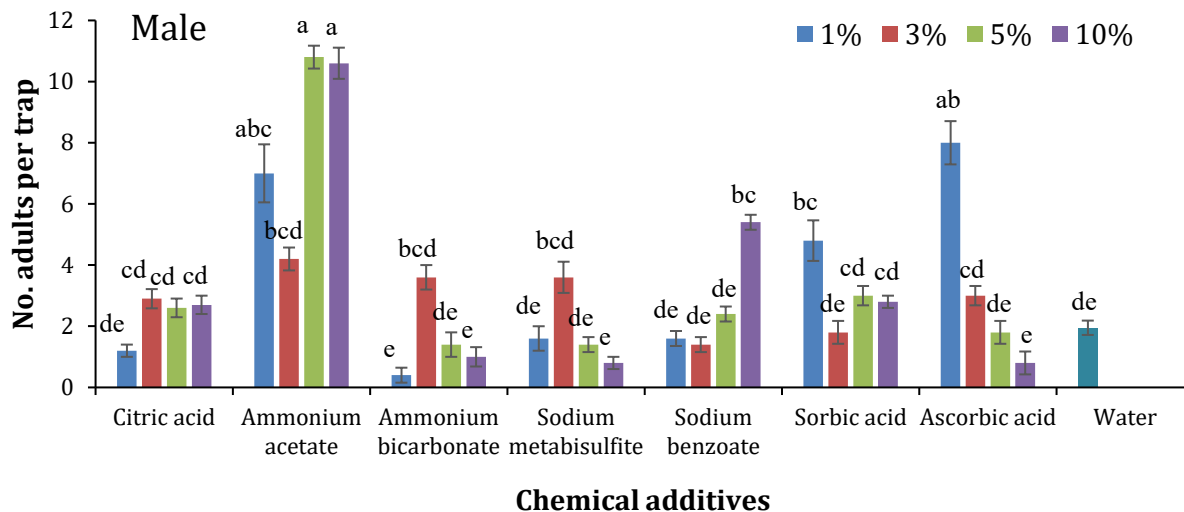


**Figure 7.** Comparative attraction of male and female *Ceratitidis capitata* to various chemicals. Each chemical additive was used at 1%, 3%, 5%, 7%, and 10% (w/v) in distilled water. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). GLM Repeated Measures: Treatment  $F(28,170) = 5.771$ ,  $P < 0.001$ ; Sex  $F(1,170) = 14.604$ ,  $P < 0.001$ ; Interaction  $F(28,170) = 1.442$ ,  $P = 0.083$ .

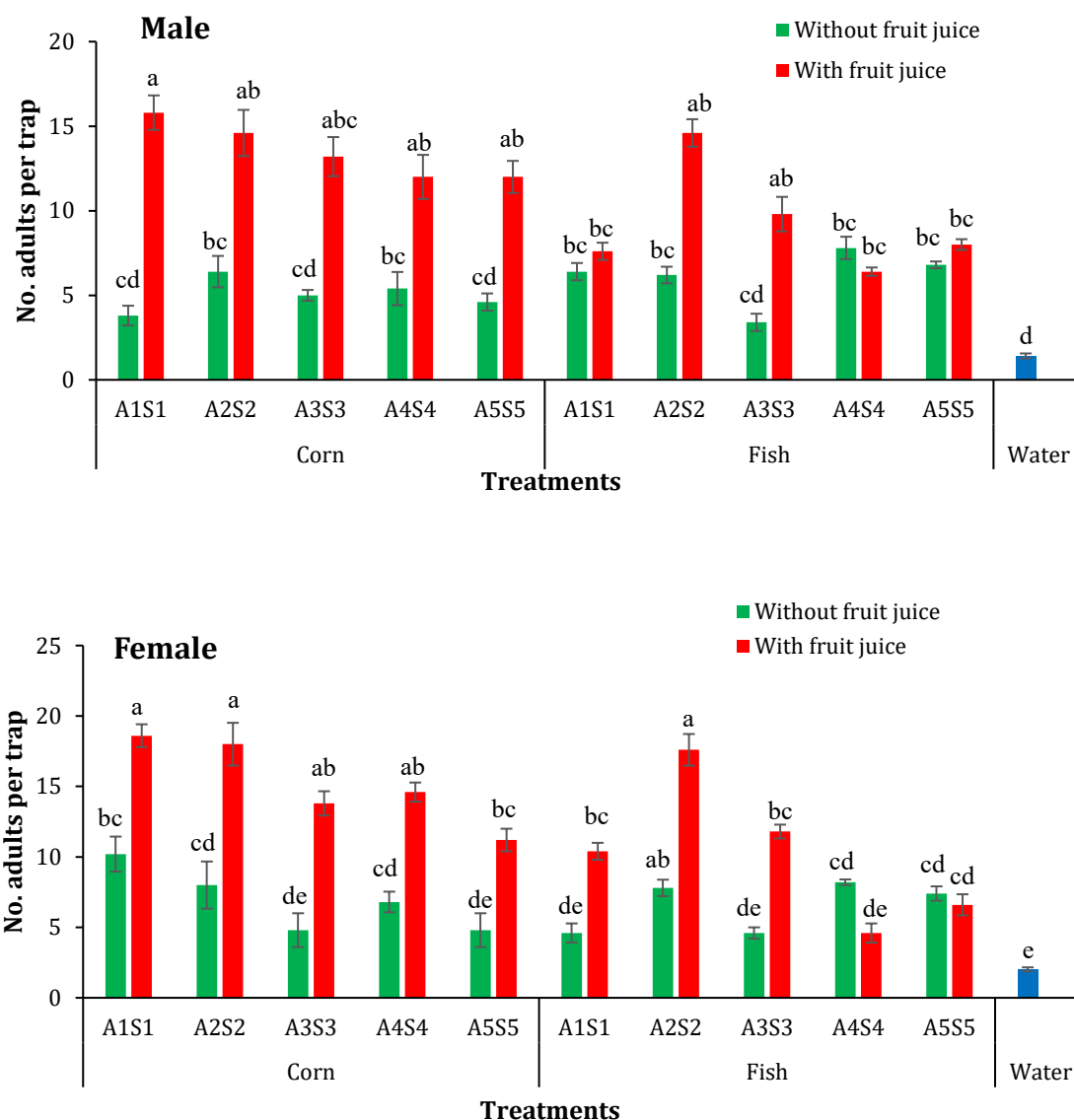


**Figure 8.** Comparative attraction of male and female *Ceratitis capitata* to various combinations of corn and fish protein hydrolysates, apple fruit juice, ammonium acetate (A), and sodium metabisulfite (S). The numbers opposite the letters indicate the grams used in the solution. In these solutions, 10 g of corn or fish protein hydrolysate and 10 mL of apple fruit juice were added to 100 ml of distilled water. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). GLM Repeated Measures: Treatment  $F(20,128) = 66.214$ ,  $P < 0.001$ ; Sex  $F(1,128) = 4.823$ ,  $P = 0.03$ ; Interaction  $F(20,128) = 2.088$ ,  $P = 0.007$ .

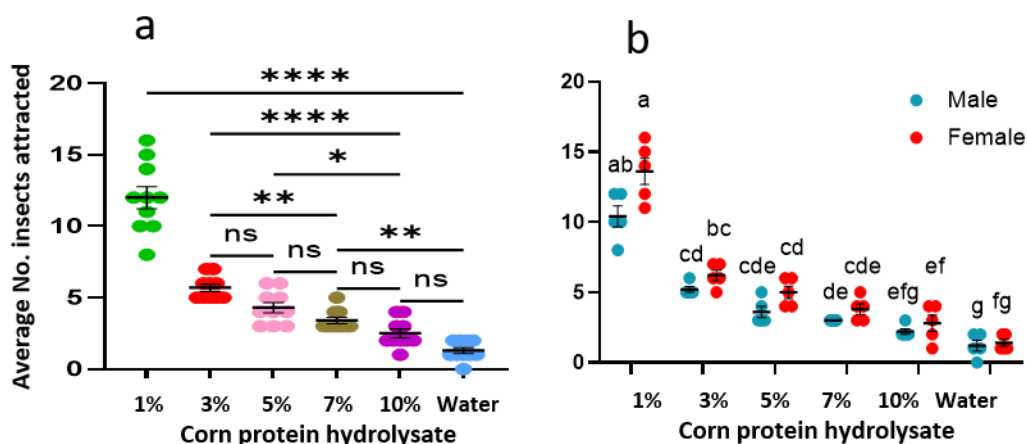


**Figure 9.** Comparative attraction of male and female *Ceratitis capitata* to various concentrations of corn protein hydrolysate: a) total, b) male and female. Each ingredient was used at 1%, 3%, 5%, 7%, and 10% (w/v) in distilled water. Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). ns, \*, \*\*, and \*\*\*\* indicate nonsignificant, and significant differences at  $P < 0.05$ ,  $0.01$ , and  $0.0001$ , respectively. GLM Repeated Measures: Treatment  $F(5,23) = 66.855$ ,  $P < 0.001$ ; Sex  $F(1,23) = 2.979$ ,  $P = 0.098$ ; Interaction  $F(5,23) = 0.215$ ,  $P = 0.952$ .

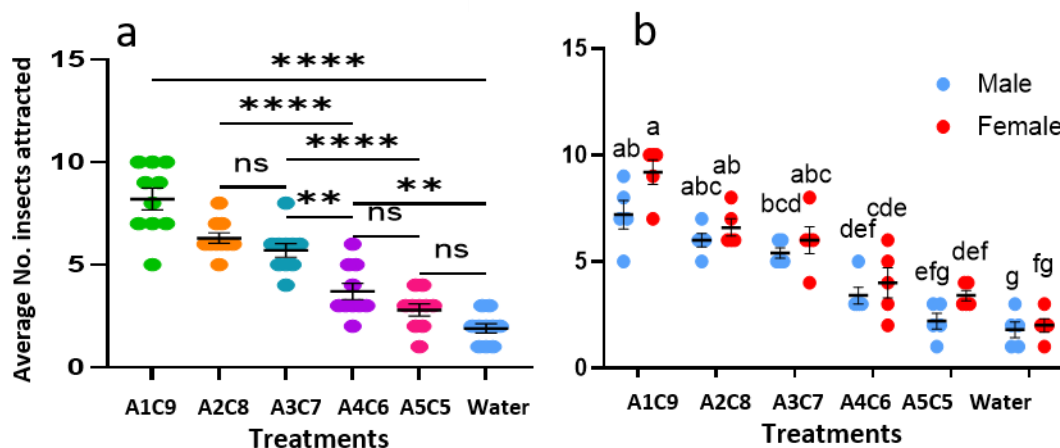


**Figure 10.** Comparative attraction of male and female *Ceratitis capitata* to various combinations of ammonium acetate (A) and corn protein hydrolysate (C): a) total, b) male and female. The numbers opposite the letters represent the grams in 100 mL of distilled water (Refer to Table 2; F1-F5). Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). ns, \*, \*\*, and \*\*\*\* indicate nonsignificant, and significant differences at  $P < 0.01$ , and  $0.0001$ , respectively. GLM Repeated Measures: Treatment  $F(5,23) = 49.715$ ,  $P < 0.001$ ; Sex  $F(1,23) = 11.179$ ,  $P = 0.003$ ; Interaction  $F(5,23) = 0.739$ ,  $P = 0.602$ .

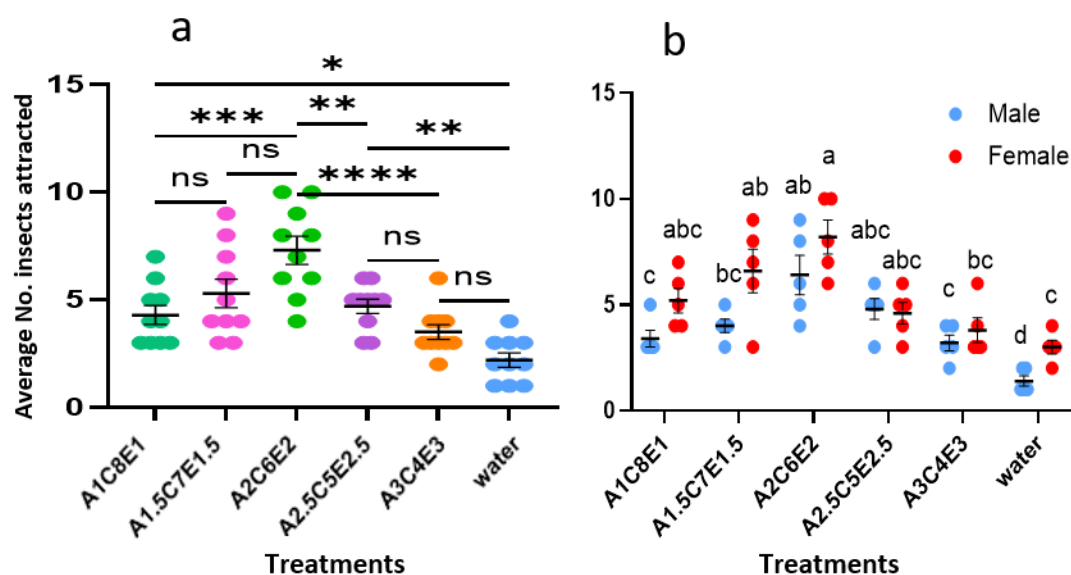


**Figure 11.** Comparative attraction of male and female *Ceratitis capitata* to various combinations of ammonium acetate (A), corn protein hydrolysate (C), and apple fruit juice (E): a) total, b) male and female. The numbers opposite the letters represent the grams in 100 mL of distilled water (Refer to Table 2; F6-F10). Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). ns, \*, \*\*, and \*\*\*\* indicate nonsignificant, and significant differences at  $P < 0.05$ ,  $0.01$ , and  $0.0001$ , respectively. GLM Repeated Measures: Treatment  $F(5,23) = 26.616$ ,  $P < 0.001$ ; Sex  $F(1,23) = 10.234$ ,  $P = 0.004$ ; Interaction  $F(5,23) = 1.59$ ,  $P = 0.202$ .

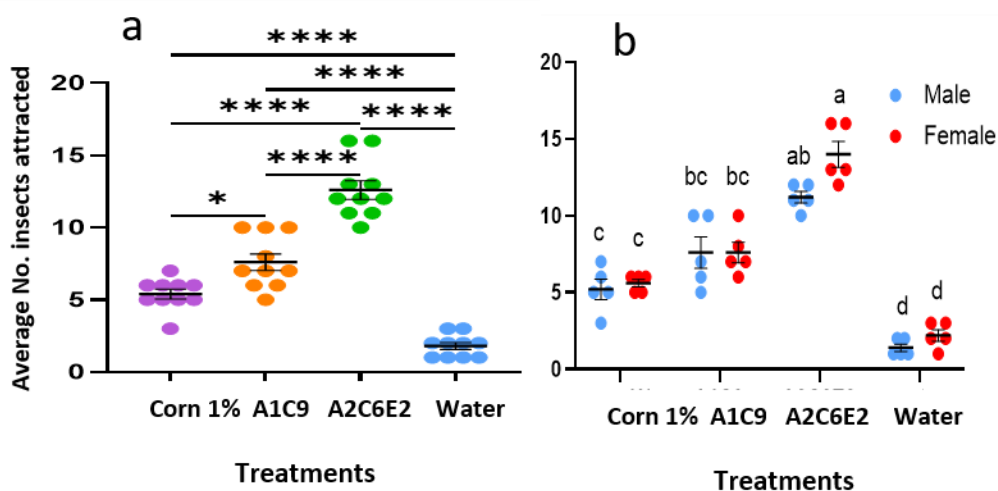


**Figure 12.** Comparative attraction of male and female *Ceratitis capitata* to various combinations of ammonium acetate (A), corn protein hydrolysate (C), and apple fruit juice (E): a) Total, b) Male and female. The numbers opposite the letters represent the grams in 100 mL of distilled water (Refer to Table 2; F8 and F1). Means with the same letters are not significantly different (Tukey's test,  $\alpha = 0.05$ ). \*, and \*\*\*\* indicate significant differences at  $P < 0.05$ , and  $0.0001$ , respectively. GLM Repeated Measures: Treatment  $F(3,15) = 125.727$ ,  $P < 0.001$ ; Sex  $F(1,15) = 1.729$ ,  $P = 0.209$ ; Interaction  $F(3,15) = 0.682$ ,  $P = 0.577$ .

ارزیابی اثربخشی مواد جلب برای مگس میوه مدیترانه‌ای (*Ceratitis capitata* (Diptera: Tephritidae) در شرایط آزمایشگاهی

معصومه قیطولی، اسماعیل اسدی آهنگرکلایی، مهرداد احمدی، و سعید محرمی پور

### چکیده

مگس میوه مدیترانه‌ای، *Ceratitis capitata*، به عنوان یکی از آفات مهم کشاورزی، موجب خسارت اقتصادی قابل توجهی در سراسر جهان می‌شود. در این مطالعه، جلب کنندگی تیمارهای مختلف شامل هیدرولیزات‌های پروتئینی، آب‌میوه‌ها و ترکیبات شیمیایی با استفاده از دستگاه بویایی سنج ارزیابی شد. در میان هیدرولیزات‌های پروتئینی، هیدرولیزات ذرت با میانگین  $14/6 \pm 0/99$  حشره کامل در هر تله (APT) بیشترین جلب کنندگی را نشان داد، در حالی که اتولیزات مخمر با میانگین  $0/9 \pm 0/23$  APT کمترین میزان جلب کنندگی را داشت. نتایج آزمون‌های مربوط به آب‌میوه نشان داد که آب سیب با میانگین  $0/49 \pm 0/73$  APT مؤثرترین جلب کننده بود، در حالی که آب پرتقال با میانگین  $0/5 \pm 0/3$  APT کمترین جلب کنندگی را نشان داد. در گروه ترکیبات شیمیایی، استات آمونیوم 5 درصد با میانگین  $1/4 \pm 10/2$  APT بالاترین میزان جلب کنندگی را به خود اختصاص داد. تحلیل بر اساس جنسیت نشان داد که مگس‌های ماده به طور معنی‌داری در تمامی گروه‌ها نسبت به نرها جلب کنندگی بیشتری به تیمارها داشتند. همچنین، در تیمارهای ترکیبی اثرات هم‌افزایی مشاهده شد. در آزمایش مقایسه‌ای نهایی، فرمولاسیون‌های منتخب از مراحل بهینه‌سازی پیشین با یکدیگر مقایسه شدند و فرمولاسیون حاوی 2 درصد استات آمونیوم، 6 درصد هیدرولیزات ذرت و 2 درصد آب سیب بیشترین میزان جلب کنندگی با میانگین  $0/63 \pm 12/6$  APT را نشان داد و به عنوان فرمولاسیون بهینه نهایی انتخاب شد. این نتایج بر ظرفیت تلفیق هیدرولیزات‌های پروتئینی، آب‌میوه‌ها و ترکیبات شیمیایی در طراحی راهبردهای هدفمند مدیریت آفات تأکید دارد؛ راهبردهایی که می‌توانند رویکردی سازگار با محیط زیست برای کنترل مگس میوه مدیترانه‌ای در سامانه‌های کشاورزی فراهم کنند.