



Gender-specific attractants for *Conopomorpha sinensis* Bradley: development and field evaluation of semi-solid slow-release formulations

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Summary

The use of semiochemicals to manipulate insect chemosensory behaviour is an emerging and environmentally sustainable approach for pest management, although its application remains limited to a few agricultural systems. In the present study, an innovative strategy was developed for the management of the litchi fruit borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae), a major pest of litchi. Whole-insect maceration was employed to obtain a broad spectrum of volatile compounds, including body- and sex-specific attractants. The extracted volatiles were purified using column chromatography and subsequently formulated into semi-solid, slow-release attractant products suitable for field application. This approach preserves the natural composition and integrity of volatile constituents, closely mimicking the chemical profile emitted by live insects. Two formulations were developed: Product 1 from female insects and Product 2 from male insects. Their attraction efficiency was evaluated using Delta traps under field conditions during the peak adult activity period. The results demonstrated clear gender-specific responses, with male moths showing strong attraction to Product 1, while female moths were preferentially attracted to Product 2. To our knowledge, this is the first report of gender-specific attractants for *C. sinensis*.

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Keywords: *Conopomorpha sinensis*; gender-specific attractants; semi-solid formulation; pest management; volatiles; pheromones

Introduction

Conopomorpha sinensis Bradley (Lepidoptera: Gracillariidae), commonly known as the litchi fruit borer, is one of the most destructive pests of litchi. Infestation can cause fruit losses of up to 48%, while shoot damage may range from 7–70%. The pest is closely associated with litchi (*Litchi chinensis*), where females lay eggs on developing fruits and the larvae feed inside, reducing both fruit quality and yield. The insect has a high reproductive capacity and overlapping generations, making its management challenging. Therefore, sustainable management approaches are needed. Integrated Pest Management (IPM), combining cultural, biological, mechanical, and judicious chemical control methods, provides an effective and environmentally sound strategy for managing *C. sinensis* while minimizing reliance on synthetic insecticides. (Ahmad et al. 2011; Beever et al. 1993; Deguine et al. 2021; FAO 2025; Zhou et al. 2024). Semiochemicals have gained considerable attention in pest management because of their species-specific action and environmental safety. By influencing insect behaviour, these compounds provide targeted and eco-friendly options for pest control. Among them, pheromone traps are widely used for monitoring and

managing insect pests, including moths (Ho et al. 1987; Hwang et al. 1996; Hagstrom et al. 2013; Guo et al. 2020; Foster & Anderson 2022, Klassen et al. 2023), aphids (Kim et al. 2023), thrips (Khan et al. 2021), and other economically important species (Kirk et al. 2017). Depending on their ecological function, pheromones are broadly classified as sex, aggregation, alarm, trail, and oviposition pheromones. Among these, sex pheromones have received considerable attention because of their potential application in monitoring, mass trapping, mating disruption, and attract-and-kill strategies. (Lu et al. 2012; Lee et al. 2014; Legner et al. 2021; Koutroumpa et al. 2022). However, isolating and synthesizing these compounds involves challenges such as volatility, oxidation, and incomplete component blends, limiting their effectiveness in field conditions. Recognizing these challenges, the global agricultural sector has embraced bio-based strategies to enhance pheromone production. Recent advancements include the genetic engineering of crops to emit pheromones and transgenic plants producing pheromone precursors (Mafra-Neto et al. 2013; Sarles et al. 2015; Mang et al. 2016; Mala et al. 2017; Ray et al. 2019; Noushini et al. 2020; Miano et al. 2022). While these methods represent progress, they often fail to replicate the full spectrum of volatile components found in natural pheromones, reducing their efficacy. Additionally, the application of pheromones across different pest species often yields suboptimal results due to species-specific chemical signatures (Schmura et al. 2004).

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To address these gaps, our study presents a novel approach that mimics nature's mechanisms. Volatile compounds were extracted from male and female *C. sinensis* insects using whole-body maceration. These compounds were purified using column chromatography and formulated into semi-solid attractants. By preserving the natural blend of volatiles, these formulations emulate the chemical profile of live insects, potentially improving attraction efficiency under field conditions. Cetostearyl alcohol was used as a carrier matrix because of its stabilizing properties and potential to provide controlled release of volatile compounds over an extended period. (Vevai 1971; Singh et al. 2017; Srivastava et al. 2020; Song et al. 2021; Tabata et al. 2023). Field trials targeting *C. sinensis*, the litchi fruit borer, revealed that the semi-solid attractants effectively captured male and female moths. These findings suggest that semi-solid formulations may provide a useful approach for the management of *C. sinensis*. (Ward et al. 2002; Vuts et al. 2008; Wang et al. 2022). The present study aimed to develop semi-solid slow-release formulations derived from male and female *C. sinensis* adults and evaluate their attraction efficiency under field conditions.

Materials and Methods

1. Source of Insects

Pupae of *C. sinensis* were collected from litchi orchards at the MS Randhawa Fruit Research Station in Gangian and the Government Garden and Fruit Nursery in Khiala Bulanda, district Hoshiarpur, Punjab, India. Pupae were collected during the peak pupation period of *C. sinensis* in litchi orchards. The pupae were maintained in a rearing cage (dimensions: 55 cm × 50 cm × 38 cm) under controlled conditions (25° ± 5°C and 80–85% relative humidity) at the Insect Rearing Facilities of Punjab Agricultural University, Ludhiana, Punjab until adult emergence.

2. Rearing of Adults

Newly emerged male and female *C. sinensis* moths were separated based on the morphology of the terminal abdominal segments and maintained in separate cages to ensure virginity until use. For volatile extraction, 2,000 virgin female moths were macerated in 500 mL hexane (Solution 1). Similarly, 2,000 male moths were macerated in 500 mL hexane to obtain Solution 2. To capture a wider range of insect-derived volatiles, whole-body extracts were prepared rather than isolating abdominal pheromone glands. The extracts were kept at room temperature for 48 h before purification and analysis.

3. Purification of Female and Male Attractants Using Column Chromatography

Female- and male-derived extracts (Solutions 1 and 2) were purified using silica gel column chromatography. The column was packed with 50 g silica gel (60–120 mesh) and topped with anhydrous sodium sulfate. Elution was carried out with 500 mL hexane, and fractions with similar chromatographic profiles were pooled. To recover fewer volatile compounds remaining on the column, methanol was subsequently used as the

eluent, yielding Component A and Component B fractions. The purified fractions were then subjected to GC–MS analysis for identification of volatile constituents.

4. GC–MS Analysis

GC–MS analysis was performed using an Agilent GC7890A gas chromatograph coupled with a 5977B mass selective detector. Separation of volatile compounds was achieved using an HP-5 MS capillary column (30 m × 0.25 mm i.d., 0.25 µm film thickness). The oven temperature was programmed from 40°C (held for 2 min) to 260°C at a rate of 10°C/min and held for 5 min. Helium was used as the carrier gas at a constant flow rate of 1.0 mL min⁻¹. The detector temperature was maintained at 280°C. Volatile compounds were tentatively identified by comparison of their mass spectra with those in the NIST 17.L (2018) mass spectral library using Agilent Mass Hunter software.

5. Preparation of Semi-Solid Slow-Release Formulations

Product 1 was prepared by mixing 1 mL of the female-derived volatile extract with 1 g of cetostearyl alcohol. The mixture was sonicated at 45°C for 5 min and cooled to room temperature to obtain a semi-solid slow-release formulation. Component A was similarly prepared using 1 mL of the methanol-washed female fraction and 1 g of cetostearyl alcohol. Product 2 was formulated by incorporating 1 mL of the male-derived volatile extract into 1 g of cetostearyl alcohol and processing under the same conditions. Component B was prepared in a similar manner using 1 mL of the methanol-washed male fraction. For the control, 1 mL of n-hexane was mixed with 1 g of cetostearyl alcohol and processed identically.

Field Deployment of Delta Traps

Delta traps (Yellow Del-Ta) (52.5 × 23.5 × 12 cm) fitted with sticky liners were obtained from Bharat Plant Protectors and Engineers, Ludhiana, Punjab, India. Traps were loaded with Product 1, Product 2, Component A, Component B and the control formulation and deployed in litchi orchards for field evaluation. Two open vials containing the respective formulations were attached to the sticky liner positioned at the base of each trap to facilitate the gradual release of volatile compounds. The numbers of trapped insects were recorded at weekly intervals and analyzed statistically.

6. Field Trials with Semi-Solid Slow-Release Formulations

Experimental Setup

Field experiments were conducted to assess the attractiveness of semi-solid slow-release formulations developed at ICAR–NBAIR, Bengaluru, against *Conopomorpha sinensis*. The treatments included Product 1, Product 2, Component A, Component B, and a control containing pure hexane. Each treatment was replicated ten times, with one Delta trap representing a replicate (Figure 1). The study was carried out in a litchi orchard at the Government Garden and Fruit Nursery,

Khiala Bulanda, Hoshiarpur, Punjab, India. The orchard covered about 4.04 ha and contained 520 litchi trees planted at 9 m spacing. Trials were conducted from early July to late August, coinciding with the late fruit-ripening stage and peak activity period of *C. sinensis*. During the study, temperatures ranged between 40 and 45°C, while relative humidity remained around 80%. Two separate field evaluations were undertaken. In the first, traps baited with Product 1, Component A, and the control were used to assess female moth attraction. In the second, Product 2, Component B, and the control were evaluated for male moth attraction.

Delta traps were hung in the middle canopy of litchi trees at a height of 2.5–3.0 m above ground. Only one trap was placed per tree to avoid interference among treatments. Treatments were arranged in a completely randomized design, and trap positions were randomized across the orchard to reduce the effects of canopy variation and wind direction. Trap catches were recorded weekly for ten weeks. Sticky liners were replaced during each observation, and the numbers of male and female moths captured were recorded for statistical analysis.



Figure 1. (a) Semi-solid slow-release attractant formulations used for field evaluation in litchi orchards of Punjab; (b) Volatile release from semi-solid formulations contained in centrifuge tubes; (c) Trapping of *C. sinensis* adults in a Delta trap containing a semi-solid slow-release attractant formulation.; and (d) moths captured on sticky liners one week after trap installation.

7. Weight Loss Analysis of Semi-Solid Slow-Release Formulations

The release characteristics of the semi-solid slow-release formulations were evaluated by measuring their weight loss under field conditions. Formulations contained in centrifuge vials were placed inside Delta traps and exposed to ambient environmental conditions throughout the experimental period. Weight measurements were recorded at weekly intervals using a precision analytical balance, and percentage weight loss was calculated relative to the initial formulation weight. Three replicates were maintained for each treatment, and the mean values were used for analysis. Only the semi-solid formulations contained within the vials were weighed for determination of weight loss. The weight of the Delta trap, sticky liner, and other trap components was excluded from the analysis. Prior to each measurement, the vials were carefully removed from the traps, cleaned to remove any external contaminants, dried, and weighed.

The control formulation exhibited complete weight loss (100%) within the first week of deployment, indicating rapid loss of volatile constituents from the formulation. Consequently, no further weight measurements could be recorded for the control treatment beyond the first week. In contrast, Product 1 and Product 2 exhibited gradual weight loss throughout the experimental period, demonstrating sustained release characteristics under field conditions. Therefore, subsequent comparisons were focused on the weight-loss patterns of the experimental formulations. The same Delta traps used for monitoring moth captures were also used for evaluating formulation persistence under field conditions. This approach enabled simultaneous

assessment of attractant release characteristics and trapping efficacy throughout the study period.

8. Data Transformation and Statistical Analysis

Before analysis, insect trap-catch data were square-root transformed [$\sqrt{(x + 0.5)}$] and percentage weight-loss data were log-transformed [$\log(x + 1)$] to stabilize variance and improve data normality. The transformed data were tested for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test. The assumptions for parametric analysis were satisfied after transformation. Statistical analyses were performed using SPSS version 20 (IBM Corp., USA). Weekly trap-catch data from male- and female-attractant experiments were analyzed separately using two-factor analysis of variance (ANOVA), with trap type (treatment) and observation period (week) as fixed factors. The interaction between treatment and observation period was also examined. Similarly, percentage weight-loss data of the semi-solid formulations were analyzed using two-factor ANOVA to evaluate the effects of treatment and observation period. Whenever significant differences were observed, means were separated using Tukey's Honestly Significant Difference (HSD) test at $p \leq 0.05$. Descriptive statistics, including mean, standard deviation (SD), and standard error (SE), were calculated for all variables. The results are presented in Tables 2 and 4.

Results

The volatile compounds identified from the female-derived extracts included 9-Tetradecenal, 9-Tetradecen-1-ol acetate, cis-9-Hexadecenal, Z,E-7,11-Hexadecadien-1-yl acetate, and E-2-Octadecadecen-1-ol (Supplementary Information 1; SI-1). The volatile

compounds identified from the male-derived extracts included 9,12-Octadecadienoic acid, Heneicosylcyclohexane, 3-Methyl-2-(3-methylpentyl)-3-buten-1-ol, and 2-Heptyne-4-one (Supplementary Information 2; SI-2).

1. Slow-Release Analysis of Percentage Weight Loss of Control and Product 1 Over a 10-Week Period

The percentage weight loss of Product 1 and the control formulation was monitored for 10 weeks under field conditions at 45°C (Figure 2). Data represent the mean of three replicates. The control formulation lost its entire weight (100%) within the first week of exposure, indicating rapid volatilization of its

constituents. Therefore, no further measurements could be recorded for this treatment. In contrast, Product 1 exhibited a slow and progressive increase in weight loss throughout the study period. Weight loss increased from 0.02% in the first week to 0.05% in the second week, 0.08% in the third week, 0.14% in the fifth week, 0.18% in the seventh week, and reached 0.25% by the tenth week. This gradual increase suggests a sustained and controlled release of volatile compounds over time. The marked difference between Product 1 and the control highlights the effectiveness of the semi-solid matrix in retaining volatile components and releasing them gradually under field conditions.

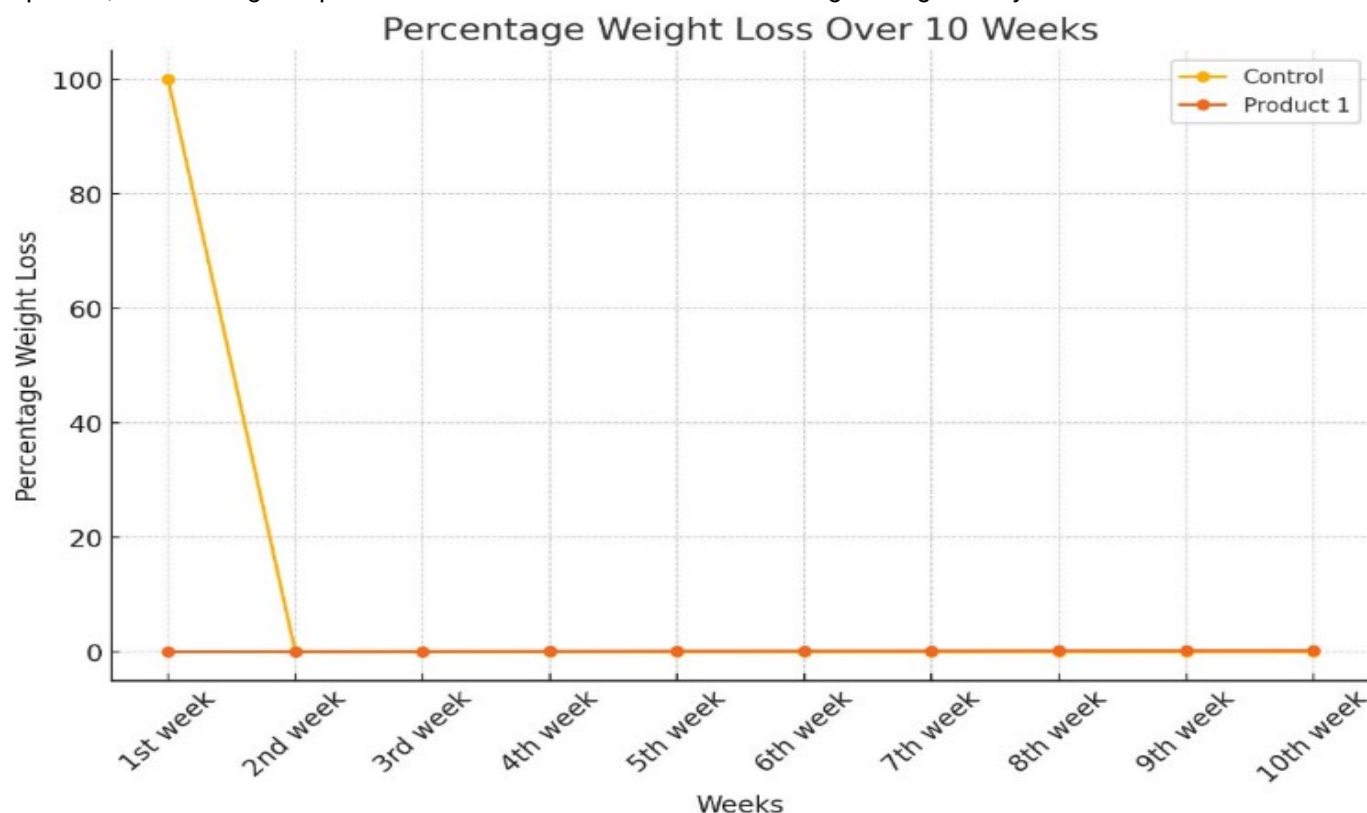


Figure 2. Percentage weight loss of Product 1 and the control formulation over a 10-week period under field conditions, illustrating the sustained-release characteristics of Product 1.

2. Slow-Release Analysis of Percentage Weight Loss of Control and Product 2 Over a 10-Week Period

The weight loss of Product 2 and the control formulation was monitored for 10 weeks under field conditions at 45°C (Figure 3). Data are presented as the mean of three replicates. The control formulation showed rapid degradation, with complete weight loss (100%) occurring within the first week, preventing further observations. In contrast, Product 2 exhibited only a gradual reduction in weight throughout the study. Weight loss increased from 0.02% during the first week to 0.06%, 0.09%, 0.12%, 0.21%, and 0.31% by weeks 2, 3, 5, 7, and 10, respectively. The slow and steady increase in weight loss suggests controlled release of volatile constituents from Product 2 over time. Unlike the control, which dissipated rapidly, Product 2 remained stable under field conditions and provided sustained release throughout the 10-week evaluation period.

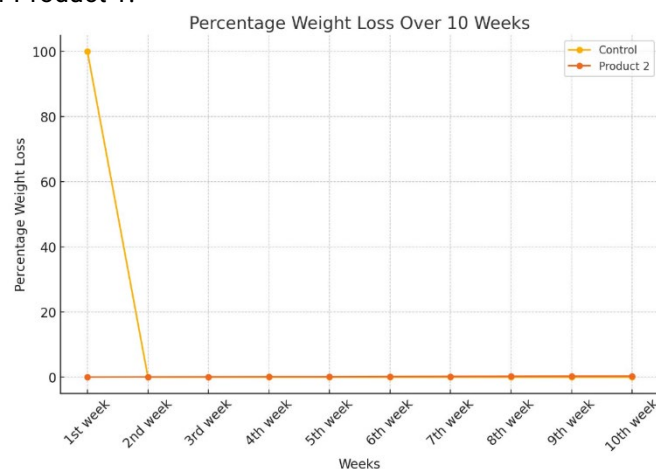


Figure 3. Percentage weight loss of Product 1 and the control formulation over a 10-week period under field conditions. Values represent the mean of three replicates.

Trapping Efficiency of Female Adults Using Male Attractant Formulations

The trapping efficiency of slow-release male attractant formulations against female *C. sinensis* adults was evaluated in a litchi orchard over a six-week period. Weekly observations were recorded, and the mean numbers of female moths captured in traps baited with Product 1, Component A, and the control (hexane) were compared (Table 1). Among the treatments, Product 1 consistently recorded the highest trap catches throughout the experimental period. The mean number of female moths captured by Product 1 decreased from 27.40 ± 0.60 insects per trap during the first week to 7.30 ± 0.44 insects per trap by the sixth week. In contrast, Component A and the control treatment captured substantially fewer female moths, with mean

trap catches ranging from 0.70 to 0.90 and 0.70 to 2.30 insects per trap, respectively.

A gradual decline in trap catches was observed across successive weeks for Product 1; however, trap captures remained considerably higher than those recorded for Component A and the control throughout the study period. Statistical analysis revealed significant differences among treatments (Tukey's HSD test, $p < 0.05$). Product 1 exhibited significantly greater trapping efficiency than both Component A and the control during all observation periods. No significant differences were observed between Component A and the control treatment. These results demonstrate the superior attractiveness of Product 1 for capturing female *C. sinensis* adults under field conditions.

Table 1. Weekly captures of female *C. sinensis* adults in Del Ta traps baited with slow-release male attractant formulations in a litchi orchard in Punjab, India

Week	Product 1 (Mean $\pm$ SE)	Control (Mean $\pm$ SE)	Component A (Mean $\pm$ SE)	Overall Mean [†]
1	27.40 ± 0.60 (5.23)	2.30 ± 0.24 (1.51)	0.90 ± 0.09 (0.94)	10.20 ^a (2.25)
2	17.70 ± 0.67 (4.20)	1.60 ± 0.20 (1.26)	0.80 ± 0.12 (0.89)	6.70 ^b (1.83)
3	10.60 ± 0.53 (3.25)	1.50 ± 0.15 (1.22)	0.80 ± 0.12 (0.89)	4.30 ^c (1.46)
4	8.70 ± 0.42 (2.94)	0.90 ± 0.09 (0.94)	0.70 ± 0.14 (0.83)	3.03 ^d (1.23)
5	7.60 ± 0.15 (2.75)	0.70 ± 0.14 (0.83)	0.70 ± 0.14 (0.83)	3.00 ^d (1.22)
6	7.30 ± 0.44 (2.70)	0.70 ± 0.14 (0.83)	0.70 ± 0.14 (0.83)	2.90 ^d (1.20)

* Mean number of female adults trapped per treatment (10 replicates). SE = standard error. Values in parentheses are transformed data. The overall mean was calculated using a harmonic mean sample size of 30.0. Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to Tukey's HSD test. Product 1 = male attractant formulation; Control = pure hexane; Component A = methanol-washed fraction of the male-derived extract.

Statistical Significance of Treatments

The two-factor ANOVA results are detailed in Table 2, showing: Treatment Effect: A highly significant difference was observed among treatments ($F=2572.519$, $p=0.0000$). Temporal Effect: A highly significant decline in trapping efficiency over weeks was evident ($F=219.482$, $p=0.0000$). Interaction of Treatment and weeks: Interaction effects were also significant ($F=170.864$, $p = 0.0000$), indicating differential trapping patterns for treatments over time. These results validate the superior performance of

Product 1 as a slow-release male attractant compared to Component A and the Control under field conditions in a litchi orchard.

Trapping Efficiency of Male Adults Using Female Attractant Formulations

The trapping performance of the slow-release female attractant formulations against male *C. sinensis* was evaluated in a litchi orchard over six weeks (Table 3). Among the treatments, Product 2 consistently recorded the highest trap catches throughout the study.

Table 2. Two-factor ANOVA for female *C. sinensis* captures in Delta traps baited with male attractant formulations in a litchi orchard, Punjab, India

Source	Sum of Squares	Mean Square	F	P value
Treatment (t)	5780.933	2890.467	2572.519	.000*
Weeks (w)	1233.041	246.608	219.482	.000*
treatment * Weeks (t*w)	1919.815	191.982	170.864	.000*
Error	179.775	1.124		
Corrected Total	9273.640			

*Significance level at $p < 0.05$

Mean captures declined gradually from 13.40 ± 0.82 moths trap⁻¹ in the first week to 7.10 ± 0.49 moths trap⁻¹ in the sixth week, suggesting that the formulation remained attractive for an extended period. In comparison, Component B and the hexane control attracted only a few moths, with catches ranging from 0.30–0.70 and 0.50–2.60 moths trap⁻¹, respectively. Although the number of moths captured by Product 2 decreased over time, it consistently outperformed the

other treatments. Tukey's HSD test ($p < 0.05$) showed that trap catches in Product 2 were significantly higher than those in Component B and the control during all observation periods. No significant difference was observed between Component B and the control.

Statistical Analysis

The two-factor ANOVA results are presented in Table 4. Both treatment and observation period had significant effects on trap catches. A highly significant treatment

effect was observed ($F = 741.013$, $p < 0.001$), indicating clear differences among Product 2, Component B, and the control. The effect of observation period was also significant ($F = 18.750$, $p < 0.001$), showing that moth captures varied during the six-week evaluation period. Overall, the results demonstrate that Product 2 was markedly more effective in attracting male *C. sinensis* than Component B and the control under field conditions.

Trap Efficacy of Semi-Solid Attractant Formulations

Delta traps baited with semi-solid formulations captured substantial numbers of *C. sinensis* adults. Product 1 (male attractant) recorded the highest female catches, declining from 27.40 ± 0.60 moths per trap in week 1 to 7.30 ± 0.44 in week 6 (Table 1).

Table 3. Weekly captures of male *C. sinensis* adults in Delta traps baited with slow-release female attractant formulations in a litchi orchard, Punjab, India

Week	Product 1 (Mean $\pm$ SE)	Control (Mean $\pm$ SE)	Component A (Mean $\pm$ SE)	Overall Mean [†]
1	13.40 $\pm$ 0.82 (3.66)	2.60 $\pm$ 0.58 (1.61)	0.70 $\pm$ 0.28 (0.83)	5.56 ^a (1.66)
2	10.20 $\pm$ 0.39 (3.19)	1.50 $\pm$ 0.51 (1.22)	0.40 $\pm$ 0.14 (0.63)	4.03 ^b (1.41)
3	10.60 $\pm$ 0.53 (3.25)	1.10 $\pm$ 0.23 (1.04)	0.40 $\pm$ 0.15 (0.63)	3.73 ^{bc} (1.36)
4	7.70 $\pm$ 0.53 (2.77)	0.80 $\pm$ 0.20 (0.89)	0.30 $\pm$ 0.28 (0.54)	2.93 ^c (1.21)
5	7.20 $\pm$ 0.34 (2.68)	0.60 $\pm$ 0.21 (0.77)	0.50 $\pm$ 0.24 (0.76)	2.76 ^c (1.17)
6	7.10 $\pm$ 0.49 (2.66)	0.50 $\pm$ 0.24 (0.70)	0.60 $\pm$ 0.21 (0.44)	2.73 ^c (1.16)

Mean values of male adults captured in 10 replicates; SE = standard error. Values in parentheses represent transformed data. **Homogeneous subsets were determined using Tukey's post hoc HSD test (95% confidence interval) based on a harmonic mean sample size of 30. Values followed by the same letter are not significantly different at $p < 0.05$. Product 2 = female attractant formulation; Control = pure hexane; Component B = methanol-washed fraction of the female-derived extract.

Table 4. Two-factor ANOVA for male *C. sinensis* captures in Delta traps baited with female attractant formulations in a litchi orchard, Punjab, India

Source	Sum of Squares	Mean Square	F	Sig.
Treatment (t)	2825.911	1412.956	741.013	.000*
Weeks (w)	178.761	35.752	18.750	.000*
treatment * weeks (t*w)	148.489	14.849	7.787	.000*
Error	308.900	1.907		
Corrected Total	3462.061			

*Significance level at $p < 0.05$.

Discussion

The litchi fruit borer, *C. sinensis*, is a major pest of litchi, causing significant losses through fruit and shoot damage. Although several studies have investigated pheromone-based management of this pest, practical field applications remain limited (Yadav & Reddy 1988; Wong et al. 1992; Yen et al. 1992; Zunic-Kosi et al. 2019; Zhang et al. 2021; Watts Moore et al. 2023; Zhou et al. 2024). In the present study, volatile compounds obtained from adult *C. sinensis* were incorporated into a Ceto stearyl alcohol-based semi-solid matrix to develop slow-release attractant formulations. Field evaluation demonstrated that these formulations attracted and captured both male and female moths under orchard conditions. A notable outcome of this work was the successful use of whole-insect macerates as attractant sources. To our knowledge, this is the first report describing semi-solid slow-release attractant formulations prepared directly from adult *C. sinensis* and used successfully against the same species. The

Product 2 (female attractant) effectively attracted males, with catches decreasing from 13.40 ± 0.82 to 7.10 ± 0.49 moths per trap over the same period (Table 3). In contrast, the control (hexane) and methanol-washed fractions (Components A and B) captured very few moths throughout the study. Female catches in the control ranged from 0.70–2.30 moths per trap, while male catches ranged from 0.50–2.60 moths per trap. Similar low catches were observed with Components A and B. Two-way ANOVA revealed significant effects of treatment, week, and their interaction on trap catches (Tables 2 and 4). Tukey's HSD test showed significant differences among treatments and weeks ($p < 0.05$). Trap catches were highest during the initial weeks and declined thereafter.

developed traps consistently attracted moths and showed potential as an environmentally friendly management tool. Field studies further revealed that volatiles derived from male moths attracted females, whereas female-derived volatiles attracted males. Product 1 (male-derived attractant) recorded the highest female captures, declining from 27.40 ± 0.60 moths per trap during the first week to 7.30 ± 0.44 moths by the sixth week. Product 2 (female-derived attractant) attracted male moths effectively, recording 13.40 ± 0.82 moths per trap during the first week. In contrast, the control treatment and methanol-washed fractions (Components A and B) captured only a few moths throughout the study. These findings suggest that biologically active attractants are present in whole-body extracts and may include compounds involved in mate location and communication. Such an approach may help overcome some limitations encountered in conventional pheromone research, particularly in species with complex mating behaviour (Yang et al.

2022). Another practical advantage of this method is that it does not rely exclusively on the identification of individual compounds before field evaluation. Although GC-MS analysis was conducted in this study to characterise the extracts, the whole-insect extraction approach provides a simple route for generating biologically active attractant blends for preliminary screening and field testing.

Overall, the results demonstrate that semi-solid slow-release formulations prepared from insect-derived volatiles can effectively attract *C. sinensis* adults in the field. The technology offers promise as a component of integrated pest management programmes and warrants further investigation on attractant optimization, longevity, and large-scale deployment. The developed formulations show promise for attract-and-kill management of *C. sinensis*. Their slow-release nature provides prolonged field activity, reducing lure replacement and management costs. The formulations are simple to prepare, easy to deploy in Delta traps, and suitable for large-scale use.

Conclusions

This study provides evidence that semi-solid slow-release formulations prepared from male and female *C. sinensis* extracts can effectively attract the opposite sex under field conditions. The formulations remained active for several weeks and captured significantly higher numbers of moths than the control treatments. The findings demonstrate the potential of whole-insect-derived attractants as practical tools for sustainable pest management by reducing dependence on synthetic insecticides and supporting attractant-based control strategies. The combination of whole-insect extraction and semi-solid slow-release technology represents a simple and potentially cost-effective approach for developing attractants in pest species where conventional pheromone research has been difficult. Further optimization and large-scale field validation may facilitate its application in *C. sinensis* and other economically important insect pests.

Supplementary Materials: The following supporting information can be downloaded <https://www.nbair.res.in/sites/default/files/2025-06/Research%20RAW%20DATA%201.pdf>.

Author Contributions: Conceptualization, D.B. and S.N.S.; methodology D.B.; S.N.S.; M.S.; and S.S.; validation, D.B.; S.N.S.; M.S.; and S.S.; formal analysis, D.B.; S.N.S.; M.S.; and S.S.; investigation, D.B.; S.N.S.; M.S.; and S.S.; resources, D.B. and S.N.S.; data curation, D.B.; S.N.S.; M.S.; and S.S.; writing—original draft preparation, D.B.; S.N.S.; M.S.; and S.S.; writing—review and editing, D.B. S.S. and S.N.S.; visualization, D.B.; S.N.S.; M.S.; and S.S.; supervision, D.B.; S.N.S.; M.S.; and S.S.; project administration, D.B.; S.N.S.; M.S.; and S.S.; funding acquisition, D.B. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available within the article and supplementary

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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