

Article

Preparation and Evaluation of a Temperature-Sensitive Cuelure Nano-Controlled Release Agent

Aqiang Wang ^{1,†} , Sihua Peng ^{1,†}, Bei Zeng ^{1,†}, Yuyang Lian ¹, Jingjing Jia ², Qiongkuan Zhang ¹, Qianxing Wu ¹ and Shihao Zhou ^{1,*} 

¹ School of Breeding and Multiplication (Sanya Institute of Breeding and Multiplication), Hainan University, Sanya 572022, China; l18876114522@126.com (Y.L.); 17864387681@163.com (Q.Z.); qianxing301@163.com (Q.W.)

² Key Laboratory of Plant Disease and Pest Control of Hainan Province, Institute of Plant Protection, Hainan Academy of Agricultural Sciences (Research Center of Quality Safety and Standards for Agricultural Products of Hainan Academy of Agricultural Sciences), Haikou 571199, China

* Correspondence: zsh88200939@126.com

† These authors contributed equally to this work.

Abstract: Cuelure, an effective lure specifically targeting Tephritid fruit flies, has been widely adopted and applied in the monitoring and control of these pests, providing significant support for agricultural pest management. However, its uncontrollable release speed and duration usually lead to a lot of waste, diminishing its effectiveness and increasing the cost of pest control. In order to solve these problems, we focused on *Zeugodacus cucurbitae* Coquillett and developed a temperature-sensitive nano-controlled release agent for cuelure. The release rate of this agent can be adjusted by adjusting the ambient temperature. The results show that the temperature-sensitive cuelure nano-controlled release agent demonstrates remarkable temperature-responsive controlled release characteristics. It still exhibits exceptional stability even after being subjected to high-temperature treatment at 60 °C for a week, and the trapping efficiency of this attractant remains between 73% and 75%. This study not only holds immense practical value in monitoring, warning, and managing of fruit fly pests, but it also lays a novel theoretical foundation for the development of insect attractants.

Keywords: temperature-sensitive attractant; *Zeugodacus cucurbitae* Coquillett; cuelure; controlled release; nano-pesticide



Citation: Wang, A.; Peng, S.; Zeng, B.; Lian, Y.; Jia, J.; Zhang, Q.; Wu, Q.; Zhou, S. Preparation and Evaluation of a Temperature-Sensitive Cuelure Nano-Controlled Release Agent. *Agronomy* **2024**, *14*, 1578. <https://doi.org/10.3390/agronomy14071578>

Academic Editor: Shun He

Received: 21 June 2024

Revised: 15 July 2024

Accepted: 17 July 2024

Published: 19 July 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Zeugodacus cucurbitae Coquillett, belonging to the Diptera (Tephritidae) family, is a widely prevalent pest in tropical, subtropical, and temperate regions, primarily targeting cucurbit plants [1–3]. However, traditional chemical pesticide spraying methods are rendered ineffective due to the insect's concealed spawning habits and formidable flying abilities. Moreover, the excessive use of these chemicals poses significant risks to food safety and environmental pollution [4]. To mitigate these detrimental effects on human health, food security, and ecosystems, it is imperative to adopt environmentally friendly pest control strategies.

The advent of insect attractants presents a novel approach to pest management. By integrating male attractants with pesticides and spraying them extensively in the field, the male-killing technology has successfully eradicated fruit fly pests [5–7]. Cuelure (CUE) is a male attractant for *Z. cucurbitae*, which was first discovered in 1960 by Beroza et al. in a series of 4-phenyl-2-butanone isomers synthesized organically [8,9]. It not only enhances the sexual mating activity of male *Z. cucurbitae* but also has the ability to attract male *Z. cucurbitae* [10]. Meanwhile, cuelure also has certain attraction activity for 56 related species, such as *Bactrocera tryoni* Froggatt and *Dacus ciliatus* Low, which are internationally recognized as important attractants for monitoring of fruit flies [11–13]. During the hot

season, the occurrence of the pest is particularly serious, which is also the optimal time to use cuelure to trap *Z. cucurbitae* [14]. However, its release speed and duration are influenced by variables such as temperature, necessitating frequent core replacements to sustain its effectiveness. This not only increases the cost of pest control, but also requires regular maintenance to prevent pest resurgence. To address these challenges, it is necessary to explore materials that can be triggered by external stimuli, such as light, heat, or pH, to regulate the rapid and extensive release of cuelure at specific temperatures to enhance the utilization rate of cuelure while extending its shelf life, ultimately reducing the costs associated with pest control.

Poly (N-isopropylacrylamide) (PNIPAM) is a widely utilized hydrogel material renowned for its temperature-sensitive properties, exhibiting a lower critical solution temperature (LCST) of approximately 32 °C. Its superior water absorbency, distinctive three-dimensional porous structure, and exceptional responsiveness to environmental stimuli have propelled its extensive application in diverse fields, including pharmaceuticals, agriculture, and biomedicine [15–17]. For instance, Wu et al. [18] successfully synthesized a PNIPAM hydrogel via free radical polymerization, revealing that an increase in temperature leads to accelerated drug release rates and enhanced cumulative release. This temperature-dependent behavior allows for precise regulation of drug release, positioning PNIPAM as an ideal candidate for controlling the release of cuelure in this study.

To bolster both the drug-loading capacity and temperature sensitivity of the PNIPAM hydrogel, we have integrated carboxylated multi-walled carbon nanotubes (MWCNTs-COOH) into its matrix. MWCNTs-COOH, owing to its remarkable drug-loading capabilities and thermal conductivity, represents an ideal additive. Carbon nanotubes (CNTs), characterized by their high aspect ratio, large specific surface area, and exceptional mechanical stiffness, have been validated as effective drug carriers, possessing numerous promising applications [19]. However, CNTs tend to exhibit poor dispersibility in aqueous solutions. By introducing hydrophilic carboxyl groups, the dispersibility of MWCNTs-COOH in aqueous media is significantly improved [20]. Furthermore, MWCNTs-COOH facilitates the targeted delivery of both hydrophilic and hydrophobic substances while maintaining drug stability [21].

In summary, to address the challenge of the uncontrollable release rates of insect attractants, we propose a novel approach utilizing *Z. cucurbitae* as the research subject, cuelure as the prodrug, MWCNTs-COOH as the carrier, and PNIPAM hydrogel as the switch. This approach aims to develop a temperature-sensitive cuelure nano-controlled release agent (hereinafter referred to as temperature-sensitive attractant), so as to realize the controlled release of cuelure. By doing so, we aim to achieve controlled release of cuelure, reduce the cost of attractant usage, and provide a theoretical foundation for monitoring and controlling *Z. cucurbitae*.

2. Materials and Methods

2.1. Insect Source

Z. cucurbitae used in this study were collected from a bitter melon plantation located in Hainan, China (109°29' E, 19°30' N). Damaged fruits were brought indoors, and the larvae and pupae of *Z. cucurbitae* were carefully extracted for artificial breeding. The average indoor temperature is kept at 25 ± 1 °C, the humidity is kept at $70 \pm 5\%$, and the light ratio is 14L:10D, so as to establish a temperature-sensitive indoor population. The formula of artificial feed for insect larvae is 200 g yeast powder, 1000 g corn flour, 200 g sucrose, 5 g sodium benzoate, 1000 g pumpkin, 8 mL concentrated hydrochloric acid, 1000 mL water, and 200 g roll paper. The formula of artificial feed for adults is yeast powder: sucrose ($w:w$) = 1:1.

2.2. Main Equipment

Intelligent artificial climate incubator (ZRX258D, Hangzhou Qianjiang Instrument and Equipment Co., Ltd., Hangzhou, China), ultra-pure water machine FST-111-TH100

(Thermo, Waltham, MA, USA), 1/10,000 analytical balance (GR-300, Iand, Yokohama, Japan), pipettes with various ranges (Research plus adjustable range pipettes, Ebend China Co., Ltd., Memmingen, Germany), ultraviolet-visible spectrophotometer (UV-vis spectrophotometer). Unico (Shanghai Instrument Co., Ltd., Shanghai, China), Sartorius aquarium Mini Plus pure water ultrapure water machine (H₂O-MA-UV-T, Germany).

Reagents and Sources

Cuelure (purity 98%, Jiangxi Yixin Perfume Co., Ltd., Jian, China), commercial attractant (General Huang, the effective component is pyrimethamine, purity 98%, China Academy of Agricultural Sciences, Beijing, China), MWCNTs-COOH (length 10–20 μ m, particle size 30–50 nm, purity 95%, carboxyl content 2.0 wt%, Jiangsu Xianfeng Nanomaterials Technology Co., Nanjing, China). Acetonitrile (AR, 99%), Methylene-Bis-Acrylamide (purity 99%), Poly (ethylene glycol) (PEG 1000, purity 99%), N,N,N',N'-tetramethylethylenediamine (TMEDA, purity 99%), and ammonium persulfate (AR, purity 99%) were all purchased from China Hainan Qingfeng Biotechnology Co., Ltd. (Sanya, China).

2.3. Experimental Methods

2.3.1. Temperature Setting

The LCST of temperature-sensitive attractants is approximately 32 °C. When the temperature is higher than the LCST of temperature-sensitive attractants, a substantial quantity of attractants will be released [22], and combined with the field temperature under field conditions, three temperature conditions of 25 °C, 33 °C, and 37 °C were set with the help of an artificial climate incubator, while maintaining the humidity at 70 $\pm$ 5%.

2.3.2. Setting of Trapping Time

Chen et al. [23] discovered that the optimal time for trapping *Z. cucurbitae* with cuelure is during the morning and noon, and the dosage of cuelure in the field was generally about 1 g, which had a good effect. With reference to the above studies and the existing foundation, we set the trapping test at 9:00 a.m. to 12:00 p.m., and the dosage of cuelure was tentatively set at 0.5 mL.

2.3.3. Evaluation of the Trapping Effect of Cuelure on *Z. cucurbitae*

To ascertain the most effective age and dosage of cuelure for capturing *Z. cucurbitae* under varying temperature conditions, cages containing 5-, 10-, 20-, and 30-day-old *Z. cucurbitae* (each cage containing 50 female and 50 male adults) were placed in an artificial climate chamber set at 25 °C, 33 °C, and 37 °C, with a humidity of 70 $\pm$ 5%. Different dosages of cuelure (0.1 mL, 0.5 mL, 1.0 mL, and 2.0 mL) were then introduced into the traps and placed in the cages for 3 h, and the treatment without cuelure is taken as the blank control (CK₁), with five replicates in each treatment and one replicate for each cage. Upon completion of the experiment, the number of *Z. cucurbitae* captured in each group was tallied and recorded.

2.4. Preparation and Evaluation of Temperature-Sensitive Attractant

2.4.1. Preparation of Temperature-Sensitive Attractant

Drawing inspiration from the method outlined by Pan et al. [24] with modifications, the preparation process was as follows: Initially, 0.5 mL of cuelure was added to 10 mL 60% acetonitrile-water (*v/v*) solution and mixed evenly. Subsequently, 1.000 g of PEG 1000 was added for ultrasonic treatment for 10 min. After this, 0.001 g of MWCNTs-COOH was added for ultrasonic dispersion for 30 min, and then sealed for 12 h. Next, 1.000 g of NIPAM, 0.02 g of Methylene-Bis-Acrylamide and 50 μ L of TEMED were added in turn, stirred and dissolved, and nitrogen was introduced for 30 min to remove oxygen in the system. Finally, 0.02 g of ammonium persulfate was added and nitrogen was continuously introduced until it was completely dissolved, sealed, and reacted at room temperature for

12 h to complete the preparation. The schematic diagram of the synthesis and release of temperature-sensitive attractants can be found in Figure 1.

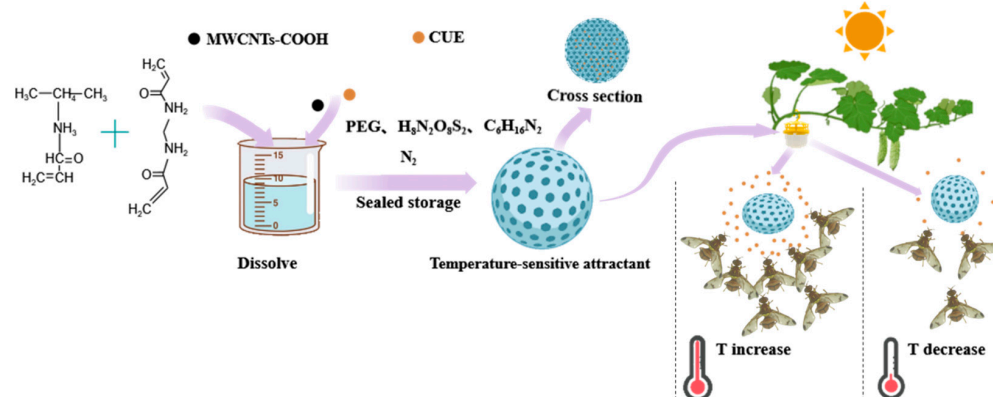


Figure 1. Schematic diagram of synthesis and sustained-release principle of temperature-sensitive attractant.

2.4.2. Plotting of Standard Curve of Cuelure Solution

Preparation of cuelure stock solution: Accurately weigh 1.000 g of cuelure, pour it into a 100 mL volumetric flask, and use 60% acetonitrile-water (*v/v*) solution to make the volume constant to 100 mL to prepare 10 mg/mL cuelure stock solution.

Preparation of standard solution of cuelure: 60% acetonitrile solution was used to dilute the above solution into cuelure standard solutions at concentrations of 1 mg/mL, 2 mg/mL, 3 mg/mL, 4 mg/mL, 5 mg/mL, 6 mg/mL, and 7 mg/mL. With 60% acetonitrile as the reference solution, the absorbance of the standard solution of cuelure was measured with an ultraviolet-visible spectrophotometer at the wavelength of 270 nm, and the standard curve was drawn with the concentration of the standard solution as the abscissa and absorbance as the ordinate.

2.4.3. The Influence of Crosslinker Content on Temperature-Sensitive Attractants

The content of the cross-linking agent will directly affect the structure and strength of the hydrogel. In order to investigate the effect of the amount of cross-linking agent on the performance of temperature-sensitive attractants, the method in Section 2.4.1 was used to prepare temperature-sensitive entrapment with different cross-linking agent contents according to Table 1.

Table 1. Dosage of crosslinking agent.

Name	Reagent	Treatment				
		1	2	3	4	5
Thermosensitive monomer (g)	NIPAM	1.0	1.0	1.0	1.0	1.0
Crosslinking agent (g)	Methylene-Bis-Acrylamide	0.02	0.03	0.04	0.05	0.06
Porogen (g)	PEG 10000	1.0	1.0	1.0	1.0	1.0
Accelerating agent (μL)	TMEDA	50	50	50	50	50
Initiator (g)	Ammonium persulphate	0.02	0.02	0.02	0.02	0.02
Solvent (mL)	60% acetonitrile aqueous solution	10	10	10	10	10

The concentration of the cross-linking agent plays a crucial role in determining the structure and mechanical strength of the hydrogel. To assess the impact of varying cross-linking agent concentrations on the performance of temperature-sensitive attractants, we employed the method outlined in Section 2.4.1 to prepare attractants with differing cross-linking agent contents, as specified in Table 1.

Then, 2.0 g of the prepared temperature-sensitive attractants was immersed in 30 mL 60% acetonitrile solution and placed at 35 °C for 3 h. During this period, 1 mL was sampled every 30 min, and 1 mL of the original solution was added to keep the total volume of the solution unchanged. The absorbance of the sample solution was detected, and the concentration of cueure in the solution was calculated by substituting the formula obtained in Section 2.4.1.

2.4.4. Effect of Porogen Content on Temperature Sensitivity of Temperature Sensitive Attractants

The content of the pore-forming agent directly affects the rate of slow release of the temperature-sensitive attractant. In order to explore the influence of the content of the pore-forming agent on the performance of the temperature-sensitive attractant, the method in Section 2.4.1 was used to prepare a temperature-sensitive attractant with different content of pore-forming agent according to Table 2, and then, 2.0 g of the prepared temperature-sensitive elicitor was immersed in 30 mL of 60% acetonitrile solution and then placed at 35 °C for 3 h. During this period, 1 mL of the samples was taken at intervals of 30 min, and 1 mL of the original solution was replenished to keep the total volume of the solution unchanged. Unchanged, the absorbance of the sample solution was detected and substituted into the formula obtained in Section 2.4.2 to calculate the concentration of cueure in the solution.

Table 2. Dosage of pore-forming agent.

Name	Reagent	Treatment				
		1	2	3	4	5
Thermosensitive monomer (g)	NIPAM	1.0	1.0	1.0	1.0	1.0
Crosslinking agent (g)	Methylene-Bis-Acrylamide	0.02	0.02	0.02	0.02	0.02
Porogen (g)	PEG 10000	0	0.5	1.0	1.5	2.0
Accelerating agent (μL)	TMEDA	50	50	50	50	50
Initiator (g)	Ammonium persulphate	0.02	0.02	0.02	0.02	0.02
Solvent (mL)	60% acetonitrile aqueous solution	10	10	10	10	10

2.5. Scanning Electron Microscope

The prepared PNIPAM hydrogel, PNIPAM porous hydrogel, and PNIPAM@MWCNTs-COOH@CUE temperature-sensitive attractant were taken as 2 g each, freeze-dried, and an appropriate amount of the solid was sprayed with gold to treat the samples before observing and analyzing the microscopic morphology of the samples using a scanning electron microscope (Verios G4 UC, Thermo Fisher, Brno, Czech Republic).

2.6. Performance Test of Temperature-Sensitive Attractant

2.6.1. Temperature Response Concentration Release Experiment

The speed of drug release in the temperature-sensitive hydrogel can reflect the temperature-sensitive performance of the hydrogel. To evaluate the performance of the temperature-sensitive attractant, multiple portions of the temperature-sensitive attractant prepared in Section 2.4.1 (2.0 g each) were put in a centrifuge tube filled with 30 mL 60% acetonitrile solution, and then, the centrifuge tubes were placed at 25 °C, 30 °C, 35 °C, 40 °C, and 45 °C for 3 h, respectively. During this period, 1 mL was sampled every 30 min, and 1 mL of the original solution was added to keep the total volume of the solution unchanged. The absorbance of the sample solution was detected, and then, the absorbance value was substituted into the formula obtained in Section 2.4.2 to calculate the concentration of cueure in the solution.

2.6.2. Determination of Entrapment Efficiency and Drug Loading

As crucial indicators of nano-drugs' key quality attributes, encapsulation efficiency and drug loading are intimately tied to the formulation and preparation technology of nano-drugs, which reflect the degree of drug encapsulation by carriers [25]. To assess the entrapment efficiency and drug loading of the temperature-sensitive attractant, we weighed three 2.0 g samples prepared in Section 2.4.1 and dissolved them in 30 mL of 60% acetonitrile solution for 30 min, maintaining a water temperature of 35 °C during ultrasonic treatment. Following ultrasonication, the supernatant was centrifuged, and its absorbance was measured using a spectrophotometer. The obtained absorbance values were then substituted into the formula derived in Section 2.4.2 to calculate the cuelure content in the solution.

Referring to Singh et al. [26] and Lim et al. [27], the encapsulation efficiency (EE) and loading content (LC) of the hydrogels were calculated according to the following Formulas (1) and (2).

$$EE (\%) = M_1/M_2 \times 100\% \quad (1)$$

$$LC (\%) = M_1/M_3 \times 100\% \quad (2)$$

M_1 : total mass of cuelure carried in temperature-sensitive attractant; M_2 : initial dosage of cuelure; M_3 : total mass of temperature-sensitive attractant.

2.7. The Effect of Temperature-Sensitive Attractant on Trapping *Z. cucurbitae* Indoors

2.7.1. Evaluation of the Trapping Effect of Temperature-Sensitive Attractants on *Z. cucurbitae* under Different Temperature

To evaluate the comparative trapping efficacy of temperature-sensitive attractants, cuelure, and commercial attractants, the 20-day-old *Z. cucurbitae* was chosen as the test insect. To ensure a controlled and consistent evaluation, a fixed dosage of 0.1 mL of each attractant was used in multiple traps. These traps were then positioned in separate cages, each housing 50 female and 50 male adult *Z. cucurbitae* (with each cage serving as a replicate). The cages were subsequently placed in distinct artificial climate incubators, each set to a different temperature (25 °C, 33 °C, and 37 °C) with a humidity of $70 \pm 5\%$. After the experiment, the number of *Z. cucurbitae* trapped in each group was counted and recorded.

2.7.2. Effect of the Dosage of Temperature-Sensitive Attractant on Trapping *Z. cucurbitae* in Different Temperature

In the previous experiment, we found that the dosage of cuelure would affect the effect of trapping *Z. cucurbitae*. Therefore, in order to evaluate the influence of the dosage of the temperature-sensitive attractant on the trapping of *Z. cucurbitae*, cages containing *Z. cucurbitae* (each cage contains 50 20-day-old females and males, and one cage was repeated) were placed in different artificial climate incubators (temperature 25 °C and 33 °C, humidity $70 \pm 5\%$), and then, different doses of temperature-sensitive attractant (0 g, 1.0 g, 2.0 g, and 3.0 g) were loaded. After the experiment, the number of *Z. cucurbitae* trapped in each group was counted and recorded.

2.7.3. High-Temperature Resistance Limit Test of Attractant

This study was conducted in Sanya, Hainan, China, which is located in the tropical region, and it is known that the maximum surface temperature in this region can reach 45 °C in summer according to the local historical temperature records. Considering the use conditions of field attractants and the characteristics of temperature-sensitive attractants, 60 °C was chosen as the temperature for the high-temperature test of attractants. The temperature-sensitive attractants, cuelure, and commercial attractants were placed in an oven at 60 °C for 7 d. On the 1st, 3rd, 5th, and 7th day of treatment, respectively, 0.1 mL of the above attractant was added to the trap, and then, the trap was placed in different cages (each cage was filled with 50 20-day-old female and male adults, which was a repetition).

Finally, the cages were cultured in different artificial climates. After the experiment, the number of *Z. cucurbitae* trapped in each group was counted and recorded.

3. Results

3.1. Evaluation of the Trapping Effect of Cuelure on *Z. cucurbitae*

3.1.1. Study on the Optimum Day Age of *Z. cucurbitae* Trapped by Cuelure under Different Temperature

Cuelure was used to trap 5-, 10-, 20-, and 30-day-old *Z. cucurbitae* under different temperatures (25 °C, 33 °C, and 37 °C). The results show that cuelure was effective in trapping *Z. cucurbitae* of different ages at different temperatures. At 25 °C and 33 °C, the number of 20-day-old and 30-day-old *Z. cucurbitae* trapped by cuelure was highest, followed by 10-day-old and 5-day-old (Figure 2). However, when the ambient temperature increased to 37 °C, the total number of *Z. cucurbitae* trapped by cuelure was significantly lower than that at 25 °C and 33 °C, which may be attributed to the fact that *Z. cucurbitae* gathered on wet cotton to escape from the high temperature when the ambient temperature was elevated, resulting in a decrease in the number of *Z. cucurbitae* trapped by cuelure. Interestingly, at 37 °C, the number of 30-day-old *Z. cucurbitae* trapped by cuelure was significantly higher than that of other days, which is due to the 30-day-old *Z. cucurbitae* having a higher tolerance to the high-temperature environment than the other ages, which led to their higher activity in the high-temperature environment.

The results showed that the number of male *Z. cucurbitae* trapped by cuelure was significantly higher than that of females at 25 °C and 33 °C (Figure 3). This suggests that cuelure primarily attracted male *Z. cucurbitae*. However, at 37 °C, there is no significant difference between them, which is due to the fact that high temperatures inhibit the aggregation of male melon *Z. cucurbitae* to cuelure.

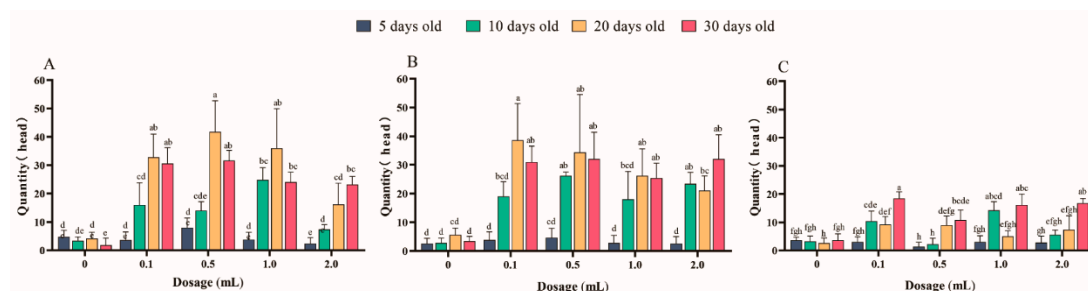


Figure 2. The number of *Z. cucurbitae* Coquillett of different ages trapped by cuelure at different temperatures. (A) 25 °C, (B) 33 °C, (C) 37 °C. The value of the bar chart is mean $\pm$ standard error, and the lowercase letters above the bar chart indicate significant differences ($p < 0.05$).

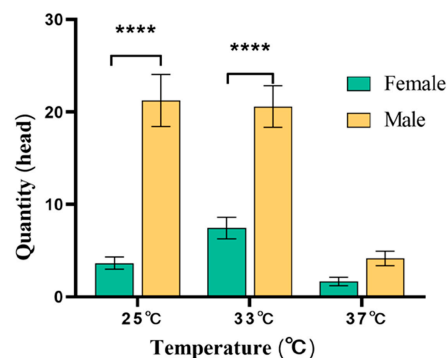


Figure 3. Number of females and males of *Z. cucurbitae* Coquillett trapped by cuelure at different temperatures. Note: the value of the bar chart is mean $\pm$ standard error, and the “****” at the top of the bar chart indicate the significant differences ($p < 0.0001$).

3.1.2. The Influence of the Dosage of Cuelure on the Trapping of *Z. cucurbitae* in Different Temperature

Using different dosages of cuelure to conduct trapping experiments on *Z. cucurbitae* under three temperature conditions of 25 °C, 33 °C, and 37 °C, the results showed that the trapping effect of cuelure was significantly influenced by its dosage and ambient temperature. Specifically, at the temperatures of 25 °C and 33 °C, when the dosage of cuelure was 0.1 mL and 0.5 mL, the number of trapped *Z. cucurbitae* was the highest. However, when the dosage increased to 1 mL, the trapping effect was secondary, and when the dosage further increased to 2 mL, the number of trapped *Z. cucurbitae* decreased significantly (Figure 4). At 37 °C, the highest number of *Z. cucurbitae* were trapped at a dosage of 0.1 mL, followed by 1.0 mL and 2.0 mL of cuelure. This result indicates that the trapping effect of cuelure does not continuously increase with its dosage. We speculate that a high concentration of cuelure may inhibit the sensitivity of *Z. cucurbitae* to cuelure, leading to a decrease in the trapping effect.

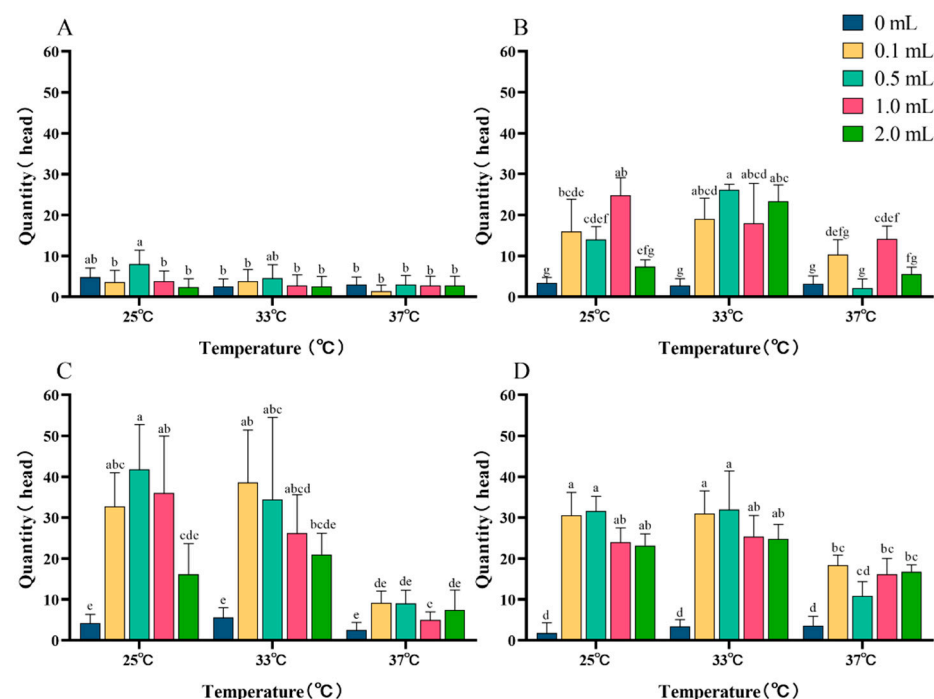


Figure 4. The number of *Z. cucurbitae* Coquillett trapped by different dosages of cuelure. (A) 5 days old, (B) 10 days old, (C) 20 days old, (D) 30 days old *Z. cucurbitae*. The value of the bar chart is mean $\pm$ standard error, and the lowercase letters above the bar chart indicate significant differences ($p < 0.05$).

Under the same dosage of cuelure, the number of *Z. cucurbitae* trapped by cuelure at 25 °C and 33 °C was significantly higher than that at 37 °C. This indicates the environmental temperature at 25 °C and 33 °C was more favorable for cuelure to trap *Z. cucurbitae*. The possible reason is that when the environmental temperature was 25–33 °C, the physiological activities such as feeding and mating were more active. When the ambient temperature reaches 37 °C, the *Z. cucurbitae* gathers on wet cotton to avoid the high temperature, which leads to a decrease in the number of *Z. cucurbitae* trapped by cuelure.

3.2. Preparation and Evaluation of Temperature-Sensitive Attractant

3.2.1. Drawing of Standard Curve of Cuelure

By measuring the absorbance of the standard solution of cuelure, a standard curve was plotted, with the concentration of cuelure serving as the abscissa and the absorbance as the ordinate. The results demonstrate a strong linear correlation between the concentration and absorbance of cuelure, evidenced by the high correlation coefficient of $R^2 = 0.9926$ (Figure 5).

This signifies an excellent linearity between the experimental data and the fitting function, indicating the reliability of the method for quantifying cuelure concentrations.

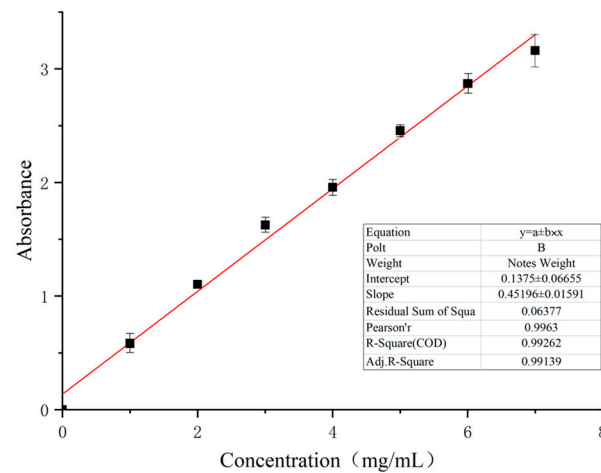


Figure 5. Standard curve of absorbance versus concentration of cuelure.

3.2.2. Effect of Crosslinking Agent Content on Temperature Sensitivity of Temperature-Sensitive Attractant

The influence of the amount of cross-linking agent on the temperature-sensitive attractant is shown in Figure 6. The results show that when the amount of cross-linking agent is 0.06 g and 0.03 g, the concentration of cuelure in the solution increases within the first 1.5 h, while the release rate of cuelure slows down in the process of 1.5–3.0 h. This is due to the cuelure in the temperature-sensitive attractant having been released into the solution in the first 1.5 h, which leads to the slow increase of the concentration of cuelure in the solution after 1.5 h of the experiment.

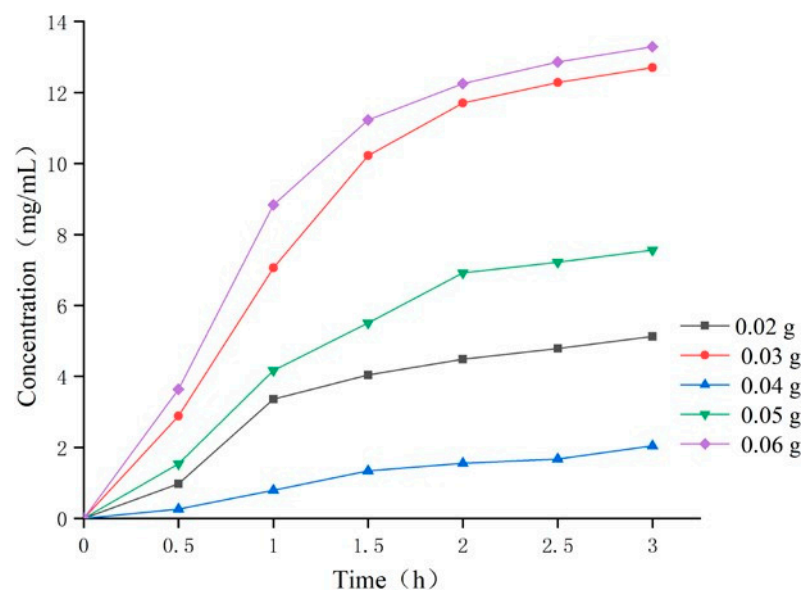


Figure 6. Effect of dosage of cross-linking agent on temperature sensitivity of temperature-sensitive inducer.

When the dosage of the cross-linking agent is 0.05 g and 0.02 g, the release rate of the drug in the temperature-sensitive attractant is relatively gentle, and the concentration of cuelure in the solution at 3.0 h was only half of that at 0.06 g and 0.03 g. This indicates that at least half of the remaining cuelure in the temperature-sensitive attractant has not been released into the solution. The reason for the change in the release rate of cuelure in

temperature-sensitive attractants may be that the amount of different crosslinking agents affects the structure of the gel (such as the number of crosslinking points in the polymer segments), which leads to the change in the temperature sensitivity of the hydrogel.

3.2.3. Effect of Pore-Forming Agent Content on Hydrogel Temperature Sensitivity

The effect of the amount of pore-forming agent on the temperature-sensitive attractant is shown in Figure 7. The results indicate that the final concentration of cuelure in the solution is inversely related to the content of the pore-forming agent used. It is due to the pore-forming agent forming many small holes in the gel, which leads to the temperature-sensitive attractant with the less pore-forming agent carrying more cuelure per unit volume.

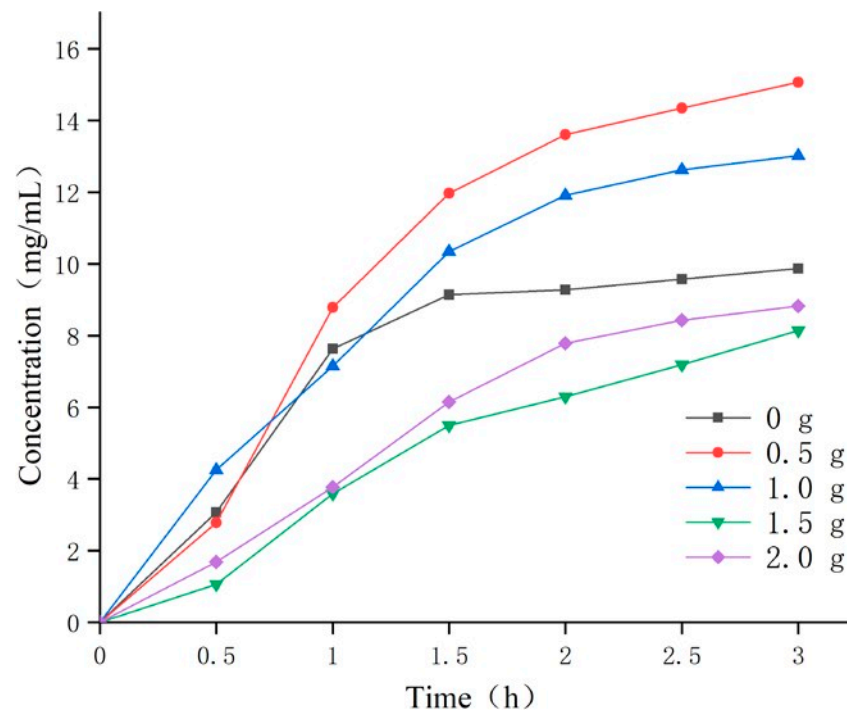


Figure 7. Effect of the dosage of pore-forming agent on the temperature sensitivity of temperature-sensitive attractant.

In the first 1 h of the experiment, the release rate and amount of cuelure in the temperature-sensitive attractant without a pore-forming agent were higher. However, after 1 h, the release rate of cuelure in the temperature-sensitive attractant without a pore-forming agent was slower than that in other treatments. This is because the surface of the temperature-sensitive sustained-release agent without a pore-forming agent collapses faster than the inside of it, and a dense epidermis layer is formed on its surface, which leads to the inability to release the cuelure inside the gel, resulting in a small change in the concentration of cuelure in the solution after 1 h. In contrast, when the dosage of the pore-forming agent is 0.5 g and 1.0 g, the release rate and amount of temperature-sensitive attractant are higher than 1.5 g and 2.0 g, indicating that the temperature-sensitive attractant prepared with the dosage of these two pore-forming agents is more conducive to its slow-release performance.

3.2.4. Morphology Characterization of Temperature-Sensitive Attractants

The scanning electron microscope (SEM) image of the hydrogel sample is shown in Figure 8. As seen in Figure 8A, the hydrogel sample without a pore-forming agent exhibits a relatively smooth surface with only a few pores. However, when the pore-forming agent is added to the hydrogel, it can be seen that a large number of pores are generated on the surface of the gel (Figure 8B). The existence of these pores will be beneficial to the release of cuelure in the temperature-sensitive attractant. By observing the prepared PNIPAM@

MWCNTs-COOH@CUE temperature-sensitive attractant at the scale of 100 μm , it can be seen that there are many holes in the network structure of the gel (Figure 8C), which not only provide sufficient channels for the release of cueure but also provide large-area attachment sites for carbon nanotubes, providing them with the ability to carry more cueure.

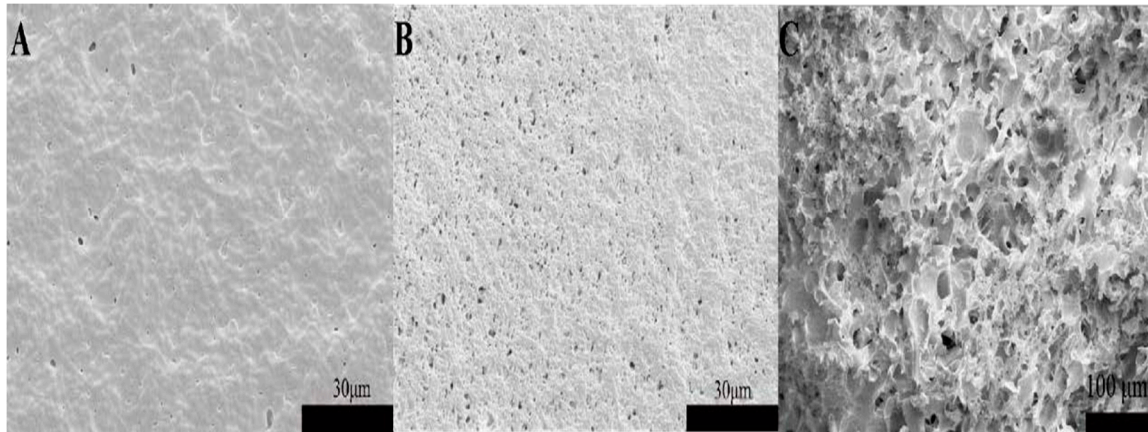


Figure 8. SEM image of hydrogel. (A) PNIPAM hydrogel, (B) PNIPAM porous hydrogel, (C) PNIPAM@MWCNTs-COOH@CUE @ CUE temperature-sensitive attractant.

3.3. Performance Test of Temperature-Sensitive Attractant

3.3.1. Temperature Response Release Experiment of Temperature-Sensitive Trap

The experimental results of the temperature-responsive release of temperature-sensitive attractants are shown in Figure 9. The results show that the release rate of temperature-sensitive attractants is positively correlated with temperature in the range of 25–45 $^{\circ}\text{C}$. Specifically, at 25 $^{\circ}\text{C}$, the drug release rate of the temperature-sensitive attractant is slow. However, as the temperature rises to 35 $^{\circ}\text{C}$ and 45 $^{\circ}\text{C}$, the drug release rate increases rapidly in unit time, and the final release concentration of the drug is also higher than 25 $^{\circ}\text{C}$. These findings suggest that the temperature-responsive attractant exhibits favorable responses to changes in temperature.

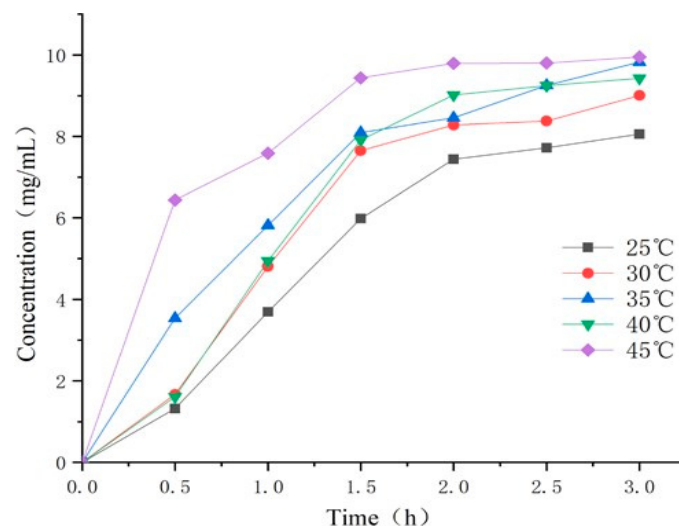


Figure 9. Temperature response release of temperature-sensitive attractant.

3.3.2. Determination of Entrapment Efficiency and Drug Loading

The entrapment efficiency of the temperature-sensitive attractant serves as a pivotal measure of the carrier's overall performance. Our study reveals that the entrapment efficiency of the prepared temperature-sensitive attractant falls within the range of 73.34% to

75.53%, with a corresponding drug loading capacity of 3.36% to 3.46% (Table 3). These findings underscore the attractant's commendable drug-loading performance, indicating its ability to efficiently encapsulate and retain the desired compound.

Table 3. Entrapment efficiency and drug loading of temperature-sensitive attractants.

Sample	Absorbance	Concentration (mg/mL)	Entrapment Efficiency (%)	Drug Loading (%)
1	1.186 ± 0.01	2.32 ± 0.01	75.53 ± 0.01	3.46 ± 0.02
2	1.174 ± 0.01	2.29 ± 0.02	74.83 ± 0.01	3.43 ± 0.03
3	1.182 ± 0.01	2.31 ± 0.03	73.34 ± 0.01	3.36 ± 0.04

3.4. Indoor Effect Determination

3.4.1. Evaluation of the Effect of Temperature-Sensitive Attractant on Trapping *Z. cucurbitae*

The results of trapping *Z. cucurbitae* indoors using the temperature-sensitive attractant are shown in Figure 10. At temperatures of 25 °C and 33 °C, there is no significant difference between the number of *Z. cucurbitae* trapped by the temperature-sensitive attractant and the number of *Z. cucurbitae* trapped by using cuelure alone. This suggests that the efficacy of trapping *Z. cucurbitae* using cuelure remains unimpaired during the preparation process of the temperature-sensitive attractant. At 37 °C, a greater number of *Z. cucurbitae* are trapped using the temperature-sensitive attractant than with cuelure alone. The possible reason is that the temperature at this time is above the LCST of the temperature-sensitive attractant, which led to the rapid volatilization of the pheromone in the temperature-sensitive attractant, thus increasing the effect of trapping *Z. cucurbitae* using the temperature-sensitive attractant.

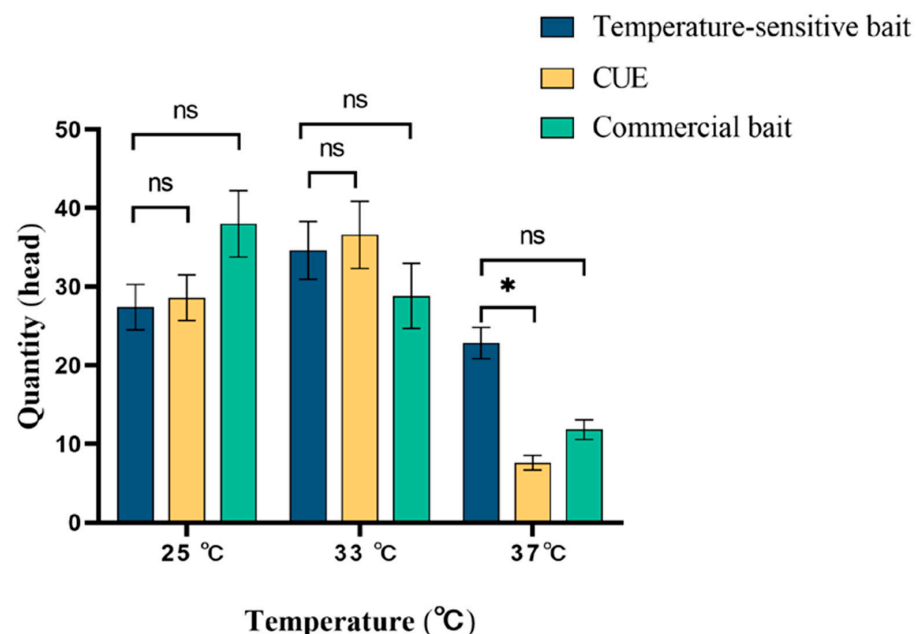


Figure 10. The number of *Z. cucurbitae* Coquillett trapped by three attractants at different temperatures. The “*” at the top of the bar chart indicates a significant difference at the $p < 0.05$ level and “ns” indicates no difference.

Furthermore, there is no significant difference in the number of *Z. cucurbitae* trapped by commercial attractants and temperature-sensitive attractants under the temperatures of 25 °C, 33 °C, and 37 °C, indicating that the temperature-sensitive attractants had a good application potential. At 25 °C, the number of *Z. cucurbitae* trapped by the temperature-sensitive attractant is less than that of the commercial attractants. When the temperature

is increased to 33 °C and 37 °C, the number of *Z. cucurbitae* trapped by the temperature-sensitive attractants is more than that of commercial attractants. This is because when the ambient temperature is 25 °C, the LCST of the temperature-sensitive attractant is not reached, and the release rate of cuelure in the attractant is slow, which leads to the number of trapped *Z. cucurbitae* being less than that of commercial attractants. When the temperature reaches 33 °C and 37 °C, which is higher than the LCST of the temperature-sensitive attractant, a large quantity of cuelure is released in a short time, which increases the effectiveness of the lure in trapping *Z. cucurbitae*.

3.4.2. Effect of the Dosage of Temperature-Sensitive Attractant on Trapping *Z. cucurbitae*

The number of *Z. cucurbitae* trapped by different dosages of temperature-sensitive attractants is shown in Figure 11. The results show that at the same temperature, the number of trapped *Z. cucurbitae* trapped by 2 g of temperature-sensitive attractants is more than that of other treatments. It shows that the trapping effect was the best when the dosage of temperature-sensitive attractant was 2 g, and it also shows that the trapping effect of cuelure would not always increase with the increase of its dosage, which was consistent with the experimental results in Section 3.1.2. The possible reason is that when the dosage of the temperature-sensitive attractant is 2 g, the release rate of cuelure in the attractant reaches an optimal level, resulting in the highest number of *Z. cucurbitae* trapped.

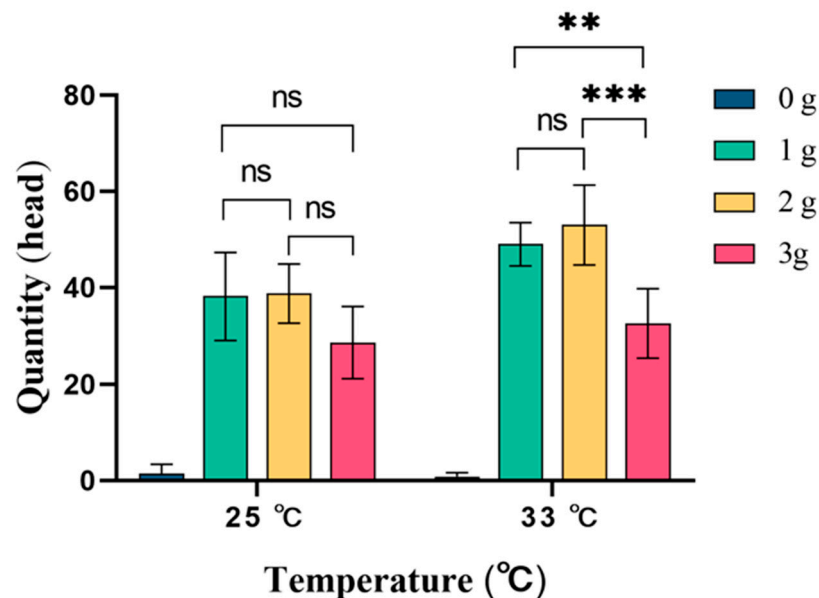


Figure 11. The number of *Z. cucurbitae* Coquillett trapped by different dosages of temperature-sensitive attractants. The “**” and “***” at the top of the bar chart indicate the significant differences ($p < 0.001$, $p < 0.0001$, respectively), and “ns” indicates no difference.

Moreover, when the dosage of temperature-sensitive attractant is the same, the number of *Z. cucurbitae* trapped at 33 °C is more than 25 °C. This is because when the temperature is 25 °C, the ambient temperature does not reach the LCST of the temperature-sensitive attractant, and only a small amount of cuelure is released. When the ambient temperature reaches 33 °C, the structure of the temperature-sensitive attractant changes phase, and a large amount of cuelure in the temperature-sensitive attractant is released into the environment, thereby attracting more *Z. cucurbitae*. The results show that the temperature-sensitive attractant can respond to the stimulation of the external temperature and thus change the release rate of the attractant.

3.4.3. High-Temperature Resistance Test

The high-temperature resistance test results of the temperature-sensitive attractants are shown in Figure 12. The results show that the number of *Z. cucurbitae* trapped by

commercial attractants, temperature-sensitive attractants, and cuelure is negatively correlated with the treatment time, which suggests that high temperature will reduce the trapping effect of these three attractants on *Z. cucurbitae*. Five days before high-temperature treatment, the number of *Z. cucurbitae* trapped by commercial attractants and cuelure is more than that of temperature-sensitive attractants. By the 5th day, the number of *Z. cucurbitae* trapped by the three attractants was close to 40. On the 7th day, the number of *Z. cucurbitae* trapped by commercial attractants and cuelure decreased to less than 40, while the number of *Z. cucurbitae* trapped by temperature-sensitive attractants remained above 40. This may be due to high temperatures accelerating the volatilization of these attractants. Although a large amount of solution in the temperature-sensitive attractant volatilizes, due to the existence of carbon nanotubes, a large amount of cuelure is adsorbed in the inner space of carbon nanotubes, which leads to the slow volatilization rate of cuelure in the temperature-sensitive attractant, thus prolonging its trapping effect.

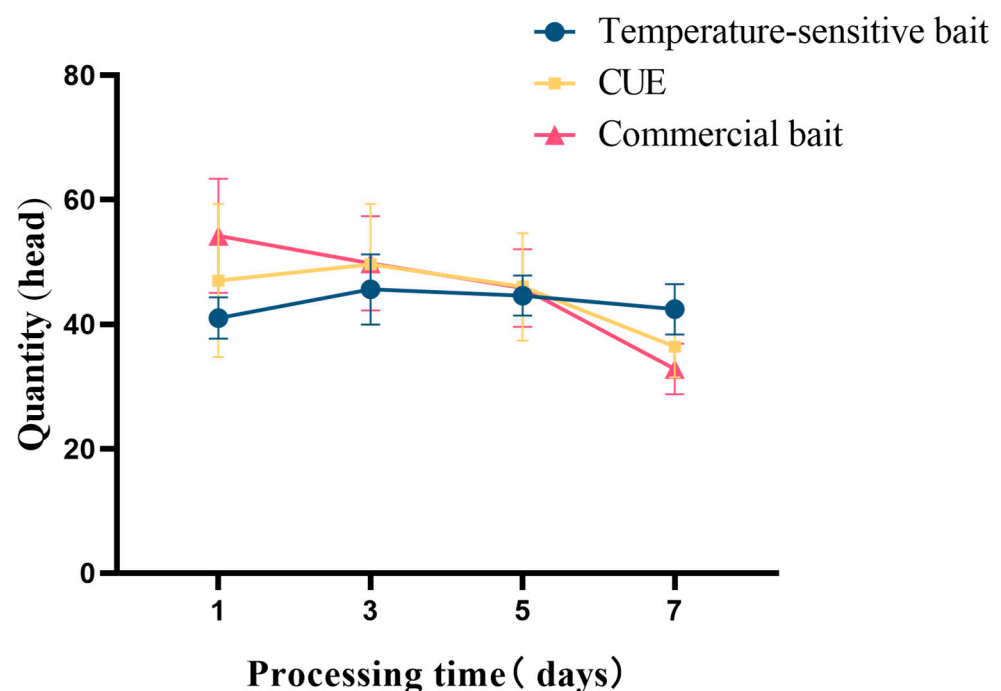


Figure 12. High-temperature resistance test of three attractants. Note: the value of the line chart is mean $\pm$ standard error.

The results show that there is a significant difference in the number of *Z. cucurbitae* trapped by commercial attractants on the first and seventh day ($p < 0.01$), while there is no significant difference in the number of *Z. cucurbitae* trapped by cuelure and temperature-sensitive attractants. This suggests that compared with commercial attractants, cuelure has better high-temperature resistance. Compared with cuelure, the number of *Z. cucurbitae* trapped by the temperature-sensitive attractant is more than 40, which shows that the high-temperature treatment for seven days has no significant effect on the trapping effect of the temperature-sensitive attractant. This indicates that the temperature-sensitive attractant has excellent high-temperature resistance.

4. Discussion

Our research results show that the attraction of cuelure to 10-day-old, 20-day-old, and 30-day-old *Z. cucurbitae* is significantly higher than that of 5-day-old *Z. cucurbitae* (Figure 2). This indicates that the trapping ability of cuelure to *Z. cucurbitae* may be related to the degree of sexual development of *Z. cucurbitae*, and the sexually mature *Z. cucurbitae* are more likely to be attracted by cuelure. Combined with the research of Yuan et al. [28], it was found that *Z. cucurbitae* began mating after reaching sexual maturity 9–11 d after

emergence, which further confirmed the results of this study. Interestingly, our study reveals that about one-sixth of the total number of female *Z. cucurbitae* were collected in traps (Figure 3), which is inconsistent with the literature. For this reason, we conducted a validation experiment in which a trap containing 0.5 mL of cuelure was placed in a cage containing only female *Z. cucurbitae* for 3 h. At the end of the experiment, no female *Z. cucurbitae* were collected in the trap, so what are the female *Z. cucurbitae* attracted to in this study? Upon reviewing the literature, Shelly et al. [29] found that the male *Z. cucurbitae* that ate the pheromone were more attractive to females than those that did not eat cuelure. This suggests that the female *Z. cucurbitae* in the trap in this study is attracted by the male who had eaten cuelure.

In addition, it was found in this study that the attraction effect of cuelure to *Z. cucurbitae* does not always increase with the increase of its use. A significant decrease in the number of *Z. cucurbitae* trapped by cuelure was found when the dosage of cuelure is increased from 0.5 mL to 1 mL and 2 mL (Figure 4). Similar results were obtained in the experiment evaluating the trapping effect of temperature-sensitive attractants on *Z. cucurbitae*. When the dosage of temperature-sensitive attractants is increased from 1 g and 2 g to 3 g, the number of *Z. cucurbitae* trapped by the attractants also decreases (Figure 11), suggesting that the high dose of cuelure might inhibit the sensitivity of male *Z. cucurbitae* to it.

PNIPAM hydrogel is a material with good temperature sensitivity. Because of its characteristics of no pollution to the environment, no biotoxicity, and recyclability, it has good application prospects in the field of pesticide-sustained release [30]. For example, Feng et al. [31] combined starch, alginate, kaolin, and PNIPAM to prepare a semi-interpenetrating network hydrogel with temperature sensitivity, and the research results showed that semi-interpenetrating network hydrogel beads containing kaolin not only have a slow-release effect before peanut flowering but can also release biocontrol agents rapidly after flowering. Xu et al. [32] used polydopamine (PDA) microspheres as the photothermal agent and then encapsulated with PNIPAM hydrogel and prepared a core-shell nanocomposite. The nanocomposite shows a high loading capacity and temperature or near-infrared controlled release properties, which showed great potential in the field of drug-controlled release. In this study, the temperature response performance of the temperature-sensitive attractant was tested and the results show that both the release rate and final concentration of cuelure are positively correlated with the temperature. Wu et al. [18] found that the higher the environmental temperature, the faster the drug release and the more the cumulative release. This result is consistent with our research results, indicating that the temperature-sensitive attractant prepared in this study has good temperature sensitivity.

PNIPAM hydrogels can not only respond to changes in external temperature and thus control the release of drugs but also maintain the stability of the drugs loaded. For example, Wang et al. [33] obtained a temperature-responsive release pesticide formulation by modifying graphene oxide with PNIPAM hydrogel and then loading lambda-cyhalothrin onto the nanocomposite carrier. The pesticide formulation could not only control the release of lambda-cyhalothrin at a specific temperature and prolong its sustained release time but also had good water dispersibility and UV resistance. In this study, the high-temperature resistance of the temperature-sensitive attractant was tested. The results show that, after being treated at 60 °C for 7 d, compared with cuelure and commercial attractants, the attraction ability of the temperature-sensitive attractant to *Z. cucurbitae* is not weakened, indicating that the temperature-sensitive attractant also has good stability in the high-temperature environment.

Since the loading of cuelure relies on the network structure inside the carbon nanotubes and PNIPAM hydrogel, without any other special conditions, other components (such as chemical pesticides) can be mixed into the temperature-sensitive attractant to further enhance the pest control effect of the attractant. In addition, cuelure can be replaced with other attractants to make different types of slow-release agents, thus expanding its application scope.

5. Conclusions

In summary, in this study, a *Z. cucurbitae* lure was successfully prepared by combining temperature-sensitive materials and cuelure, which can control the release rate via temperature change. The lure has a good temperature-response ability and is attractive to *Z. cucurbitae*. After one week of continuous treatment at 60 °C, the lure still had good attraction performance for *Z. cucurbitae*. This study is not only important for the monitoring and prevention of solid fly pests but also provides new ideas for the development of pest lures.

Author Contributions: Conceptualization, A.W., S.P., B.Z., Y.L., J.J., Q.Z., Q.W. and S.Z.; Methodology, A.W., S.P., B.Z., Y.L., J.J., Q.Z., Q.W. and S.Z.; Software, A.W., S.P., B.Z., Y.L., J.J., Q.Z., Q.W. and S.Z.; Validation, A.W., S.P., B.Z., Y.L., J.J., Q.W. and S.Z.; Formal analysis, A.W., S.P., J.J. and S.Z.; Investigation, A.W., S.P. and S.Z.; Resources, A.W., S.P. and S.Z.; Data curation, A.W., S.P. and S.Z.; Writing—original draft, A.W. and S.Z.; Writing—review & editing, A.W. and S.Z.; Visualization, A.W.; Supervision, A.W. All authors have read and agreed to the published version of the manuscript.

Funding: The research was supported by the Project of Sanya Yazhou Bay Science and Technology City (SCKJ-JYRC-2023-14).

Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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

References

- Chen, Y.; Ma, C.S. Effect of global warming on insect: A literature review. *Sheng Tai Xue Bao* **2010**, *30*, 2159–2172.
- Ma, C.; Ma, G. The Impacts of Extreme High Temperature on Insect Populations under Climate Change: A Review. *Sci. Sin. Vitae* **2016**, *46*, 556–564. [[CrossRef](#)]
- Zhou, S.H. Studies on the Responses of *Bactrocera cucurbitae* to High Temperature Stress and Its Molecular Basis. Ph.D. Thesis, Hainan University, Hainan, China, 2016.
- Maula, F.; Khan, A.A.; Ali, A.; Younus, M.; Israr, M.; Rauf, M.A.; Khan, I.A. Inamullah Evaluation of different traps and lures combinations for monitoring and eco-friendly management of fruit fly (*Bactrocera* spp.) in peach orchards. *J. Entomol. Zool. Stud.* **2022**, *10*, 105–110. [[CrossRef](#)]
- Witzgall, P.; Philipp, K.; Alan, C. Sex pheromones and their impact on pest management. *J. Chem. Ecol.* **2010**, *36*, 80–100. [[CrossRef](#)] [[PubMed](#)]
- Shelly, T.; Epsky, N.; Jang, E.B.; Reyes-Flores, J.; Vargas, R. *Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies: Lures, Area-Wide Programs, and Trade Implications*; Springer: Berlin/Heidelberg, Germany, 2014.
- Kong, W.; Wang, Y.; Guo, Y.; Chai, X.; Li, J.; Ma, R. Behavioral effects of different attractants on adult male and female oriental fruit moths, *Grapholita molesta*. *Pest Manag. Sci.* **2020**, *76*, 3225–3235. [[CrossRef](#)] [[PubMed](#)]
- Biswas, M.; Hossain, J.; Mainali, B.; Inskeep, J.R.; Gaire, S.K.; Cross, D.; Stringer, L.D.; Taylor, P.W.; Rempoulakis, P. Extended holding period and yeast hydrolysate in pre-release diet increase abundance of mature sterile Queensland fruit fly males in the field. *J. Pest Sci.* **2022**, *95*, 291–301. [[CrossRef](#)]
- Beroza, M.; Alexander, B.H.; Steiner, L.F.; Mitchell, W.C.; Miyashita, D.H. New Synthetic Lures for the Male Melon Fly. *Science* **1960**, *131*, 1044–1045. [[CrossRef](#)] [[PubMed](#)]
- Gupta, A.; Regmib, R. Efficacy of different homemade and commercial baits in monitoring of fruit flies at Maranthana, Pyuthan, Nepal. *Malays. J. Sustain. Agric.* **2022**, *6*, 101–109. [[CrossRef](#)]
- Kumaran, N.; Hayes, R.A.; Clarke, A.R. Cuelure but not zingerone make the sex pheromone of male *Bactrocera tryoni* (Tephritidae: Diptera) more attractive to females. *J. Insect Physiol.* **2014**, *68*, 36–43. [[CrossRef](#)]
- Arya, V.; Srinivasa, N.; Tyagi, S.; Raju, S.V.S. A guide to prepare Cue-Lure for *Bactrocera cucurbitae* (Coquillett) management in cucurbits. *Indian Entomol.* **2022**, *3*, 45–47.
- Yazdani, M. Developing Lines of Queensland Fruit Flies with Different Levels of Response to a Kairomone Lure. *Insects* **2022**, *13*, 666. [[CrossRef](#)] [[PubMed](#)]
- Li, M.; Wei, X.M.; Li, J.; Wei, S.M.; Zhang, J.L.; Chen, G.H.; Zhang, X.M. Effect of short-term exposure to high temperatures on the reproductive behavior and physiological enzyme activities in the fruit fly *Zeugodacus tau* (Walker). *Front. Physiol.* **2023**, *14*, 1036397. [[CrossRef](#)] [[PubMed](#)]
- Lu, Y.-T.; Zeng, K.; Fuhrmann, B.; Woelk, C.; Zhang, K.; Groth, T. Engineering of Stable Cross-Linked Multilayers Based on Thermo-Responsive PNIPAM-Grafted-Chitosan/Heparin to Tailor Their Physiochemical Properties and Biocompatibility. *ACS Appl. Mater. Interfaces* **2022**, *14*, 29550–29562. [[CrossRef](#)] [[PubMed](#)]

16. Majstorović, N.; Agarwal, S. Strong, Stretchable, Dual-Responsive PNIPAM Nanogel Cross-Linked UCST-type Macrogels for Biomedical Applications. *ACS Appl. Polym. Mater.* **2022**, *4*, 5996–6005. [\[CrossRef\]](#)
17. Xiao, Q.; Cui, Y.; Meng, Y.; Guo, F.; Ruan, X.; He, G.; Jiang, X. PNIPAm hydrogel composite membrane for high-throughput adsorption of biological macromolecules. *Sep. Purif. Technol.* **2022**, *294*, 121224. [\[CrossRef\]](#)
18. Wu, J.Y.; Liu, S.Q.; Heng, P.W.S.; Yang, Y.Y. Evaluating proteins release from, and their interactions with, thermosen-sitive poly (N-isopropylacrylamide) hydrogels. *J. Control. Release* **2005**, *102*, 361–372. [\[CrossRef\]](#) [\[PubMed\]](#)
19. Baydin, A.; Tay, F.; Fan, J.; Manjappa, M.; Gao, W.; Kono, J. Carbon Nanotube Devices for Quantum Technology. *Materials* **2022**, *15*, 1535. [\[CrossRef\]](#) [\[PubMed\]](#)
20. Zhang, R.; Wen, Q.N.; Wu, G.Y.; Shi, Y.; Xu, P. Reliability of ultrafiltration centrifugation in the evaluation of entrapment efficiency: A case study of Panax notoginseng saponins chitosan nanoparticles. *Chin. Pharm. J.* **2022**, *57*, 1367–1373.
21. Zhang, X.; Meng, L.; Lu, Q.; Fei, Z.; Dyson, P.J. Targeted delivery and controlled release of doxorubicin to cancer cells using modified single wall carbon nanotubes. *Biomaterials* **2009**, *30*, 6041–6047. [\[CrossRef\]](#)
22. Wang, Q. Synthesis and Properties of Thermo-Responsive Copolymers Based on N-Sopropylacrylamide. Master's Thesis, Shenzhen University, Shenzhen, China, 2017.
23. Chen, X.; Feng, C.H.; Shen, Y.L.; Lin, D.Q.; Feng, B.; He, Z.Q.; Du, Y.J. Chemical synthesis of cuelure and its attractive activities to *Bactrocera cucurbitae*. *China Plant Prot.* **2011**, *31*, 9–13.
24. Pan, S.P.; Tao, Q.; Wang, Y.T. Study on the preparations and properties of temperature-responsive injectable hydrogel based on poly (N-isopropylacrylamide). *Mod. Chem. Res.* **2021**, *22*, 7–9.
25. Zhang, X.; Zhang, W.; Dai, J.; Sun, M.; Zhao, J.; Ji, L.; Chen, L.; Zeng, F.; Yang, F.; Huang, B.; et al. Carboxylated carbon nanotubes with high electrocatalytic activity for oxygen evolution in acidic conditions. *InfoMat* **2021**, *4*, e12273. [\[CrossRef\]](#)
26. Singh, A.; Kar, A.K.; Singh, D.; Verma, R.; Shraogi, N.; Zehra, A.; Gautam, K.; Anbumani, S.; Ghosh, D.; Patnaik, S. PH-responsive eco-friendly chitosan modified cenosphere/alginate composite hydrogel beads as carrier for controlled release of Imidacloprid towards sustainable pest control. *Chem. Eng. J.* **2022**, *427*, 131215. [\[CrossRef\]](#)
27. Lim, G.-P.; Ahmad, M.S. Development of Ca-alginate-chitosan microcapsules for encapsulation and controlled release of imidacloprid to control dengue outbreaks. *J. Ind. Eng. Chem.* **2017**, *56*, 382–393. [\[CrossRef\]](#)
28. Yuan, S.Y.; Kong, Q.; Li, Z.Y.; Xiao, Z.Y.; Chen, B.; Zhang, D.G. Study on biology of *Bactrocera* (*Zeugodacus*) *cucurbitae*. *Acta Agric. Boreali-Occident. Sin.* **2005**, *3*, 43–45+67.
29. Shelly, T.E.; Villalobos, E.M. Cue Lure and the Mating Behavior of Male Melon Flies (Diptera: Tephritidae). *Fla. Entomol.* **1995**, *78*, 473. [\[CrossRef\]](#)
30. Gheysoori, P.; Paydayesh, A.; Jafari, M.; Peidayesh, H. Thermoresponsive nanocomposite hydrogels based on Gela-tin/poly (N-isopropylacrylamide) (PNIPAM) for controlled drug delivery. *Eur. Polym. J.* **2023**, *186*, 111846. [\[CrossRef\]](#)
31. Feng, J.C.; Dou, J.P.; Zhang, Y.Z.; Wu, Z.D.; Yin, D.X.; Wu, W.F. Thermosensitive hydrogel for encapsulation and controlled release of biocontrol agents to prevent peanut aflatoxin contamination. *Polymers* **2020**, *12*, 547. [\[CrossRef\]](#) [\[PubMed\]](#)
32. Xu, X.; Bai, B.; Wang, H.; Suo, Y. A Near-Infrared and Temperature-Responsive Pesticide Release Platform through Core-Shell Polydopamine@PNIPAm Nanocomposites. *ACS Appl. Mater. Interfaces* **2017**, *9*, 6424–6432. [\[CrossRef\]](#)
33. Wang, Y.; Song, S.; Chu, X.; Feng, W.; Li, J.; Huang, X.; Zhou, N.; Shen, J. A new temperature-responsive controlled-release pesticide formulation—poly(N-isopropylacrylamide) modified graphene oxide as the nanocarrier for lambda-cyhalothrin delivery and their application in pesticide transportation. *Colloids Surfaces A Physicochem. Eng. Asp.* **2021**, *612*, 125987. [\[CrossRef\]](#)

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.