LABORATORY AND GREENHOUSE PERFORMANCE OF FIVE COMMERCIAL LIGHT TRAPS FOR CAPTURING MOSQUITOES IN CHINA

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ABSTRACT. Mosquito light traps for household use are popular because they are small, cheap, user friendly, and environment friendly. At present, there are many variations and specifications of mosquito traps intended for household use on the market. The light traps claim they are powerful, but research and evaluation are lacking. Key parameters such as capture rates in the laboratory and field of 5 popular mosquito traps were evaluated as intended for household use. This study found that in the laboratory experiments, the capture rate of the mosquito traps selected was between 34.7% and 65.0%. Field tests in greenhouses found that the 5 mosquito traps had high catch rates for Culex quinquefasciatus. The percentage of Cx. quinquefasciatus, Aedes albopictus, Anopheles sinensis, and other flying insects captured was 51.76%, 25.29%, 14.12%, and 8.82%, respectively. There was no significant difference in the capture rate of Ae. albopictus and An. sinensis by the 5 mosquito traps in the greenhouse, but a significant difference in the catch rate of Cx. quinquefasciatus. The analysis showed that the fan speed and design of the air guide of the traps are important factors that affect the mosquito catch rate and that the ultraviolet wavelength (395–400 nm) used by the traps did not impact mosquito catch rates. Therefore, the mosquito traps intended for household use can be improved by adjusting the fan speed and optimizing the air guide.

KEY WORDS Aedes albopictus, Anopheles sinensis, capture rate, Culex quinquefasciatus, mosquito traps, UV wavelength

INTRODUCTION

Mosquito-borne diseases such as malaria, dengue fever, chikungunya fever, and Zika virus disease are important threats to global health, especially dengue fever, which has increased 30-fold in the past 50 years (Lee et al. 2018, Huang et al. 2019, Wilder-Smith et al. 2019). Of the over 50 mosquito-borne diseases known, vaccines are available only for epidemic encephalitis and yellow fever. The basic way to curb other mosquito-borne diseases is mosquito control (Baldacchino et al. 2015, Oliveira et al. 2019, de Thoisy et al. 2020, Idoko et al. 2020, Trovato et al. 2020). During mosquito season or a mosquito-borne disease epidemic, it is necessary not only to implement integrated mosquito control in the external environment, but also to control mosquitoes and prevent bites in residential homes.

In malaria-endemic Africa, indoor control methods for the malaria vector Anopheles mosquitoes are mainly by indoor residual spraying (IRS), which usually requires implementation by professional pest control operators (Bouckenooghe et al. 2019, Hamre et al. 2020, Kakilla et al. 2020, Lees et al. 2020, Hien et al. 2021). Mosquito incense and aerosols are traditional mosquito control methods in home environments in dengue-endemic Southeast Asia and southern China. Because of the social attention to environmental protection and health concern, the number of families who have adopted non-chemical mosquito control methods is increasing. One of these methods is the use of a mosquito trap.

Mosquito traps intended for household use are based on light trapping techniques, such as the ultraviolet light trap for mosquito surveillance issued by the Centers for Disease Control and Prevention (CDC) (Sriwichai et al. 2015, Li et al. 2016). Mosquito traps for household use are popular because they are small, cheap, user friendly, and environment friendly. The design principle of the trap is the same as that used by professionals. The light source used is an ordinary ultraviolet light or light-emitting diode (LED). The wavelength range of the ultraviolet light is 320 nm–400 nm, and a fan is set to provide a guiding airflow, which draws the mosquitoes into the mosquito collection device, where they are trapped.

At present, there are many variations and specifications of mosquito traps intended for household use on the market. These traps claim they are powerful, but research and evaluation is lacking. For that reason, we selected 5 popular mosquito traps costing 200 RMB ($30) or less and evaluated their mosquito control performance in the home environment. We paid attention especially to how well they were made, and their mosquito capturing performance in the laboratory and in the field.

MATERIALS AND METHODS

Source of mosquito trap

We purchased ultraviolet mosquito traps intended for household use from a well-known eCommerce...
store in China (JD.com; stock code: JD). We selected 5 with the highest sales and popular variations of mosquito traps with a price not exceeding 200 RMB ($30) for research and evaluation. The product parameters are shown in Table 1. These traps are directly connected to the power supply when they are used in the laboratory or the greenhouse.

### Detection of radiation wavelength of mosquito traps

The radiation wavelength detection of the ultraviolet (UV) light of mosquito traps was conducted in the Mosquito Trap Quality Monitoring Laboratory of Zhongshan Protoplast Optoelectronic Co., Ltd. The test method conformed to the inspection method for appliances with UV radiation lamps stipulated in Article 32 of the Chinese National Standard Household and Similar Electrical Appliances—Safety—Particular Requirements for Insect Killers (Institute CHEAR 2008). The test equipment used was the PMS-80 UV-visible (VIS)-near infrared (NIR) spectroscopy analysis system, which measures radiation at 1 m.

The total effective radiation was calculated by the following formula.

\[
E = \sum_{250 \text{nm}}^{400 \text{nm}} S_j E_j \Delta j
\]

where: \( E \) = effective radiation; \( S_j \) = relative spectral weight factor; \( E_j \) = spectral irradiance (W/m²·nm); \( \Delta j \) = bandwidth (nm).

The effective radiation of each wavelength is calculated as the spectrum according to the UV of the spectrum weight factors of different wavelengths. The total effective radiation \( E \) should not exceed 1 mW/m².

### Ultraviolet mosquito trap air suction fan speed determination

The test was carried out by following the stipulations of the Chinese National Standard Laboratory Efficacy Test Methods and Criterion of Public Health Equipment—Electronic Trap for Mosquitoes and Flies (Prevention GPCfDCa 2011). The insecticide-sensitive strain of *Culex quinquefasciatus* (Say) was reared in this laboratory, and adult female mosquitoes, 3–5 days after emergence without blood feeding, were use in the study. The test conditions were 26°C ± 1°C and 65% ± 10% relative humidity (RH). The experiment started at approximately 5 p.m. The capture rate was calculated as follows:

Capture rate

\[
\text{Capture rate} = \frac{\text{number of mosquitoes captured}}{\text{number of mosquitoes released in the room}} \times 100\%
\]

The test was repeated 3 times, and a total of 300 mosquitoes were released, 100 at a time. The blank control was tested by turning on the fan, but no light.

### Comparison of household mosquito traps in greenhouse setting

The greenhouse capture test was performed in November 2019. The field sites used were 3 connected greenhouses of Guangxi Pastoral Biochemical Co., Ltd. in Nanning City, Guangxi Zhuang Autonomous Region. Geographically, the test site is 108.26°N longitude, 22.86°E latitude, and 77 m above sea level. It has a humid subtropical monsoon climate, with an annual average temperature ranging from 20°C to 29°C and annual average precipitation of 1304.2 mm. The greenhouse is 21 m long, 14 m wide, and 5 m high. It is surrounded by walls on 4 sides, and both sides of the longitudinal wall have a 1-square-meter ventilation window. Corn, eggplants, rice, peppers, and other crops were grown in the greenhouse during the test. When testing the mosquito traps, related crop trials were stopped 1 month in advance to reduce unnecessary interference and impact. The average daily temperature and humidity in the greenhouse was 30°C and 80% RH, respectively.

The test method followed the mosquito trap and the human landing catch method stipulated in the China National Standard for Vector Density Moni-

### Table 1. Parameters of 5 household mosquito traps used in the experiment.

| Product No. | Product model | Power (W) | Power supply | Net weight (g) | Band | Price (RMB) | Color | Province of origin |
|-------------|---------------|-----------|--------------|---------------|------|-------------|-------|-------------------|
| Trap 1      | DH-03S        | 5         | DC5 V        | 430           | 120 × 174 | SOHOW      | 161   | Black             |
| Trap 2      | MY-100        | 5–0.5     | DC5 V/0.5 A  | 370           | 137 × 225 | GREEN      | 99    | White             |
| Trap 3      | KLY-188       | 5         | 220 V/50 HZ  | 200           | 120 × 215 | XiangJuYuan| 79    | White             |
| Trap 4      | N/A           | 5         | DV 5 V-1A    | 310           | 120 × 220 | MrClean    | 49    | White             |
| Trap 5      | N/A           | 4         | 220 v        | 500           | 170 × 340 | Greensky   | 199   | Purple            |
Species identification and statistical analysis

Morphological identification of mosquitoes captured, including mosquito species and genders, was performed using an anatomical microscope, and the capture performance of the 5 mosquito traps was evaluated. All statistical analyses were performed using RStudio (Version 1.2.5001, 64 bit) backends. Shapiro–Wilk test, analysis of variance, Tukey test, and Pearson correlation coefficient were used to analyze the data. In terms of statistical significance level, alpha for all comparisons was set at 0.05.

RESULTS

Product quality

The ultraviolet wavelengths of the 5 mosquito traps as measured by a PMS-80 ultraviolet (UV)-visible (VIS)-near infrared (NIR) spectroscopy analysis system are shown in Table 2. According to the Chinese National Standard Household and Similar Electrical Appliances—Safety—Particular Requirements for Insect Killers (Institute CHEAR 2008), mosquito traps exceeding 1 mW/m² total effective radiation are deemed unqualified. Therefore, mosquito trap 5 was judged to be unqualified, because its total effective radiation was 2.1980 mW/m², which exceeds the standard allowance. The remaining 4 traps were qualified according to the standard.

| Trap no. | UV wavelength (nm) | Effective radiation (mW/m²) | Fan speed (m/s)¹ |
|----------|-------------------|-----------------------------|-----------------|
| 1        | 400               | 0.1300                      | 1.53 ± 0.10 b   |
| 2        | 400               | 0.3902                      | 1.32 ± 0.12 b   |
| 3        | 395               | 0.0874                      | 1.01 ± 0.08 c   |
| 4        | 400               | 0.3029                      | 1.15 ± 0.14 b   |
| 5        | 395               | 2.1980                      | 2.10 ± 0.07 a   |

¹ Columns with different letters are significantly different from each other (P < 0.05).

The fan speed test results of the suction fan of the traps are shown in Table 2. The average fan speed of mosquito trap 5 was 2.10 m/sec, which was the highest among all the traps.

Laboratory tests

The results of the mosquito capture rate test in the laboratory are shown in Table 3. The results of analysis of variance and the Tukey’s test showed that there were significant differences in the trapping rate of the 5 mosquito traps (P < 0.001). The capture rate of mosquito traps 5 and 1 exceeded 50%, which was significantly higher than that of the other 3 mosquito traps. Meanwhile, there were no mosquitoes collected in the blank control group.

| Trap no. | Total release number | Re-capturing number | Capturing rate (%)¹ |
|----------|----------------------|---------------------|---------------------|
| 1        | 300                  | 179                 | 59.7 a              |
| 2        | 300                  | 136                 | 45.3 b              |
| 3        | 300                  | 121                 | 40.3 b              |
| 4        | 300                  | 104                 | 34.7 b              |
| 5        | 300                  | 195                 | 65.0 a              |

¹ Columns with different letters are significantly different from each other (P < 0.05).

Greenhouse tests

In the greenhouse test, 170 specimens were collected from the 5 mosquito traps; 143 (84.12%) of the total specimens were female mosquitoes (Table 4). The dominant mosquito species captured was Cx. quinquefasciatus, 88 (51.76%), followed by Ae. albopictus (Skuse), 43 (25.29%), and An. sinensis (Wiedemann), 24 (14.12%) of the total mosquitoes captured. The above 3 are the prevalent species in the urban environment of China, and thus, were the most captured mosquito species in our study.

The results showed that mosquito trap 5 caught the most Ae. albopictus on average every night (2.67±0.61). However, there were no significant differences in the average number of mosquitoes captured per night among the 5 traps tested. For Cx. quinquefasciatus, there were significant differences among the 5 traps. The average number of Cx. quinquefasciatus captured per night in trap 5 was about 8.7 times greater than trap 4, 3.9 times greater than trap 3, and 7.2 times greater than trap 1. In terms of the number of An. sinensis captured, only trap 5 captured more than 1 of this species, and there was no significant difference among the capture by the 5 traps.

Based on the Kruskal–Wallis test, there were significant differences among the 5 mosquito traps in the average number of mosquitoes captured per night. The average number of mosquitoes captured per night in trap 5 was ~3.7 times greater than trap 4,
3.0 times greater than trap 3, 2.66 times greater than trap 2, and about 1.8 times greater than of trap 1 in that order. The mosquito capture performance of trap 5 was the best among the 5 traps tested, followed by trap 1.

**DISCUSSION**

The UV light of all 5 household mosquito traps had a wavelength range of 390–400 nm, which conformed to the standard UV light range. According to the Pearson correlation coefficient, the correlation coefficient between the UV light wavelength of the 5 mosquito traps and the mosquito capture rate in the laboratory was subtle \((P > 0.05)\). Therefore, the UV light wavelength was not a significant factor influencing the difference in the selected mosquito trap capture rate in this research. The attraction preferences of blue (430 nm), green (570 nm), red (660 nm), and UV (390 nm) light to mosquitoes showed that blue and green light had relatively higher mosquito trapping efficiency than other colors (Tchouassi et al. 2012). The research supports that LED mosquito traps equipped with green (520 nm) and blue (470 nm) light have higher trapping ability (Costa-Neta et al. 2017). However, another study showed that the traps that emit UV light (10–400 nm) were better than green (490–570 nm) and red (620–780 nm) light, which was in contrast to the results of previous studies (Ponlawat et al. 2017). It has been shown that the effect of UV (364 nm) LED mosquito traps is equal to or better than the CDC incandescent lamp, and the indoor effect is better than outdoor (Mwanga et al. 2019). The mosquito traps in this study have a relatively small range of UV light and did not involve research in the visible light band. Follow-up work will expand the UV light band and select blue and green light as used in the previous studies.

In this study, the fan speed and laboratory capture rate exhibited a linear relationship according to Pearson correlation coefficient analysis on the air suction efficiency of the mosquito traps, which showed that fan speed might be a crucial factor influencing the mosquito capture performance of the traps. Other researchers also tested the effect of different fan speeds against the performance of the trap in capturing mosquitoes. The result showed that 1.7 m/sec was the ideal suction rate to obtain a high capture rate and minimal damage to the mosquitoes captured (Zhang Hong-Xiang et al. 2002). In our study, mosquito trap 5 had the highest capture rate with an air suction rate of 2 m/sec. And the mosquitoes captured did not show critical damage to their bodies. Therefore, we propose the mosquito capture performance can be enhanced by appropriately increasing the air suction rate in further studies.

In this study, mosquito trap 5 and trap 1 had the highest mosquito capture rates during the laboratory and greenhouse tests. This may be due to their shape and structural design, which were different from the other

| Mosquito species | Total number of individuals | Total number of females | Total number of captures |
|------------------|-----------------------------|------------------------|-------------------------|
| *Aedes albopictus* | 38                          | 16                     | 12                      |
| *Aedes aegypti*   | 44                          | 24                     | 12                      |
| *Culex quinquefasciatus* | 21                      | 15                     | 12                      |
| *Anopheles sinensis* | 17                          | 4                      | 12                      |

Table 4. Comparison of 5 household mosquito traps in field settings.

Rows with different letters are significantly different from each other \((P < 0.05)\). N = total number of individuals per trap, SE = Standard Error. Total number of individuals = the sum of the catches.
3 mosquito traps (Fig. 1). Trap 5 and trap 1 have inclined upward-opening entries, which means they can capture mosquitoes from 360° around the top, whereas the entries in the other 3 traps are at the middle (Fig. 1B), where the airflow into the entries is parallel, thus resulting in a smaller capture area. The capture area might be 1 factor influencing the mosquito capture rate.

According to the National Institute for Communicable Disease Control and Prevention and Chinese Center for Disease Control and Prevention, the main mosquito species in residential areas in 2018 was Cx. quinquefasciatus, accounting for (60.25%) of the total (Gou Yu-Hong et al. 2019); in 2019, the species composition in residential areas consisted of Cx. quinquefasciatus (57.73%), followed by An. sinensis Wiedemann, Cx. tritaeniorhynchus Giles, and Ae. albopictus (Zhao Ning et al. 2020). In the greenhouse experiment, the most collected mosquito species was Cx. quinquefasciatus, followed by Ae. albopictus. The capture of Cx. quinquefasciatus is roughly in line with the national survey over the past 2 years in China. The population density of Ae. albopictus was higher than the national total, which also reflected one of the reasons for the frequent outbreaks of dengue fever in Guangxi in recent years, which may be caused by the increasing population density of Ae. albopictus.

Mosquito trap 5 and trap 1 had a significantly higher capture rates than the other 3 traps. Furthermore, the difference was significant for collecting Cx. quinquefasciatus. The total effective radiation of mosquito trap 5 exceeded the standard quite a bit, and its air suction rate was also the largest, which may be the reason for its high capture rate. Mosquito trap 1 achieved high capture efficiency under the premise of product compliance and should be an excellent choice among the 5 mosquito traps for household use that we evaluated.

There have been few studies on the capture rate of mosquito traps for household use. This study tested the product parameters of 5 popular mosquito traps, the capture rate in the laboratory, and the capture rate in a greenhouse test and obtained preliminary data, which provided research and development ideas for improving the performance of mosquito traps marketed for household use in China.

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