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A new home trap for capturing and killing Culicidae with emphasis on *Aedes aegypti* (Diptera: Culicidae)

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ABSTRACT

One of the ways to help control mosquito vectors of human diseases is through traps that can capture them. One example includes adultraps; however, due to the complex components in their structure, they are expensive for people in tropical zones-areas which are most affected by Culicidae mosquitoes. Here we present the design of a new trap to capture adult mosquitoes that has been tested in laboratory and field. Functional models were constructed to assess the color, size, and the number of entrances an effective trap should have. The number of entrances was determined by examining the average number of adult mosquitoes captured and with the evidence of oviposition in test models with 1, 2, 3, and 4 entrances. Color choice for such a model was assessed by contrast of colors including red (body)/black (entrance), orange (body)/black (entrance), green (body)/black (entrance) and black (body)/red (entrance) combinations. Trap size was tested with 3 size scales 1:0.75 (111 mm x 60 mm x 60 mm), 1:1 (150 mm x 80 mm x 80 mm) and 1:1.25 (185 mm x 100 mm x 100 mm). In addition, this experiment also tested for contrast of 2 colors, which resulted from a previous experiment (red (body)/black (entrance) and all black). All the experiments were developed in the laboratory and field simultaneously. The trap with the most extensive entrance (64 cm² top and 9 cm² bottom) captured significantly more adult mosquitoes [Kw; H (4, N = 40) = 22.3 p = 0.0002], and the color contrasts that favored the adult mosquitoes capture were red/black and black [Kw; H (7, N = 64) = 35.6 p = 0.000]. Interestingly, trap size was not a significant factor in capturing adult mosquitoes [Kw; H (7, N = 120) = 3.5 p = 0.839]. The novel trap design described here can capture mosquitoes that vector pathogens, such as *Aedes aegypti*, *Aedes albopictus and Culex quinquefasciatus.*

KEYWORDS: mosquitoes, arbovirus infections, surveillance, mosquito control.

1. INTRODUCTION

Some mosquitoes (Culicidae) can be vectors of etiologic agents such as viruses, filaria and protozoa [1]. Transmission of these pathogens through the bite of female mosquitoes of the *Culex*, *Aedes* and *Anopheles* can cause disease in humans, such as dengue fever, chikungunya, Zika, filariasis and malaria, among others [2]. In the case of dengue, approximately 390 million cases are reported around the world every year and it is estimated that 3 billion people, in 128 countries, are at risk of contracting this ailment. Thus it is imperative to create new strategies for the control the *A. aegypti* mosquito population [3].

Currently, there are no effective commercial vaccines or therapeutic treatments for treating diseases caused by arboviruses. Current control efforts include the search for immature forms, treatment with larvicides

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and spraying of insecticides in households [4]. One aspect that does not contribute to decreasing population of mosquitoes and the transmission of diseases is the fact that there is little participation of the affected community in the activities to control these vectors [5]. This is possibly due to the fact that no effective traps have been designed to be handled by people who directly suffer from the presence of mosquitoes in their homes or workplaces.

Among the tools for mosquito control there are devices available for capturing adult mosquitoes. One example includes adultraps; however, due to the complex components in their structure, they are expensive for people in tropical zones-areas which are most affected by Culicidae mosquitoes. Other elaborate traps such as BG-sentinel, BG Mosquitaire CO_2 and BG-Suna traps [6] are expensive and complicated because they depend on mechanical and electrical elements, such as fans, whose role is to suck in any insect that passes by. These components not only raise the cost of the traps, but also have been shown to result in low-average capture of *Aedes aegypti* mosquitoes [7].

The BG-sentinel trap, which is the most recognized around the world, has a similar mechanical system and like the BG Mosquitaire and BG-Suna, it utilizes CO_2 as an attractant. Alternative models use lures such as octenol, Bg-lure, or Bg-sweetscent. Other traps like BG-Gat trap is composed of a water-filled container with oviposition signals to attract gravid females. This container is maintained in a transparent chamber impregnated with adhesives, oils or insecticides. In Brazil (Adultrap) and the U.S. (ALOT), traps have been developed to capture adult mosquitoes, both of which are aimed at capturing one species of mosquito, *A. aegypti*. Their versions contain water-filled containers with sticky surfaces as a trapping mechanism. Other traps may have surfaces impregnated with insecticides to enhance the trapping and killing of mosquitoes. In Colombia, two types of mosquito traps have been designed, one for entomological surveillance, StegTrap [8, 9] and the other to capture mosquitoes in homes, HomeTrap [10]. Despite the promise theses traps hold, the capturing efficiency of Culicidae mosquitoes is low [11].

One neglected aspect in mosquito monitoring and control is community participation. According to Lühken *et al.*, community participation plays a crucial role in the design of capture devices because people can express their opinion on the issue [12]. Understanding the perspectives of the community can help with the evolution of design alternatives and the successful installation process in homes. That is why the opinion of the community was considered important for the development of our novel trap during the final phase of this methodology.

The purpose of this work was to design a novel trap to efficiently capture and kill adult mosquitoes as another tool for mosquito control. To fulfill this purpose, laboratory and field experiments were conducted to evaluate potential factors such as type of material, color, size, and physical characteristics of the trap entrance to facilitate mosquito access and successful entrapment.

2. MATERIALS AND METHODS

2.1. Mosquito breeding for the experiments

The bioassays in laboratory conditions were performed with a colony of *A. aegypti*, Rockefeller strain (CDC, Colombia) contained in cages (400 × 400 × 400 mm) which remained in an insectary under controlled conditions of temperature 25 ± 5 °C, humidity 70 ± 5% and photoperiod 12:12. The female *A. aegypti* were continually fed with a solution of honey at 10% (75% carbohydrates) in a glass cup lined with filter paper. When more individuals were needed, a Wistar albino rat (WI IOPS AF/Han) was placed in the breeding colony in order to obtain blood and provide the mature eggs with protein. The rat was supplied by the vivarium of the Universidad Industrial de Santander, in compliance with the provisions of Law 84/1989 of the Colombian Congress and Resolution 8430/1993 of the Colombian Ministry of Health. The larvae obtained from the mother colony were bred in plastic trays and fed with 0.5 g TetraMin Tropical Flakes® fish concentrate per day.

2.2. Trap design

The design of the device was based on a methodology focused on product development [13] which combines marketing, design and manufacturing methods. The modeling and experimentation were carried out in parallel with lab and field experimentation in the Refugio district of Piedecuesta, Santander, Colombia between April-November of 2016 (6°59'43.52"N, 73° 3'57.79"W).

The development stage of trap alternatives or concepts took into account the biological aspects of Culicidae, such as their eating behavior, places of oviposition and refuge; all of these aspects help us to establish the requirements of the final product. Six experts were consulted on topics such as handling mosquito traps, entomology, biology and control methods. This information was used to establish the product specifications and generate several design alternatives (Supp. Table S1).

2.2.1. Selection of alternatives

The alternatives were selected by means of 2 matrices (Supp. Table S2 and Supp. Table S3). In the first one, known as the selection matrix, each alternative was compared to a product on the market to check the aspects considered the best or to be improved. 5 alternatives resulted from this matrix, 4 of which were combined to generate the 3 final alternatives shown in Fig. 1. In the second one, known as the evaluation matrix, we used selection criteria weighted by scores between 1 and 5 for each alternative in each of the criteria, thus resulting in one alternative for which test models were made to conduct the lab and field experiments; the design of the experiments took into consideration the aspects mentioned above, such as the number of entrances, color and trap size (Fig. 2-Fig. 4).

2.2.2. Lab experiments

To assess the test models, we used 4 cubic crystal cages measuring 650 mm on each side, in which we placed 80 gravid females of *A. aegypti* from 5 to 7 days of age, 2 to 3 days after being fed with rat blood; there were 20 females per cage (N = 4), 4 replicates were made per treatment, each one corresponding to one of the crystal boxes and 2 repetitions of the same experiment were performed on different days. These experiments were developed between Feb-Nov of 2016.

The test models used in the experiments, except in the third evaluation, had general dimensions of 150 x 80 x 80 mm, which consisted of a body in the form of 2 truncated pyramids, the top of which is inverted and with a proportion of 23/10 with respect to the height of the bottom pyramid, which has 4 windows with openings impregnated by entomological adhesive (Tangle-Trap®); the container of oviposition substrate (0.3% agarose gel plus 2 g of commercial Sweetscent® lure) is introduced through the bottom. Each of these models varied in terms of color, size and variation of the system of attraction at the assessment of the final prototype.

Once the test models were installed, the experiments ran on for 5 days, taking a reading of the number of adult mosquitoes captured at the entomological adhesive and amount of eggs found in the gel containers every 24 h. Each time a reading was taken, the treatments were rotated counterclockwise [8].

2.2.2.1. First evaluation: The effect of the number of entrances on the trap

Assessment of the number of entrances on the trap was done between Feb-May of 2016. The number of entrances was assessed using a test model, according to the research conducted with regard to the existing devices, showing that they all had just 1 entrance. Thus, through experimentation, it was confirmed that the number of entrances influences the capture number of adult mosquitoes per day. 4 treatments were used with test models that had 1, 2, 3 and 4 entrances. As a control, a trap was used with the same characteristics, but with just 1 wide entrance at the top (Fig. 2). The models used in this experiment were red contrasted against black according to the development of the trap for entomological surveillance, StegTrap [8].

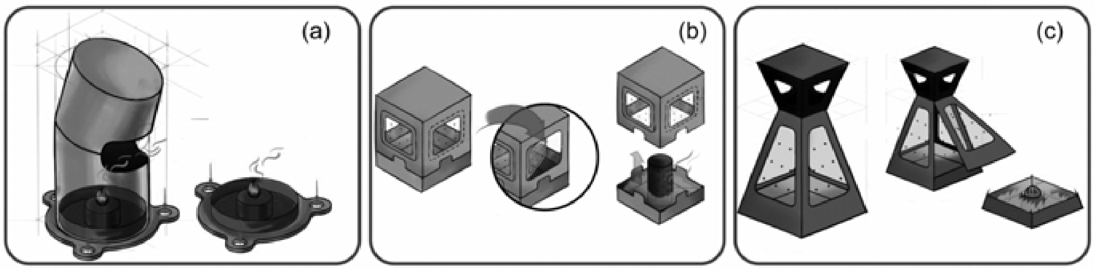


Fig. 1. Alternatives from the selection matrix (Supp. Table S2 and S3), (a) Alternative “Cylinder”, (b) Alternative combination 2 and 8 “Bag-External”, (c) Alternative combination 3 and 7 “Mailbox-Clock”.

Fig. 2. Experimental setup to determine the response to trap entrances. Treatments include 1, 2, 3, 4 entrances and 1 wide entrance (4 replicas per treatment).

Fig. 3. Experimental setup to determine the response to color contrast. Treatments include red/black, orange/black, green/black and black/red and 4 control: red, orange, green and black (4 replicates per treatment).

2.2.2.2. Second evaluation: The effect of the color contrast of the trap

Assessment of color contrast according to wavelength was done between Jun-Oct of 2016. It is known that color plays an essential role in attracting adult mosquitoes and in the amount of mosquitoes captured as shown in the development of the StegTrap trap [8] and the ALOT ovitrap [12]. That is why further confirmation of this variable was done using 4 treatments: red/black, orange/black, green/black and black/red and 4 controls: red, orange, green and black, as illustrated in Fig. 3.

2.2.2.3. Third evaluation: The effect of the trap size and color contrast

Assessment of trap size and contrast color was done between Oct-Nov of 2016. The purpose of this assessment was to confirm whether size influences the capture rate per day. This experiment was carried out in 2 phases. In the first, 3 black traps were used, and in the second, 3 traps were used with the colors red on the body and black at the entrance. The 2 color contrasts were selected based on the previous contrast experiment, which showed that more captures were achieved with red and black. The size scales used were 1:075 small (111 mm x 60 mm x 60 mm), 1:1 medium (150 mm x 80 mm x 80 mm) and 1:1.25 large (185 mm x 100 mm x 100 mm), as illustrated in Fig. 4. The results of these 2 phases were presented at the same time.

2.2.3. Field experiments

In tandem with the laboratory experiments, tests were run in field conditions where the same types of models as those evaluated in the lab were installed. To do so, 5 sampling areas with the presence of

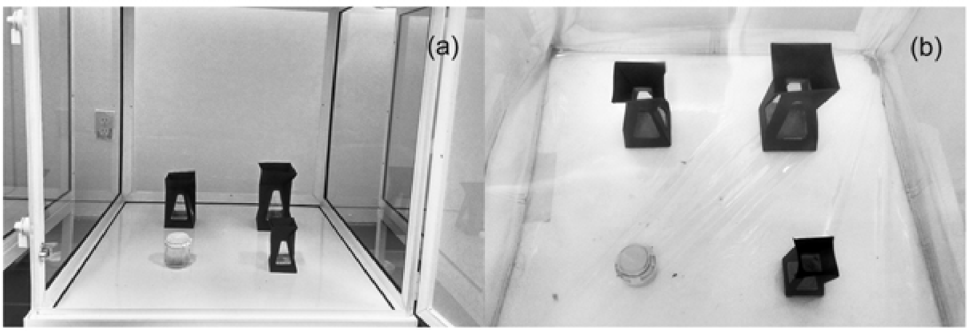


Fig. 4. Experimental setup to determine the response to size and color. The size scales were 1:075 small (111 mm x 60 mm x 60 mm), 1:1 medium (150 mm x 80 mm x 80 mm) and 1:1.25 large (185 mm x 100 mm x 100 mm). (a) Treatments using black trap; (b) Treatments using red/black traps (4 replicas per treatment).

mosquitoes were established in the municipality of Piedecuesta and at the “Parque Tecnológico y de Investigaciones”. 5 replicas were carried out for each test. Six days after their installation, they were removed for the reading of the experiment, and the adult mosquitoes captured in the adhesive and the eggs found in the gel inside the containers were counted.

2.2.4. User test and construction of the final prototype

Once the evaluation phase of the variables was complete, a trap prototype was designed. To determine the applicability of the trap prototype in the community, an evaluation of the device set-up was performed. In this evaluation, we assessed the amount of time a person took to assemble the trap. For this reason, we designed 3 different assembling alternatives, of which each user had to assemble each trap model in the shortest possible time. This evaluation complements the requirements of the trap, considering the observations provided by the users and choosing the most appropriate model in terms of assembling time.

2.2.5. Assessment of the final prototype

This assessment was carried out at the Bucaramanga Reservoir on the road to Tona, Santander (7° 9'19.94"N, 73° 5'25.27"W). 13 sampling points were established at the pre reservoir, reservoir and post reservoir points, distributed in inhabited rural sectors, facilities of the “Acueducto Metropolitano de Bucaramanga” (amb) and in the areas surrounding the reservoir. The assessment was carried out over a period of 4 months, from Nov 2017 to Mar 2018. The performance of the new trap was assessed in a time-frame of 2 weeks per each month and was compared to the Bg-sentinel. For this trap, the exposure time was 2 days due to battery life. In total, we used 180 new traps (the treatments included traps with agarose gel, with Sweetscent® lure plus agarose gel and traps without bait) and 13 traps of Bg-Sentinel (the treatments included a trap with Sweetscent® lure and a trap without bait). In all experiments the same number of traps was used every month for the evaluation.

2.3. Identification of the mosquitoes captured

Mosquitoes captured in each trap were collected carefully from acetate windows. The acetate pieces cut were glued to the mosquitoes without damaging the taxonomic structures. Next, entomological pins were used to mount each sample with an information label notifying the collection location. Species identification was carried out with commonly accepted morphological characteristics of the Culicidae family such as scales, hairs, spiracular bristles, proboscis and wing veins [11, 14, 15].

2.4. Statistical analysis

The analysis was conducted using Statistica v.10 software. We used a normality and homoscedasticity test to identify whether the data showed a parametric or non-parametric distribution. For the data that showed a non-parametric distribution, the Kruskall-Wallis (Kw) test was applied, and for the parametric data, the analysis of variance (ANOVA, One Way test) was applied. Only the data with $P \leq 0.05$ were considered significant. All data are shown as percentage of mosquitoes captured and percentage of eggs found.

3. RESULTS

3.1. Trap design

3.1.1. Development of alternatives by users

Experts were sought to provide suggestions over the design of our device. Advice regarding the point of view of potential users, the number of entrances, biological security, storage capacity, ease of assembly and durability of materials were suggested and taken into consideration during the creative phase of the trap modeling (Supp. Table S1).

Selection of alternatives: The creation of the selection and assessment matrices yielded important data for the development and evolution of alternatives, such as trap stability, number of entrances, provision of lure, ease of use, capture signal and versatility of installation, Supp. Table S2 and Supp. Table S3.

3.1.2. Lab and field experiments

3.1.2.1. First evaluation: The effect of the number of entrances on the trap

When determining how an entrance impacts the number of mosquitoes captured, we found a significant difference between a model with a wide entry and models with varying number of entries. There were more adult mosquitoes in the wide entry model [Kw; H (4, N = 40) = 22.3 P = 0.0002 and Kw; H (4, N = 40) = 27.3 P = 0.000] (Fig. 5). The control treatment, wide entrance at the top, resulted in the highest mean capture rate at 20.3% and mean oviposition rates at 24.9%, while the treatment with 4 entrances had a lower mean capture rate at 0.6% (Fig. 5). The control trap was able to capture more mosquitoes compared to models with one, two, three, and four entries (Fig. 5). It was also noted that an inverted truncated pyramid located at the entrance makes it hard for mosquitoes to get out once they are inside. In the field experiment, a log was made on adult mosquitoes captured in treatments using trap models having 1 and 4 entrances; the same was done in the control experiment (Wide entrance at the top). However, the results do not reflect significant differences in mosquitoes capture [Kw; H (4, N = 50) = 4,5 P = 0.343] and in the number of eggs found; no positive data were recorded in any of the treatments (Fig. 6). The control treatment (Wide entrance at the top) resulted in the highest mean capture rate at 11.5% of the total, although oviposition data was not obtained. The results were consistent with the results recorded in the lab. These results show that the wide entrance facilitates the attraction and capture of adult mosquitoes. In this field assessment, species such as *Aedes aegypti*, *Culex quinquefasciatus* and *Culex nigripalpus* (Table 1) were captured.

3.1.2.2. Second evaluation: The effect of the color contrast of the trap

In all the treatments, color contrast influenced the capture of adult mosquitoes and the number of eggs collected by the traps, although significant differences

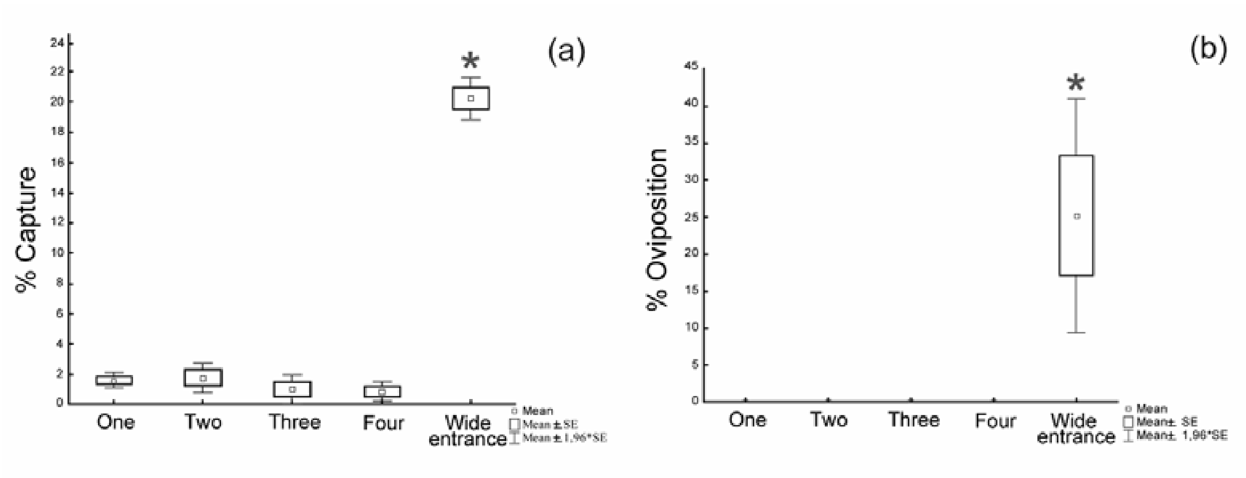


Fig. 5. Evaluation of different entrances (First evaluation in lab). Percentage of (a) Adult mosquitoes captured and (b) Oviposition. *: Statistically significant differences ($P \leq 0.05$; Kruskall-Wallis (Kw) test).

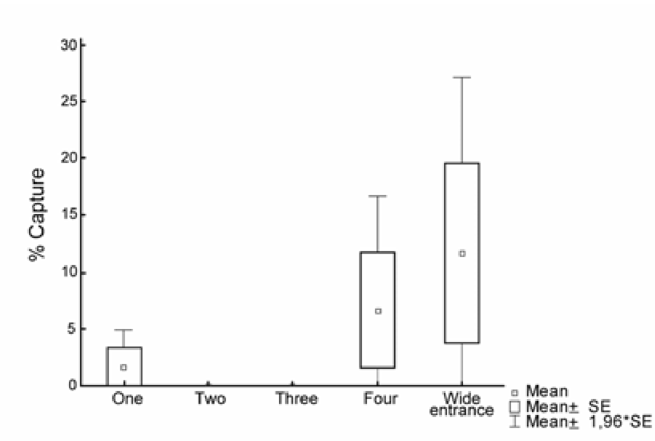


Fig. 6. Evaluation of different entrances in field conditions (Parque Tecnológico Guatiguará UIS) (First evaluation). Capture percentage at the entomological adhesive after 6 days of exposure to the traps. Not significantly different ($P > 0.05$; Kruskall-Wallis (Kw) test).

were detected only in mosquitoes captured [Kw; H (7, N = 64) = 35.6 *P* = 0.000], but nevertheless no significant differences in oviposition data were detected [Kw; H (7, N = 64) = 12.0 *P* = 0.100] (Fig. 7). Treatments using black trap at 6.5% and red/black trap at 5.9% resulted in the highest mean capture and oviposition rates, at 10% and 2.7%, respectively, while the treatment using green trap resulted in the lowest mean capture rate at 0.26% (Fig. 7). The results indicate that treatments using black trap and black/red traps were similar to each other and the capture of mosquitoes and egg collection were significantly better compared to the other color contrast treatments. This demonstrates that both black and the contrast with red contribute to the attraction and capture of adult mosquitoes. In the field experiment, the adult mosquitoes captured in all the treatments were recorded, except for those captured in orange/black and green traps. However, these results do not reflect significant differences in adult mosquitoes captured [Kw; H (7, N = 120) = 3,5 *P* = 0,839] and in the number of eggs found; no positive data were recorded in any of the treatments (Fig. 8). With this and the results in mind, it can be observed that the treatments using black trap and black/red traps resulted in the capture of a mean of 1.56% of the individuals. This confirms the data recorded in the laboratory experiment, although the highest adult mosquito capture rate was not recorded (Fig. 8). The results show that the black and the red/black contrast contribute to the attraction and capture of adult mosquitoes. In this field assessment, *A. aegypti* and *Culex nigripalpus* mosquitoes were captured (Table 2).

3.1.2.3. Third evaluation: The effect of the trap size and color contrast

When examining how trap size and color affects mosquito collection, we observed that these parameters did not influence the capture of adult mosquitoes and number of eggs collected. No significant differences were detected in adult

Table 1. % Adult capture (± SD). Identification of individuals captured in the field evaluation one: Number of entrances.

Treatments	% Adult capture (± SD)	Species
One	10.0 ± 0.3	*Culex quinquefasciatus*♀
Two	0 ± 0	-
Three	0 ± 0	-
Four	30.0 ± 0.7	*Culex quinquefasciatus*♀ (10%); *Culex* sp.♂ ♀(20%)
Wide entrance at the top	60.0 ± 1.3	*Aedes aegypti*♀ (20%); *Culex nigripalpus*♀ (20%); *Culex* sp.♀ (10%); Unidentified♂ (10%)

♂Male and ♀Female; SD:Standard deviation

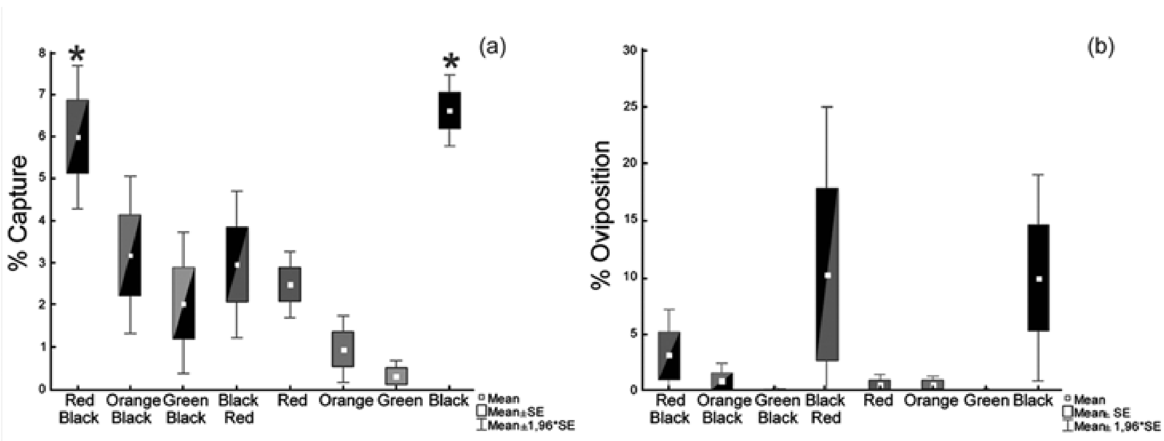


Fig. 7. Evaluation of different color contrast (Second evaluation in lab). Percentage of (a) Adult mosquitoes captured and (b) Oviposition. *: Statistically significant differences ($P \leq 0.05$; Kruskall-Wallis (Kw) test).

mosquitoes captured [Kw; H (5, N = 48) = 9.1 *P* = 0.105] and oviposition rates [Kw; H (5, N = 48) = 11.8 *P* = 0.037] (Fig. 9). The control treatment, a medium scale 1:1, 150 mm x 80 mm x 80 mm model, using black trap resulted in the highest mean rate in oviposition at 9.1% and adult mosquito mean capture at 4.9%, while the large trap (1:1.25 [185 mm x 100 mm x 100 mm]) with black color resulted in the highest mean capture rate at 5% but oviposition rate at 0%. The large trap size with a red/black color scheme resulted in the lowest rates of adult mosquito mean capture at 2.3% and mean oviposition rate at 2% (Fig. 9). Since there were no significant differences, it was concluded that size does not influence the attraction and capture of adult mosquitoes. However, there were high oviposition and capture rates in the control treatment using each color. In the field experiment, the capture rate recorded in the treatment using the small-scale trap size of 1:0.75 (111 mm x 60 mm x 60 mm) with black color was 4.9% and, in the control, using red/black was 14.8%. However, the results do not reflect significant differences in adult mosquito mean capture [Kw; H (5, N = 60) = 7.2 *P* = 0.203] and in the number of eggs found (Fig. 10). The control model resulted in the

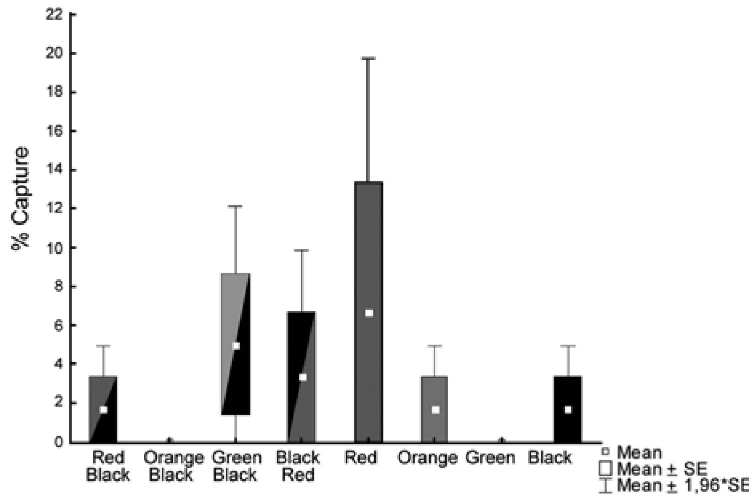


Fig. 8. Evaluation of different color contrast in field conditions (Parque Tecnológico Guatiguará UIS) (Second evaluation). Capture percentage at the entomological adhesive after 6 days of exposure to the traps. Not significantly different ($P \leq 0.05$; Kruskall-Wallis (Kw) test).

Table 2. % Adult capture (± SD). Identification of individuals captured in the field evaluation two: Color contrast.

Treatments	**% Adult capture (± SD)**	**Species**
Red/Black	14.3 ± 0.3	*Culex nigripalpus* ♀
Orange/Black	0 ± 0	-
Green/Black	28.6 ± 0.4	*Culex* sp. ♂ ♀
Black/Red	14.3 ± 0.3	*Aedes aegypti* ♂
Red	14.3 ± 0.3	*Aedes aegypti* ♂
Orange	14.3 ± 0.3	*Aedes aegypti* ♀
Green	0 ± 0	-
Black	14.3 ± 0.3	*Culex* sp. ♂

♂Male and ♀Female; SD:Standard deviation

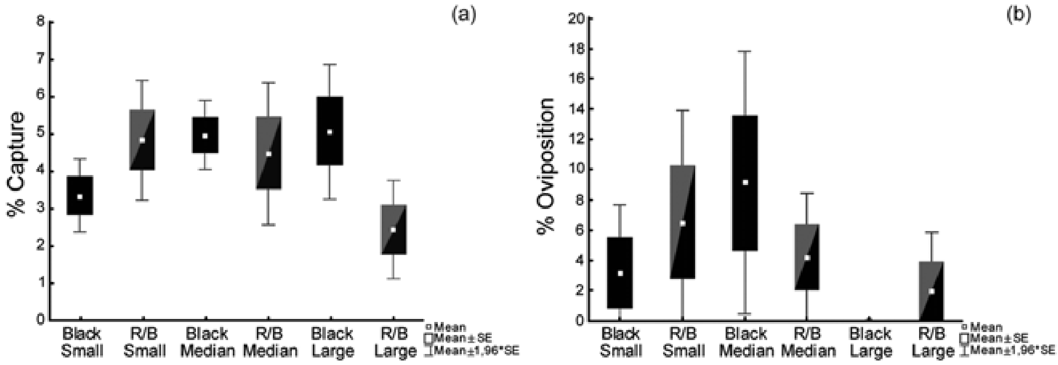


Fig. 9. Evaluation of color contrast and size scale (Third evaluation in lab). Percentage of (a) Adult mosquitoes captured and (b) Oviposition. Not significantly different (*P* > 0.05; Kruskall-Wallis (Kw) test).

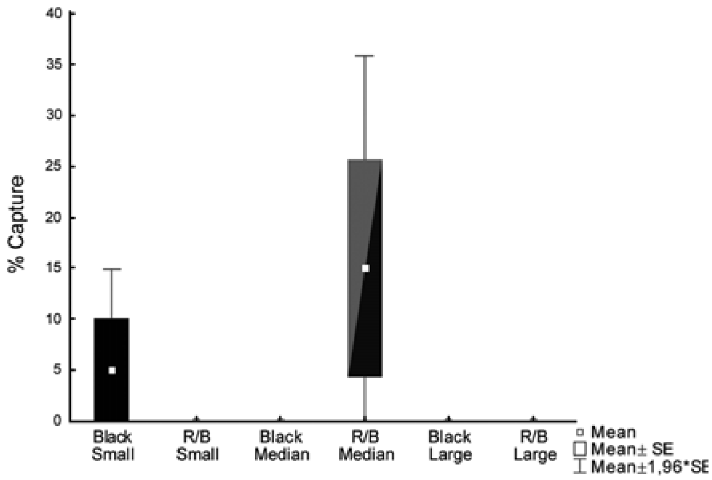


Fig. 10. Evaluation of color contrast and size scale in field conditions (Parque Tecnológico Guatiguará UIS) (Third evaluation). Capture percentage at the entomological adhesive after 6 days of exposure to the traps. Not significantly different (*P* > 0.05; Kruskall-Wallis (Kw) test).

highest capture rate. This is consistent with the result of the lab experiment, since the control treatment contributes to the attraction and capture of adult mosquitoes. With regard to color, there were no significant differences to favor either of the 2 color contrasts. In field tests, however, there was a preference of the combination of the red/black contrast with the medium size trap, which resulted in the highest catch percentage. In this assessment, the *Culex* sp species was the only species captured (Table 3).

3.1.3. Construction of the final prototype

In order to assess the difficulty of assembling our prototype models, we determined the amount of time it takes a user to assemble a trap. Here, 10 users were asked to assemble 3 developed models while being timed. We observed a significant difference in the duration of assembling time with final trap models [Kw; H (2, N = 30) =17.2 *P* = 0.0002]. Simultaneously, we obtained user feedback to further refine the final trap in terms of assembling, manufacturing, and miscellaneous additions to improve usability and the correct way to dispose of the product with the user's safety in mind (Supp. Figure S1). Based on our lab and field results, a red trap was built with a black entrance. The trap size was established according to the results of the experiments with the following measurements: 150 mm x 80 mm x 80 mm. On each side of the trap,

Table 3. % Adult capture (± SD). Identification of individuals captured in the field evaluation three: Size and color.

Treatments (Red/Black trap)	% Adult capture (± SD)	Species
Small	0 ± 0	-
Median	66.7 ± 0.4	*Culex* sp.
Large	0 ± 0	-
Treatments (Black trap)	**% Adult capture (± SD)**	**Species**
Small	33.3 ± 0.3	*Culex* sp.
Median	0 ± 0	-
Large	0 ± 0	-

SD: Standard deviation

Fig. 11. Final prototype of the trap based on the results obtained in the experiments performed in laboratory and field.

there are 4 windows that are covered by sheets of cellulose acetate with holes. At the bottom, there is a closing system that allows entry into the acetate container, which contains agarose gel (Fig. 11).

3.1.4. Assessment of the final trap

The Bg-Sentinel trap (sw) had a total capture rate of 58.06%, showing significant differences with respect to the treatments using the new trap (without lure, gel, sw+gel) and Bg-Sentinel (without lure) [*F*: 15.7; *P*: 0.00003] (Table 4). Regarding *Aedes albopictus*, there were significant differences in the Bg-Sentinel trap in comparison with the new trap (without lure, gel, sw+gel) and the Bg-Sentinel trap (without lure) [*A. albopictus*; *F*: 6.7; *P*: 0.0025] (Table 4). Over the 4 months of collection, the Bg-Sentinel trap with Sweetscent® lure captured significantly more adult mosquitoes, although the new trap captured more mosquito species, including *Wyeomyia* sp. and *Limatus durhamii*.

4. DISCUSSION

During the trap development process, there were various findings. The behavior of *A. aegypti* in the selection of oviposition sites is based on the presence of a proper oviposition substrate [16]. For *A. aegypti*, the presence of a water source encourages oviposition, but it has the disadvantage that it may contribute to the formation of a breeding site in the device. In order to prevent the formation of a breeding site, an agarose gel solution at 0.3% of concentration was used, which encouraged oviposition by simulating a water surface. Benefits for using agarose gel include its ability to prevent deposited eggs from developing, the gel is easy to handle, gel does not spill, and enables ease of transportation. We take advantage of the fact that Culicidae mosquitoes oviposit in many different types of natural or artificial containers of different sizes and materials [17]. This facilitates the design of new containers that provide adequate shelter for them to lay their eggs.

The volumetric shape of the trap structurally considers factors such as aesthetics, functionality, symbolism, usability and production costs. These characteristics guarantee an effective product whose production and sale will contribute to the control of these mosquitoes that transmit human pathogens [18]. The visual responses of the female *A. aegypti* have been widely studied over time and findings indicate that mosquitoes are able to discriminate wavelength in the ultraviolet (323 nm) and orange-red (621 nm) range [8, 12, 19]. Thus, it was crucial for us to take color into consideration when designing a product. With respect to the

Table 4. % Adult capture (± SD). Mosquitoes captured in field and species identified.

Trap	**% Adult capture ± SD**		**Species**
Torre Vigía (without bait)	16.1 ± 1.6	(a)	*Culex* sp (12.9%); *A. albopictus* (3.2%)
Torre Vigía (Gel)	19.4 ± 4.2	(a)	*Wyeomyia* sp (6.5%); *Culex* sp (6.5%); *Limatus durhamii* (6.5%)
Torre Vigía (Sweetscent+Gel)	6.5 ± 1.9	(a)	*Culex* sp (6.5%)
Bg-Sentinel (Sweetscent)	58.1 ± 12.9	(b)	*Culex* sp (22.6%); *A. albopictus* (25.8%); *A. aegypti* (9.7%)
Bg-Sentinel (without bait)	0 ± 0	(a)	-

[(a)]Indicates no significant differences; [(b)]Indicates significant differences ($P \leq 0.05$ ANOVA one way test) (F: 15.7; P: 0,00003); [SD:]Standard deviation.

preference for oviposition site, the female *A. aegypti* seek shelter in dark places [20]. In the design of the StegTrap developed in Colombia, which was patented in 2013, the color red contrasting with black resulted in the attraction of Culicidae mosquitoes [8]. In subsequent designs of traps such as the ALOT trap, color was an important factor for trapping mosquitoes [12]. These results are consistent with our current study.

The novel trap designed here has a wide entrance in the form of an inverted truncated pyramid from which the oviposition substrate can be viewed from the top. The design features of this trap enable the attraction of mosquitoes flying over the device. The broad opening of the trap allows mosquitoes to freely enter the container. This type of entrance is not used in commercially available traps, such as the BG-Sentinel (Biogents®) or utilized in mosquito capture studies [6]. Other traps, such as the BG-GAT [21], Adultrap [22] and ALOT [12] use water as an oviposition substrate and have a screen that prevents the mosquitoes from coming into contact with the water. This was not necessary in our designed trap because the agarose gel provides enough surface consistency with the added benefit of not allowing the development of the deposited eggs. This provides the trap with more time for action, facilitates handling and prevents spills.

Our results showed that mosquitoes prefer the red/black contrast and all black models. This is why we decided to use the 50/50 contrast of each color for the trap prototype. The red/black contrast was used in the StegTrap [8] and HomeTrap [10] developed at the Universidad Industrial de Santander, Colombia and the ALOT trap developed in the U.S. [12]. Black has been used in devices such as the Adultrap developed in Brazil [22]. The field experiments did not indicate significant differences. However, it was observed that the red/black contrast and all black resulted in adult captures. This validates the data obtained by the laboratory although a higher adult capture rate was not reported.

As for trap size, a size at 1:1 scale was used, the size that has been used from the beginning. Most devices have larger dimensions, such as the products mentioned herein, and in an experiment, it was confirmed that size is not directly related to trap efficiency since no significant differences were reported. However, the medium 1:1 trap reported the highest adult capture rate. Considering the results and design aspects, such as size for ease of storage, use of biological material, ease of transport, ease of assembly, non-use of mechanical and electronic systems, simple manufacturing processes and ease of use, the medium 1:1 scale was used, which occupies a volume of 150 mm x 80 mm x 80 mm.

By using the results obtained in the study, we developed a trap prototype known as the "Torre Vigía" (Vigilant-Tower) to capture mosquitoes from the Culicidae family, such as *Aedes*, *Culex*, and possibly *Anopheles*. The prototype is made of biodegradable cardboard with a thickness of 0.40 cm. It has windows with holes and a container where the oviposition substrate can be placed inside. The windows and the container are made of biodegradable cellulose acetate.

The "Torre Vigía" (patent application number NC2018/0012563) has the following characteristics 1) A container made up of biological material, which consists of a body in the form of 2 truncated pyramids, the top of which is inverted by a proportion of 23/10 with respect to the height of the bottom pyramid, 2) the faces of the trap have 4 windows with holes and are impregnated with entomological adhesive (the females will be captured on this adhesive), and 3) the container of the substrate and lure is a transparent recipient that contains a gel solution that encourages the oviposition of the female mosquito.

The studies conducted with devices to capture adults showed that they are a tool that can play an effective role in mosquito control activities. For instance, when evaluating the BioDiVector tent trap in Tapachula, Mexico, 3,128 individual *A. aegypti* and 833 *A. albopictus* were captured in 9 months of study [23]. In another study conducted in 6 suburban neighborhoods in Gainesville, U.S., whose objective was to capture *A. albopictus*, 6 traps were evaluated, two of which were commercial propane-based traps (Mosquito MagnetTM Professional trap and Mosquito Magnet Liberty trap), 2 traps that specifically capture *A. aegypti* (Fay- Prince Omnidirectional trap and Wilton trap), 1 experimental trap (Mosquito Magnet X trap) and the CDC trap. In that study, 5,280 (14.2%) *A. albopictus* [24] were collected from 6 locations in northern and southern Germany, a comparison of the traps was carried out (EVS trap, CDC trap and Magnet Patriot Mosquito trap), which capture a significant percentage of the species *Aedes vexans* (30.0%), *Aedes cinereus* (17.0%) and *Culex pipiens* (12.2%) [25]. Finally, a study conducted near Cairns, Australia assessed the effectiveness of a new folding trap compared to the CDC and EVS trap. Characteristics of the trap such as entrance, color in the different traps and types of trap were evaluated. As a result, *Aedes* had a capture rate of 35%, followed by *Culex* (28%) and *Anopheles* (26%) [26]. With all this in mind, it was demonstrated that the traps can contribute to mosquito control but differentiating devices must be proposed to facilitate this work to the extent possible.

CONCLUSION

The trap designed in this study is named "Torre Vigía," which signifies a device that can capture different mosquito species in the wild. We present this trap as a simple, biodegradable tool that is easy to handle, transport, and user friendly. A future optimized commercial version of Torre Vigía could play a significant role in mosquito control by the trapping and elimination of mosquito vectors that transmit pathogens that cause dengue, Zika, chikungunya, and yellow fever among others.

SUPPLEMENTARY INFORMATION

Table S1

Product Specifications

Functional	Number of entrances Visual elements Entrance size
Usability	Biological safety Bait storage Installation places Assembly steps
Support	Removable bait unit Ease of assembly
Reliability	Entrance / block visibility Waterproof material Capture indicator
Performance	Anti-reflective material Large collection unit
Plus	Trap size Local manufacturing processes

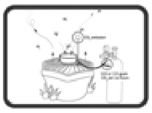
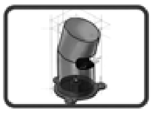
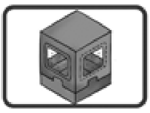
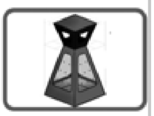
Table S2

Selection Matrix

Selection criteria	Ref.	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Alt.7	Alt.8	Alt.9
Functional										
Number of entrances	0	0	+	+	-	-	0	+	+	+
Visual elements	0	+	+	+	+	0	-	+	+	+
Entrance size	0	+	+	+	+	+	+	+	+	0
Distance bait and entrance	0	-	-	0	-	-	-	0	+	-
Usability										
Biological safety	0	+	+	-	+	0	0	+	-	-
Bait storage	0	-	-	-	-	-	-	-	-	-
Installation places	0	+	+	+	-	0	+	+	0	+
Assembly steps	0	+	-	0	-	-	+	+	+	-
Support										
Removable bait unit	0	+	+	+	+	+	+	+	-	+
Ease of assembly	0	+	+	+	0	+	+	0	+	+
Reliability										
Waterproof material	0	-	-	+	+	0	-	-	-	-
Capture indicator	0	0	-	-	-	-	+	-	0	-
	0	0	0	+	-	0	-	0	+	-
Performance										
Anti-reflective material	0	+	+	+	+	+	-	+	+	+
Large collection unit	0	+	+	+	-	+	+	+	+	-
Sum +	0	13	13	14	10	9	9	13	12	10
Sum 0	19	3	1	2	3	5	2	3	3	1
Sum -	0	3	5	4	8	5	8	3	6	8
Net evaluation	0	10	8	10	2	4	1	10	6	2
¿Continue?	-	Yes	C	C	No	No	No	C	C	No

Table S3

Evaluation Matrix

		Mosquitaire CO2		Alternative 1		Alternative 2.8		Alternative 3.7	
									
Selection criteria	Weight	Qual.	Weig.	Qual.	Weig.	Qual.	Weig.	Qual.	Weig.
Functional	23%								
Number of entrances	3	3	9	3	9	4	12	5	15
Visual elements	7	3	21	3	21	3	21	3	21
Entrance size	6	3	18	2	12	4	24	4	24
Distance bait and entrance	2	3	6	1	2	5	10	2	4
Usability	26%								
Biological safety	10	3	30	4	40	3	30	4	40
Bait storage	5	3	15	1	5	1	5	1	5
Installation places	3	3	9	5	15	3	9	5	15
Assembly steps	8	3	24	4	32	3	24	4	32
Support	14%								
Removable bait unit	5	3	15	4	25	1	15	5	20
Ease of assembly	9	3	27	5	36	3	9	4	45
Reliability	18%								
Entrance / block visibility	4	3	12	1	4	4	16	3	12
Waterproof material	4	3	12	2	8	2	8	2	8
Capture indicator	5	3	15	3	15	3	15	4	20
Performance	13%								
Anti-reflective material	7	3	21	4	28	3	21	4	28
Large collection unit	6	3	18	2	12	2	12	2	12
Standard deviation					11,4		7,5		11,5
Summation		3		3,32		2,99		3,69	
¿Continue?		-		No		No		Yes	

User test (Assemble time)

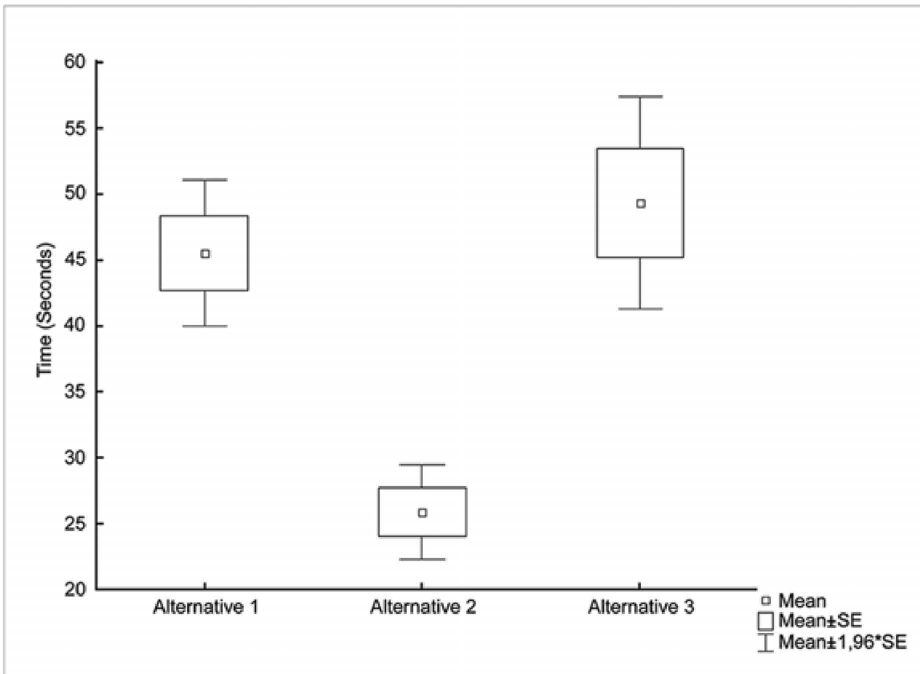


Figure S1

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CONFLICT OF INTEREST STATEMENT

None to declare.

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