



Evaluation of enhanced oviposition attractant formulations against *Aedes* and *Culex* vector mosquitoes in urban and semi-urban areas

Devi Shankar Suman¹

Received: 13 June 2018 / Accepted: 24 January 2019 / Published online: 4 February 2019
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

Abstract

Surveillance is not only an important tool to assess the population dynamics of vector mosquitoes, but it can also be used to control vector-borne diseases. Mosquito vectors that belong to several genera such as *Anopheles*, *Aedes*, and *Culex* play a crucial role in the transmission of malaria, dengue, chikungunya, Zika, and elephantiasis diseases worldwide. We tested the efficacy of two commercial-grade oviposition attractant formulations that were developed for the container-inhabiting *Aedes aegypti*, *Aedes albopictus*, and *Culex quinquefasciatus* mosquitoes present in urban or semi-urban environments. These attractants can lure gravid females. Field trials were conducted in residential yards during a post-rainy season in September and October. Our data showed considerable efficacy for both attractants. *Aedes*-attractant collected 1.6-fold more larvae (101.2 ± 10.5 larvae/trap) than the control, and *Culex*-attractant collected 1.27-fold more larvae (151.2 ± 12.5 larvae/trap) than the control, resulting in 0.8 and 0.7 oviposition attraction indices (OAI), respectively. Regression analysis indicated that the *Aedes*-attractant was more stable than the *Culex*-attractant. Location and time did not alter the efficacy of these attractants. Our experiment suggests that these attractants can be used for the development of species-specific gravid traps to detect, estimate, and control the mosquito population in urban and semi-urban areas.

Keywords Oviposition attractant · Ovitrap · Mosquito surveillance · Container mosquito · Arboviruses · Vector-borne diseases

Introduction

Aedes and *Culex* mosquitoes are among the key vectors for several diseases of public and animal health. According to the World Health Organization (WHO), more than 2.5 billion people in over 100 countries are at risk of dengue infection alone (WHO 2014). In the twentieth century, more than 100 species of viruses causing infection were reported to be transferred by mosquito bites (Gould et al. 2017). Specifically, *Aedes aegypti* and *Aedes albopictus* mainly transmit dengue, chikungunya and Zika viruses globally, whereas *Culex quinquefasciatus* and *Culex vishnui* group mosquitoes

transmit Japanese encephalitis in India and other countries (NVBDCP 2018). Although vaccine is available for Japanese encephalitis, there is no vaccine or effective treatment available for dengue, chikungunya, and Zika virus infections. Thus, mosquito vector control is currently the best tool to manage the arthropod-borne viral infections.

Both *Aedes* and *Culex* mosquito genera have adapted to survive in a variety of domestic and peridomestic habitats under urban and semi-urban environmental conditions, where they are the most prominent mosquito species (Sirivanakaran 1976; Hawley 1988; WHO 2009). These mosquitoes have diverse host choices, which makes it difficult to adopt a single surveillance strategy for all species (Silver 2007). An effective surveillance method enhances population estimate accuracy, resulting in more efficient control applications (Farajollahi et al. 2009, 2012; Fonseca et al. 2013; Unlu et al. 2017). Many methods are used for sampling each life stage; however, they can be tedious, cumbersome, and costly and require extensive manpower.

Section Editor: Norbert Becker

✉ Devi Shankar Suman
dssuman37@gmail.com

¹ Zoological Survey of India, New Alipore, Kolkata, WB 700053, India

Ovitrap surveillance is an efficient but passive method that captures eggs (Perich et al. 2003; Ritchie et al. 2009; Unlu et al. 2017). It has been used effectively for the surveillance of container-inhabiting *Aedes* mosquitoes in urban and semi-urban environments in previous studies (Bellini et al. 1996; Abramides et al. 2011; Fonseca et al. 2013; Achee et al. 2015; Codeco et al. 2015). Field deployment of ovitraps has shown a reduction in the density of *Ae. albopictus* and other mosquitoes in the USA and Italy (Jackson et al. 2012; Degener et al. 2014; Englbrecht et al. 2015). Ovitrap differ in design and oviposition attractant composition, yielding mixed efficacy (Reiter et al. 1991; Trexler et al. 1998; Ponnusamy et al. 2010, 2015; Unlu et al. 2017). Ovitrap modified into lethal ovitraps/gravid traps have become an alternative control method (Barrera et al. 2014; Johnson et al. 2017). However, few efforts have been made to develop ovitraps for *Culex* mosquitoes.

The development of a strong, long-lasting, species-specific oviposition attractant for *Aedes* and *Culex* mosquitoes is required for effective ovitraps to assess the population density with higher sensitivity and for use as an effective control tool. In this study, we have tested the hypothesis that the enhanced formulations of oviposition attractants can provide species-specific and long-term attractancy to *Aedes* and *Culex* vector mosquitoes. We have shown the efficacy of two attractants for the gravid females of *Aedes* and *Culex* mosquitoes in field conditions.

Material and methods

Field locations

To test the efficacy of oviposition attractants against *Aedes* species (*Ae. aegypti* and *Ae. albopictus*) and *Culex quinquefasciatus* mosquitoes, five locations were selected in residential areas in semi-urban and urban communities in Kolkata, West Bengal, India, where the climate was hot and humid with frequent rain. These locations were situated in north, south, east, west and central regions of the city, spaced out 5–10 km apart. These locations were surveyed for the prevalence of the larvae and pupae of both mosquitoes before selection. In the survey, tires, discarded buckets, household containers, water tanks, and other possible temporary and permanent structures were inspected for the presence of mosquito larvae/pupae. For the site selection, an area containing bushes, trees, and shade from house structures were chosen for the placement of ovitraps.

Oviposition attractant and ovitrap

Two oviposition attractants developed for container-inhabiting mosquitoes (*Aedes* (Mosquito Lure) and *Culex*

spp. (*Culex* Mosquito Accelerator™)) were obtained from Maxtech Mosquito Control Inc., Ontario, Canada. These attractants were developed for the trap, the Mosquito Preventer™. The *Aedes* attractant was a mixture of multiple synthetic materials based on n-heneicosane, whereas *Culex* attractant was a plant-based product containing rabbit chow. Both attractants were in a standard packing for a single application in a recommended volume of water (10 L) in the ovitrap. Ovitrap were constructed with plastic buckets (12 L, 28 cm diam.). The *Aedes*-attractant is a water-soluble/miscible compound which was readily mixed with gentle steering; however, the *Culex*-attractant is packed into a floatable perforated sachet to generate infusion while absorbing the water.

Deployment of ovitraps and sampling

After pre-sampling in August 2017, ovitraps were placed under tree shade or bushes to avoid direct sunlight and filled with 10 L of tap water. Each site received three ovitraps, *Aedes*-attractant, *Culex*-attractant, and control. These traps were at least 25–30 m apart from each other. Both *Aedes* and *Culex* traps contained tap water infused with oviposition attractants, whereas control ovitraps contained only tap water. The day of placement is denoted as week 0. Weekly sampling was carried out at all the locations. The number of larvae and pupae in each trap was counted and converted into larvae/trap to measure the efficacy of oviposition attractants. Larvae were brought to the laboratory and sorted to genus by a trained expert and further reared for species confirmation.

Statistical analysis

Data from weekly ovitrap collections were pooled and checked for the normal distribution curve. To assess the species specificity of attractants, the density of respective species in their attractant and controls against other mosquitoes was analyzed for significant differences using one-way ANOVA or Kruskal-Wallis test at $P < 0.05$. More than 98% hatch was observed in the laboratory from field-collected eggs during pre-experimental collections; hence, it was assumed that the larva number is proportional or equal to the egg density and the oviposition rate in the trap. The oviposition attractancy index (OAI) for both attractants against control at each week was calculated followed by Kramer and Mulla (1979): $OAI = T - C / T + C$, where T represents the number of eggs/larvae in treatment and C denotes the number of eggs/larvae in control traps. This index ranges between +1 and -1, with positive values indicating attractancy and negative values indicating repellency.

To assess the attractant stability and attractancy over time, a multiple regression analysis was conducted between time duration (X-axis) and % population captured in treatments (Y-

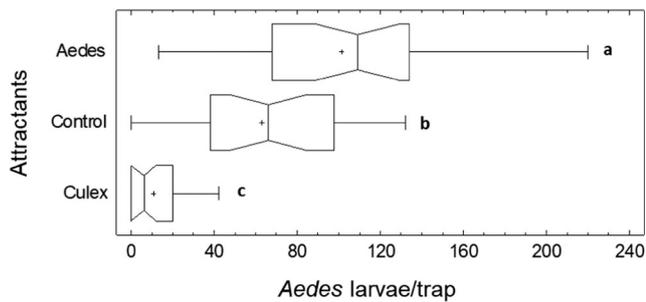


Fig. 1 Box-and-whisker plot showing species specificity of the *Aedes*-attractant for gravid *Aedes* mosquitoes against the *Culex*-attractant and control (tap water). The significant differences among the treatments are denoted by different letters (one-way ANOVA, $p < 0.0001$, Fisher's LSD = 22.22). The horizontal black line in the box-whisker plots is the median. The open small box represents the outlier, and the plus sign in the box plot represents mean value. Whiskers depict the confidence interval for each box plot

axis) in comparison to control and another attractant. Regression lines of *Aedes* and *Culex* attractants were also compared with each other for significant differences by assuming equal intercepts ($p < 0.05$). Unless otherwise specified, the data are represented as mean \pm standard error (SE).

Results

Mosquito population collection

During this study, 8228 mosquito larvae were collected from all the traps deployed including *Aedes*-attractant, *Culex*-attractant, and control ovitraps. A total of 4373 were *Aedes* and 3855 were *Culex*. *Aedes* populations included *Ae. aegypti* (32%) and *Ae. albopictus* (68%), whereas *Culex quinquefasciatus* was 98% of the *Culex* population. The *Culex* larval population was almost double that of the *Aedes* population in control traps.

Species specificity of oviposition attractants

The *Aedes*-oviposition attractant was most effective for luring *Aedes*, compared to the control and *Culex*-attractant, with significantly greater collection of *Aedes* mosquitoes (101.2 ± 10.5 larvae/trap) in *Aedes* ovitraps than the control (63.0 ± 8.2 larvae/trap) and *Culex* ovitraps (10.6 ± 2.7 larvae/trap) (Fig. 1, Table 1, one-way ANOVA $df = 2, 72$, f -ratio = 33.3, $p = 0.0001$, LSD = 22.2).

Table 1 One-way analysis of variance (ANOVA) for the efficacy of *Aedes*-oviposition-attractant in comparison to control and *Culex* attractant

Source	Sum of squares	df	Mean square	f -ratio	p value	LSD
Between groups	103,445.0	2	51,722.3	33.29	0.0000	22.22
Within groups	111,861.0	72	1553.63			
Total (Corr.)	215,306.0	74				

LSD Fisher's least significant difference

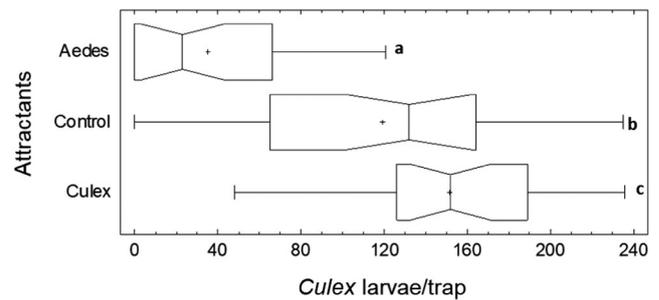


Fig. 2 Box-and-whisker plot showing species specificity of the *Culex*-attractant for *Culex* mosquitoes against *Aedes*-attractant and control (tap water). The significant differences among the treatments are denoted by different letters (one-way ANOVA, $p < 0.0001$, Fisher's LSD = 32.46). The horizontal black line in the box-whisker plots is the median. The open small box represents the outlier, and the plus sign in box plot represents mean value. Whiskers depict confidence interval for each box plot

The *Culex*-attractant also showed more attractancy to *Culex* mosquitoes in comparison to control and *Aedes*-attractant, capturing more *Culex* (151.2 ± 12.5 larvae/trap) than the control (118.9 ± 14.5 larvae/trap) and *Aedes*-attractant (35.2 ± 7.7 larvae/trap) (Figs. 2, Table 3, one-way ANOVA $df = 2, 72$, f -ratio = 27.1, $p = 0.0001$, LSD = 32.5).

Oviposition attraction index

The oviposition attraction index (OAI) represents either the strength of attractancy if positive, or repellency if negative. In the first week, the *Aedes*-attractant showed maximum attractancy (0.8 ± 0.1 OAI) which was reduced to 0.3 ± 0.1 in the second week, persisting to the fifth week with a slight reduction during the fourth week (Fig. 3). Similarly, the *Culex*-attractant showed 0.7 ± 0.1 OAI in the first week and reduced to 0.4 ± 0.03 in the second week. There was a further decline in its attractancy and finally became negative (repellent) in the fourth and fifth weeks (Fig. 3).

Impact of time and locations on the efficacy of oviposition attractants

Both *Aedes*- and *Culex*-attractants were evaluated for 5 weeks on different field conditions to assess their persistence performance. The *Aedes*-attractant showed a significant increase from 19.6 ± 4.0 larvae/trap/week at week 1 to 146.2 ± 5.9

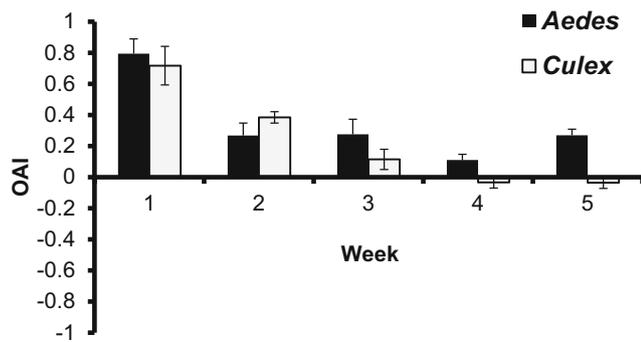


Fig. 3 Oviposition attraction index (OAI) of *Aedes*- and *Culex*-attractants under field conditions

larvae/trap/week at week 4 and declined slightly to 126.8 ± 9.2 larvae/trap/week (Fig. 4, Table 2, multiple-way ANOVA $df=4$, f -ratio = 21.44, $p=0.0001$, LSD = 11.2). There was no significant difference among the locations for the density of the population captured (Tables 2, multiple-way ANOVA $df=4$, f -ratio = 1.28, $p=0.318$, LSD = 11.2).

We noted that the *Culex* population density in the trap deployed with the *Culex*-attractant was 61.4 ± 7.3 larvae/trap/week at week 1, which increased significantly to 170.2 ± 13.6 larvae/trap/week in week 2, varied non-significantly in weeks 3 and 4, and finally declined significantly in week 5 (Fig. 5, Table 4, multiple-way ANOVA $df=4$, f -ratio = 18.8, $p=0.0001$, LSD = 38.2). No difference was found among the various locations for the density captured in the traps (Table 4, multiple-way ANOVA $df=4$, f -ratio = 0.62, $p=0.65$, LSD = 38.2).

Multiple regression analysis of oviposition attractants

The multiple regression analysis showed an R value of 69.63% and downward slope for both *Aedes*-attractant (percent = $85.3261 - 7.01014 \times \text{week}$) and *Culex*-attractant (percent = $94.9996 - 12.5808 \times \text{week}$) (Fig. 6). The analysis also indicates significant differences in the analysis of variance analysis between the attractants (Table 5). When intercepts were assumed equal for the analysis of regression lines of both attractants, both lines were significantly different from each

Table 2 Multiple-way analysis of variance for the efficacy of *Aedes*-oviposition-attractants to assess the effect of location and time

Source	Sum of squares	df	Mean square	f -ratio	p value	LSD
Main effects						
A: location	3213.36	4	803.34	1.28	0.3184	11.19
B: time	53,768.2	4	13,442.0	21.44	0.0000	
Residual	10,031.0	16	626.94			
Total (corr.)	67,012.6	24				

LSD Fisher's least significant difference

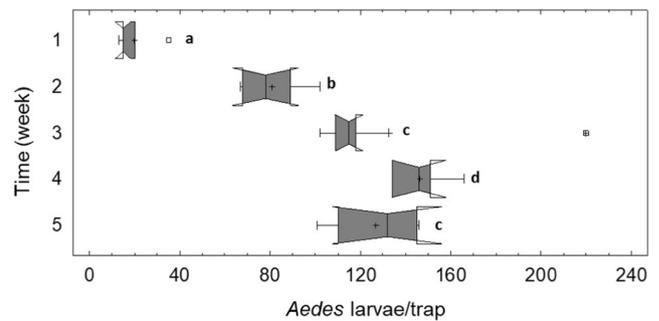


Fig. 4 Box-and-whisker plot showing the long-term efficacy of *Aedes*-attractant measured by population density in traps per week. The significant differences among the treatments are denoted by different letters (one-way ANOVA, $p < 0.0001$, Fisher's LSD = 11.19). The horizontal black line in the box-whisker plots is the median. The open small box represents the outlier, and the plus sign in the box plot represents the mean value. Whiskers depict confidence interval for each box plot

other (Table 5), indicating that the *Culex*-attractant lost efficacy faster than the *Aedes*-attractant.

Discussion

The oviposition attractant is a vital component of the ovitraps (Trexler et al. 1998; Barrera et al. 2014). The development of stronger attractants enhances the ovitrap efficacy for the surveillance and population management of mosquitoes, which helps in the refinement of vector-borne disease control. The present study reports on new and effective oviposition attractant formulations that were tested under the field conditions. Our data show a considerably higher attractiveness of oviposition attractants for the *Culex* and *Aedes* mosquitoes; however, the *Aedes*-attractant was found to be much more species-specific than the *Culex* mosquitoes. Both attractants were active for a 1-month period under the field conditions.

Surveillance is the backbone of any successful vector control program. Analyzing the spatiotemporal patterns of mosquito populations is necessary for the development and execution of mosquito control measures (WHO 2009; Wong et al. 2011; Fonseca et al. 2013). Several studies have shown the utility of different traps for capturing the adults, larvae, and eggs (Ritchie et al. 2009; Barrera et al. 2014; Johnson et al. 2017). The adult trap that uses light cues, such as CDC miniature light traps, has been used effectively for the surveillance of nocturnal *Culex* and *Anopheles* mosquitoes (Arunachalam et al. 1999). However, light traps are ineffective for the collection of diurnal *Aedes aegypti* and *Ae. albopictus* mosquitoes (Silver 2007). Since *Aedes* mosquitoes are synchronized with human activity and have evolved day-biting rhythms for blood feeding, the use of light trap during daytime is ineffective. BG-Sentinel traps, based on

Table 3 One-way analysis of variance (ANOVA) for the efficacy of *Culex*-oviposition-attractant in comparison to control and *Aedes* attractant

Source	Sum of squares	df	Mean square	f-ratio	p value	LSD
Between groups	179,919.0	2	89,959.3	27.14	0.0000	32.46
Within groups	238,636.0	72	3314.39			
Total (corr.)	418,554.0	74				

LSD Fisher's least significant difference

synthetic chemicals mimicking human hosts, have also been evaluated against *Aedes* mosquitoes (Farajollahi et al. 2012). BG-Sentinel traps are highly sensitive to determine the population density for the control operations (Unlu et al. 2017). Despite the high cost, BG-Sentinel traps were successfully used by various mosquito control agencies in USA, Europe, Australia, and Africa (Williams et al. 2007; Degener et al. 2015; Englbrecht et al. 2015; Kampen et al. 2017). However, costly traps may not be affordable for an individual for personal protection. Gravid oviposition traps are relatively inexpensive, providing an alternative tool for the surveillance and management of *Aedes* mosquitoes by luring the females looking for suitable larval habitats.

Developing an oviposition trap and lure for both *Aedes* and *Culex* is difficult due to their strikingly different physiology, biology, oviposition behaviors, and selection of habitats (Clements 1992). The eggs of *Ae. aegypti* and *Ae. albopictus* are encased in a tough and collapse-resistant shell, usually attached individually on the container wall, just above the water surface (Suman et al. 2011, 2013). In contrast, the eggs of *Culex* mosquitoes are less collapse-resistant than the *Aedes* eggs, and are found in free-floating egg-rafts, joined together by lateral finger-like projections, making egg collection difficult (Suman et al. 2008, 2009).

An oviposition trap attracts gravid females and induces them to oviposit in the trap by providing favorable

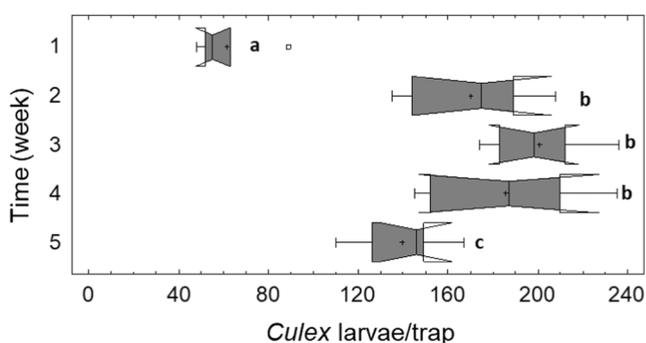


Fig. 5 Box-and-whisker plot showing the long-term efficacy of *Culex*-attractant measured by population density in traps per week. The significant differences among the treatments denoted by different letters (one-way ANOVA, $p < 0.0001$, Fisher's LSD = 38.15). The horizontal black line in the box-whisker plots is the median. The open small box represents the outlier, and the plus sign in the box plot represents mean value. Whiskers depict confidence interval for each box plot

conditions for larval development (Trexler et al. 1998; Perich et al. 2003; Ritchie et al. 2009; Wong et al. 2011). The oviposition behavior of mosquitoes involves two crucial events. The first is to find a suitable habitat using long-range cues such as color, texture, and chemical cues. The second is the short-range cues used by gravid females to make a decision to lay eggs in the habitats, such as disturbance, the chemical properties of the water, and presence of conspecific individuals or other organisms (Bentley and Day 1989; Day 2016). These components make it difficult to characterize larval habitats. Nonetheless, efforts have been made to analyze various components of the larval habitats; for instance, several chemicals have been isolated and evaluated to develop "mosquito attractive media" (Trexler et al. 1998; Ponnusamy et al. 2010, 2015); however, several modern traps are still reliant on crude plant infusion or tap water (Ritchie et al. 2009; Barrera et al. 2014; Unlu et al. 2017).

The efficacy and stability of oviposition attractants are important for the active life of the gravid traps (Gaugler et al. 2017). Gaugler et al. (2017) demonstrated that the plant-derived attractants lose the efficacy quickly and become unattractive within 1–2 weeks. This is mainly attributed to the degradation of plant materials into the water, changing the physicochemical properties of the infusion, which may turn into a deterrent or repellent to the target mosquito. Multiple studies on mosquito surveillance have used plant infusions and synthetic chemicals as oviposition attractants, although these attractants need to be replaced or replenish on a weekly basis (Fonseca et al. 2013; Unlu et al. 2017). Both plant-based and synthetic attractants have their merits and disadvantages; botanical

Table 4 Multiple-way analysis of variance for the efficacy of *Culex*-oviposition-attractants to assess the effect of location and time

Source	Sum of squares	df	Mean square	f-ratio	p value	LSD
Main effects						
A: location	2006.64	4	501.66	0.62	0.6552	38.16
B: time	60,983.0	4	15,245.8	18.82	0.0000	
Residual	12,960.6	16	810.035			
Total (corr.)	75,950.2	24				

LSD Fisher's least significant difference

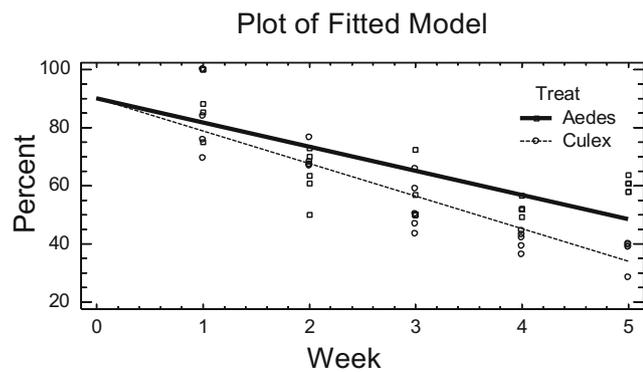


Fig. 6 Regression analysis of the efficacy of *Aedes*- and *Culex*-attractants over time and comparison of their slope for a significant difference (slope, $p < 0.009$)

products are highly attractive, but inconsistent in quality as their chemical composition varied depending on the seasons and geographical regions. Synthetic attractants are inexpensive and can maintain their quality, but have poor efficacy, making them inviable in the market. Our preliminary study on the development of oviposition attractants using oak infusion against n-heneicosane has shown superior efficacy of plant-based product over the synthetic product (unpublished data, Suman et al.). We show that the enhanced formulations extend the longevity of attractants. For example, rabbit chow packed into the pouch increased the longevity of the attractant for 4 weeks after the deployment of the traps and collected around 170 larvae of *Culex quinquefasciatus* per week. Similarly, the other synthetic oviposition attractant formulation developed for *Aedes* mosquitoes showed effective attractancy

for 5 weeks continuously, even after rain events, suggesting that testing the long-term seasonal efficacy of this attractant may lead to the development of a commercial product.

Chemical cues are the most significant as decision-making factors. They may act as either a repellent/deterrent or an attractant/arrestant (Bentley and Day 1989; Trexler et al. 1998; Sharma et al. 2008, 2009; Seenivasagan et al. 2010; Wong et al. 2011). Here, we show that the synthetic *Aedes*-attractant is highly specific for *Aedes* mosquitoes with fewer *Culex* larvae near the end of the test, whereas the *Culex*-attractant developed for the *Culex* behaves differently, attracting *Aedes* mosquitoes at the beginning of the test and becoming repellent at the end of the test; however, it was highly attractive to *Culex* in mid-phase. This indicates that infusion quality changes over the time, shifting mosquito species' preferences. This suggests that the rabbit chow formulation infusion is more applicable for the *Culex* mosquito attraction rather than *Aedes*.

Conclusion

The oviposition attractants evaluated for the container *Aedes* and *Culex* mosquitoes have shown species-specific and long-lasting activity in urban and semi-urban areas. The findings may be useful for the development of gravid traps for the surveillance and control measures of container-inhabiting *Ae. aegypti*, *Ae. Albopictus*, and *Cx. quinquefasciatus* vector mosquitoes.

Table 5 (A) Multiple regression analysis of the efficacy of oviposition attractancy of *Aedes*- and *Culex*-attractants and weeks and (B) comparison of regression slopes of both *Aedes*- and *Culex*-attractants for significant differences

(A) Multiple regression analysis						
Parameter	Estimate	Standard error	T statistic	<i>p</i> value		
Constant	85.3261	4.78769	17.822	0.0000		
Week	-7.01014	1.44354	-4.85621	0.0000		
Treat = <i>Culex</i>	9.67357	6.77081	1.42872	0.1598		
Week*treat = <i>Culex</i>	-5.57063	2.04148	-2.72873	0.0090		
Source	Sum of squares	<i>df</i>	Mean square	<i>f</i> -ratio	<i>p</i> value	
Analysis of variance						
Model	10,990.1	3	3663.37	35.16	0.0001	
Residual	4792.77	46	104.191			
Total (corr.)	15,782.9	49				
(B) Comparison of regression lines						
Week	9595.09	1	9595.09	90.10	0.0000	
Slopes	1182.35	1	1182.35	11.10	0.0017	
Model	10,777.4	2				

Regression equation: percent = 85.3261 - 7.01014 * (treat = *Aedes*) * week + 9.67357 * (treat = *Culex*) - 5.57063 * week * (treat = *Culex*). *R*-squared = 69.6331%, *R*-squared (adjusted for *df*) = 67.6527%, standard error of est. = 10.2074, Durbin-Watson statistic = 1.14597 ($p = 0.0001$), lag 1 residual autocorrelation = 0.376443

Acknowledgements The author sincerely thanks Dr. Kailash Chandra, Director, Zoological Survey of India, New Alipore, Kolkata, India, for his support and providing the facilities to accomplish this study. I thank Subhas Vasudeva, Maxtech Mosquito Control Inc., Ontario, Canada, for providing samples of oviposition attractants. I also thank the students and staff who helped in the study and premises owners for their permission to conduct the study. The author would like to thank Dr. Sarwar Hashmi and Dr. Alexandra Gillett for proof-reading the article.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

- Abramides GC, Roiz D, Guitart R, Quintana S, Guerrero I, Gimenez N (2011) Effectiveness of a multiple intervention strategy for the control of the tiger mosquito (*Aedes albopictus*) in Spain. *Trans R Soc Trop Med Hyg* 105:281–288. <https://doi.org/10.1016/j.trstmh.2011.01.003>
- Achee NL, Gould F, Perkins TA, Reiner RC Jr, Morrison AC, Ritchie SA, Gubler DJ, Teyssou R, Scott TW (2015) A critical assessment of vector control for dengue prevention. *PLoS Negl Trop Dis* 9:e0003655. <https://doi.org/10.1371/journal.pntd.0003655>
- Arunachalam N, Samuel PP, Hiriyan J, Gajanana A (1999) A comparative study on sampling techniques for *Aedes aegypti* (Diptera: Culicidae) surveillance in Madurai. *South India Trop Biomed* 16:25–29
- Barrera R, Amador M, Acevedo V, Caban B, Felix G, Mackay AJ (2014) Use of the CDC autocidal gravid ovitrap to control and prevent outbreaks of *Aedes aegypti* (Diptera: Culicidae). *J Med Entomol* 51:145–154
- Bellini R, Carrieri M, Burgio G, Bacchi M (1996) Efficacy of different ovitraps and binomial sampling in *Aedes albopictus* surveillance activity. *J Am Mosq Control Assoc* 12:632–636
- Bentley M, Day J (1989) Chemical ecology and behavioral aspects of mosquito oviposition. *Annu Rev Entomol* 34:401–421
- Clements AN (1992) The biology of mosquitoes, development, nutrition and reproduction, vol 1. Chapman & Hall, New York, NY, USA, pp 222–285
- Codeco CT, Lima AW, Araujo SC, Lima JB, Maciel-de-Freitas R, Honorio N, Galardo AK, Braga IA, Coelho GE, Valle D (2015) Surveillance of *Aedes aegypti*: comparison of house index with four alternative traps. *PLoS Negl Trop Dis* 9:e0003475
- Day F (2016) Mosquito oviposition behavior and vector control. *Insects* 7:65. <https://doi.org/10.3390/insects7040065>
- Degener CM, Eiras AE, Azara TMF, Roque RA, Rosner S, Codeco CT, Nobre AA, Rocha ESO, Kroon EG, Ohly JJ, Geier M (2014) Evaluation of the effectiveness of mass trapping with BG-sentinel traps for dengue vector control: a cluster randomized controlled trial in Manaus, Brazil. *J Med Entomol* 51:408–420
- Degener CM, Mingote Ferreira de Ázara T, Aparecida Roque R, Rösner S, Rocha ESO, Geessien Kroon E, Torres Codeço C, Araújo Nobre A, Ohly JJ, Geier M, Eiras AE (2015) Mass trapping with MosquiTRAPs does not reduce *Aedes aegypti* abundance. *Mem Inst Oswaldo Cruz, Rio de Janeiro* 110:517–527
- Englbrecht C, Gordon S, Venturelli C, Rose A, Geier M (2015) Evaluation of BG-Sentinel traps as a management tool to reduce *Aedes albopictus* nuisance in an urban environment in Italy. *J Am Mosq Control Assoc* 31:16–25
- Farajollahi A, Healy SP, Unlu I, Gaugler R, Fonseca DM (2012) Effectiveness of ultra-low volume nighttime applications of an adulticide against diurnal *Aedes albopictus*, a critical vector of dengue and chikungunya viruses. *PLoS One* 7:e49181. <https://doi.org/10.1371/journal.pone.0049181>
- Farajollahi A, Kesavaraju B, Price DC, Williams GM, Healy SP, Gaugler R, Nelder MP (2009) Field efficacy of BG-Sentinel and industry-standard traps for *Aedes albopictus* (Diptera: Culicidae) and West Nile virus surveillance. *J Med Entomol* 46:919–925
- Fonseca DM, Unlu I, Crepeau T, Farajollahi A, Healy SP, Bartlett-Healy K, Strickman D, Gaugler R, Hamilton G, Kline D, Clark GG (2013) Area-wide management of *Aedes albopictus*. Part 2: gauging the efficacy of traditional integrated pest control measures against urban container mosquitoes. *Pest Manag Sci* 69:1351–1361. <https://doi.org/10.1002/ps.3511>
- Gaugler R, Wang Y, Kshitij C, Suman DS (2017) Collapsible stackable disposable inexpensive pesticide free traps and attractant for surveillance and control of *Aedes* container breeding mosquitoes and other container breeding insects. <https://patents.google.com/patent/US20170000101A1/en>. Accessed May 2017
- Gould E, Pettersson J, Higgs S, Charrel R, de Lamballerie X (2017) Emerging arboviruses: why today? *One Health* 4:1–13. <https://doi.org/10.1016/j.onehlt.2017.06.001>
- Hawley WA (1988) The biology of *Aedes albopictus*. *J Am Mosq Control Assoc Suppl* 1:1–39
- Jackson MJ, Gow JL, Evelyn MJ, McMohan TJS, Howay TJ, Campbell H, Blancard J, Thielman (2012) An evaluation of the effectiveness of a commercial mechanical trap to reduce abundance of adult nuisance mosquito populations. *J Am Mosq Control Assoc* 28:292–300. <https://doi.org/10.2987/12-6241r.1>
- Johnson BJ, Hurst T, Quoc HL, Unlu I, Freebairn C, Faraji A, Ritchie SA (2017) Field comparisons of the gravid *Aedes* trap (gat) and BG-sentinel trap for monitoring *Aedes albopictus* (Diptera: Culicidae) populations and notes on indoor GAT collections in Vietnam. *J Med Entomol* 54:340–348. <https://doi.org/10.1093/jme/tjw166>
- Kampen H, Schuhbauer A, Walther D (2017) Emerging mosquito species in Germany—a synopsis after 6 years of mosquito monitoring (2011–2016). *Parasitol Res* 116:3253–3263. <https://doi.org/10.1007/s00436-017-5619-3>
- Kramer LW, Mulla SM (1979) Oviposition attractants and repellents of mosquitoes: oviposition responses of *Culex* mosquito to organic infusions. *Environ Entomol* 8:1111–1117
- NVBDCP (2018) National Vector Borne Disease Control Programme. Directorate General of Health Services. Ministry of Health & Family Welfare, Govt. of India. Diseases. <http://www.nvbdc.gov.in/#> (Accessed on 11.06.2018)
- Perich MJ, Kardec A, Braga IA, Portal IF, Burge R, Zeichner BC, Brogdon WA, Wirtz RA (2003) Field evaluation of a lethal ovitrap against dengue vectors in Brazil. *Med Vet Entomol* 17:205–210
- Ponnusamy L, Schal C, Wesson DM, Arellano C, Apperson CS (2015) Oviposition responses of *Aedes* mosquitoes to bacterial isolates from attractive bamboo infusions. *Parasit Vectors* 8:486. <https://doi.org/10.1186/s13071-015-1068-y>
- Ponnusamy L, Xu N, Böröczky K, Wesson DM, Ayyash LA, Schal C, Apperson CS (2010) Oviposition responses of the mosquitoes *Aedes aegypti* and *Aedes albopictus* to experimental plant infusions in laboratory bioassays. *J Chem Ecol* 36:709–719. <https://doi.org/10.1007/s10886-010-9806-2>
- Reiter P, Amador MA, Colon N (1991) Enhancement of the CDC ovitrap with hay infusions for daily monitoring of *Aedes aegypti* populations. *J Am Mosq Control Assoc* 7:52–55
- Ritchie SA, Rapley LP, Williams C, Johnson PH, Larkman M, Silcock RM, Long SA, Russell RC (2009) A lethal ovitrap-based mass trapping scheme for dengue control in Australia. I. Public acceptability and performance of lethal ovitraps. *Med Vet Entomol* 23:295–302. <https://doi.org/10.1111/j.1365-2915.2009.00833.x>

- Seenivasagan T, Sharma KR, Ganesan K, Prakash S (2010) Electrophysiological, flight orientation and oviposition responses of three species of mosquito vectors to hexadecyl pentanoate: residual oviposition repellent activity. *J Med Entomol* 47:329–337. <https://doi.org/10.1603/ME09130>
- Sharma KR, Seenivasagan T, Rao AN, Ganesan K, Agrawal OP, Malhotra RC, Prakash S (2008) Oviposition responses of *Aedes aegypti* and *Aedes albopictus* to certain fatty acid esters. *Parasitol Res* 103:1065–1073. <https://doi.org/10.1007/s00436-008-1094-1>
- Sharma KR, Seenivasagan T, Rao AN, Ganesan K, Agrawal OP, Prakash S (2009) Mediation of oviposition responses in the malaria mosquito *Anopheles stephensi* Liston by certain fatty acid esters. *Parasitol Res* 104:281–286. <https://doi.org/10.1007/s00436-008-1189-8>
- Silver JB (2007) Mosquito ecology: field sampling methods. Springer Science+Business Media B.V., Dordrecht. <https://doi.org/10.1007/978-1-4020-6666-5>
- Sirivanakaran S (1976) Medical entomology studies—III. A revision of the subgenus *Culex* in the Oriental region (Diptera: Culicidae). *Contrib Am Ent Inst* 12:1–272
- Suman DS, Shrivastava AR, Pant SC, Parashar BD (2011) Differentiation of *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae) with egg surface morphology and morphometrics using scanning electron microscopy. *Arthropod Struct Dev* 40:479–483
- Suman DS, Shrivastava AR, Parashar BD, Pant SC, Agrawal OP, Prakash S (2009) Variations in morphology & morphometrics of eggs of *Culex quinquefasciatus* mosquitoes from different ecological regions of India. *J Vector Ecol* 34:191–199
- Suman DS, Shrivastava AR, Parashar BD, Pant SC, Agrawal OP, Prakash S (2008) Scanning electron microscopic studies on egg surface morphology and morphometrics of *Culex tritaeniorhynchus* and *Culex quinquefasciatus* (Diptera: Culicidae). *Parasitol Res* 104:173–176
- Suman DS, Wang Y, Bilgrami AL, Gaugler R (2013) Ovicidal activity of three insect growth regulators against *Aedes* and *Culex* mosquitoes. *Acta Trop* 128:103–109. <https://doi.org/10.1016/j.actatropica.2013.06.025>
- Trexler JD, Apperson CS, Schal C (1998) Laboratory and field evaluations of oviposition responses of *Aedes albopictus* and *Aedes triseriatus* (Diptera: Culicidae) to oak leaf infusions. *J Med Entomol* 35:967–976
- Unlu I, Suman DS, Wang Y, Klingler K, Faraji A, Gaugler R (2017) Effectiveness of autodissemination stations containing pyriproxyfen in reducing immature *Aedes albopictus* populations. *Parasit Vectors* 10:139. <https://doi.org/10.1186/s13071-017-2034-7>
- WHO [World Health Organization] (2009) Dengue: guidelines for diagnosis, treatment, prevention and control. In: In: organization WH (ed.). World Health Organization, Geneva
- WHO [World Health Organization] (2014) A global brief on vector-borne diseases. In: Organization WH (ed) A global brief on vector-borne diseases. World Health Organization, Geneva
- Williams CR, Long SA, Webb CE, Bitzhenner M, Geier M, Russel RC, Ritchie SA (2007) *Aedes aegypti* population sampling using BG-Sentinel traps in north Queensland, Australia: statistical considerations for trap deployment and sampling strategy. *J Med Entomol* 44:345–350
- Wong J, Stoddard ST, Astete H, Morrison AC, Scott TW (2011) Oviposition site selection by the dengue vector *Aedes aegypti* and its implications for dengue control. *PLoS Neg Trop Dis* 5:e1015. <https://doi.org/10.1371/journal.pntd.0001015>