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New tools for *Aedes* control: mass trapping

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Abstract

Aedes aegypti, the main vector of dengue, chikungunya, and Zika viruses uses artificial containers around homes to undergo immature development, making household-level detection and control extremely difficult in large urban areas. Mass trapping is an emerging methodology to control container-*Aedes* species such as *Aedes aegypti and Aedes albopictus* because effective traps for adult stages of these mosquitoes were developed recently. There are three main approaches to mass-trapping these mosquitoes: 1) Pull (attract/kill), 2) push (repel) - pull (attract/kill), and 3) pull (attract/contaminate/infect) - push (fly away). Effective mass-trapping depends on trap quality (capture efficiency, sturdiness, frequency of servicing), trap density and areal coverage, community involvement, and safety. Recent studies showed that *Ae. aegypti* populations can be sustainably controlled by mass trapping, although more area-wide studies showing effectiveness at preventing disease are needed for all trapping systems. Cost-effectiveness studies are needed for all emerging *Aedes* control approaches.

Keywords

Aedes aegypti; mosquito trap; mosquito control; dengue

Introduction

Aedes aegypti is the main mosquito vector of dengue, chikungunya, and Zika viruses around the tropical and subtropical world [1]. There are several reasons why this mosquito is such an important vector, including its domesticity and high preference for biting people [2]. This mosquito species has access to shelter inside homes, human blood to produce eggs, and indoor/outdoor container aquatic habitats that are needed for immature development. Habitats that overlap between *Ae. aegypti* and people facilitate epidemics of arbovirus in urbanized areas. A main challenge to controlling arboviral epidemics consists of keeping the abundance of this mosquito species below levels that would prevent or control the transmission of arboviruses (mosquito density threshold) [3].

Defining and validating mosquito density thresholds partially depends on the tools used to assess mosquito abundance (e.g., immature surveys, counts of adult mosquitoes landing on humans, ovitraps, adult mosquito traps) and the stage of the mosquito (e.g., eggs, larvae,

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pupae, adults) [4]. Mosquito density thresholds provide well-defined targets for Mosquito Control Programs. The relatively recent development of new and effective mosquito traps targeting *Ae. aegypti* adults provides opportunities to improve its surveillance and control. A recent review of evidence recommended mass trapping of gravid females of *Ae. aegypti* using newer generation, larger traps that compete with naturally occurring aquatic habitats [5].

Trapping systems

A trap is defined by WHO [6] as a "Structure or device unto which vectors enter and/or make contact with, which ultimately results in their capture, death and/or sterilization". Currently, there are three main control approaches using trap devices: 1) pull (attract/kill) (e.g., ovitraps, adult mosquito traps, attractive toxic sugar baits), 2) push (repel) - pull (attract/kill) (e.g., use of spatial repellent devices and adult mosquito traps) , and 3) pull (attract/contaminate with a control agent) - push (fly away to disseminate a control agent) (e.g., autodissemination devices impregnated with an insect growth regulator product that is dispersed by ovipositing females in aquatic habitats nearby).

Pull (attract/kill).

1. Ovitraps.: These are small dark containers (e.g., black, red) made from different materials (e.g., glass, metal, plastic, rubber) containing water (e.g., 0.25 – 2 lt) or water with decomposing organic material (e.g., hay, leaves, yeast), and a substrate to collect mosquito eggs (e.g., wooded tongue depressor, germination paper, cloth). Ovitraps were produced to detect the presence of *Ae. aegypti* during the eradication campaign of this mosquito in the Americas [7]. Ovitraps target eggs from ovipositing gravid female mosquitoes, so that mass ovitrapping intends to reduce the fecundity of the *Aedes* population. A principal limitation of small ovitraps as an area-wide mass trapping strategy is the need for servicing them frequently to replace water, attractants, and oviposition substrates, but also to prevent hatched larvae from becoming adults. The latter issue has been addressed by adding larvicides that do not repel ovipositing females (*Bacillus thuringiensis* var. *israelensis*, spinosad, novaluron, S-methoprene, yeast interfering RNA) [8,9]. Chan et al. [10] developed an autocidal ovitrap to control *Ae. aegypti* in Singapore that prevented the emergence of adult mosquitoes developing inside the ovitrap by mechanical means (asphyxiation). The authors recommended the use of autocidal ovitraps along with source reduction to maximize control. There are no recent publications that address controlling *Aedes* species using ovitraps and earlier studies on mass trapping were reviewed by Johnson et al. [5]. Currently, insecticidal traps are not considered for mass trapping *Aedes* species.

2. Gravid-female adult traps.: Like ovitraps, gravid traps are dark, although some other colors such as terracotta and dark blue resulted in similar attraction to *Ae. aegypti* in field studies in Puerto Rico [8]. Gravid traps are usually bigger than ovitraps (e.g., 2 - 10 1) and contain water with decomposing organic material to attract gravid females looking for a place to lay eggs. Adult mosquitoes are retained on a sticky glue board [11,12], killed with a residual insecticide [13], or impaired to fly with canola oil [14]. It is important to monitor and control the gravid adult female mosquito population because those females must have had a blood meal to produce eggs, and therefore, it is the most likely stage of the mosquito to be infected with arboviruses. Additionally, monitoring the presence of arboviruses in gravid *Ae. aegypti* mosquitoes has been useful to detect local transmission of chikungunya, dengue, and Zika viruses [15,16].

There are a several recent studies showing significant effectiveness of mass trapping with gravid traps at reducing: *Ae. aegypti* populations [17,18,19], prevalence of arborvirus in mosquitoes [15], and risk of human infections with chikungunya [50%; 20] and dengue viruses [36%; 18]. Non insecticidal gravid traps have been used to propose *Ae. aegypti* density thresholds in Puerto Rico (e.g., < 3 females *Ae. aegypti*/trap/week) to prevent chikungunya and Zika transmission [15,21]. Mass trapping has produced relatively stable, below thresholds densities in small communities for several years and in a medium-size city, as shown by a cluster randomized step-wedge intervention during the 2016 Zika epidemic in Puerto Rico [17]. Modeling has shown that a steady reduction of 70-80% of the female *Ae. aegypti* population, such as that observed in these studies does not require removing 70-80% of mosquitoes. The reason for such population reduction, other than directly eliminating a fraction of the gravid females, is a significant reduction of the average longevity of the mosquito female population [22]. So far, there are no reports that local control of gravid females of *Ae. aegypti* by non-insecticidal mass trapping for several years had caused the evolution of trap's avoidance behavior by *Ae. aegypti*. A recent investigation tested the hypothesis that long-term mass trapping of gravid *Ae. aegypti* would eliminate insecticide resistance in populations that were initially resistant to commercially available domestic insecticides. It was thought that insecticide susceptibility could be restored (loss of resistant genes) from processes happening in small populations such as genetic drift, bottle neck events, or lack of adaptive selection if residents discontinued the use of insecticides [23]. The results showed that mass trapping did not restore insecticide susceptibility and provided evidence of high *Ae. aegypti* migration from nearby resistant populations. These results highlight the importance of scale on dynamic processes involving factors (e.g., migration) that can only be assessed by large area-wide studies of mosquito population control.

Several factors contribute to the effectiveness of mass trapping for controlling *Ae. aegypti* and perhaps, other container mosquitoes: trap efficiency (capacity to attract and retain, kill, or contaminate nearby mosquitoes), effective number of traps per house or area (e.g., three traps/home), good areal coverage (e.g., > 60-80% of houses/area with traps), long periods without trap servicing, timely trap maintenance, acceptance from the community, an efficient system to collect real time data in the field using computer applications in cell phones or tablets to monitor quality control, and use of Geographical Information Systems (GIS) to keep track of traps' location and condition. Additionally, Johnson et al. [5] recommended involving residents in trap servicing for sustainability [24], avoiding the use of insecticides against landing female mosquitoes given current widespread insecticide resistance in *Ae. aegypti* and using organic larvicides to prevent the production of mosquitoes in unattended traps. Traps requiring frequent maintenance (e.g., < 2-3 mo.) will have high staffing costs. Community involvement could lower cost of mass trapping if traps can be fabricated locally and are durable and easy to maintain. A general need for all emerging new tools for the control of *Ae. aegypti* that applies to mass trapping, is cost-benefit studies to understand if they are affordable and if they have a significant impact on reducing or preventing arbovirus transmission and disease, particularly in lower-income settings.

3. Attractive toxic sugar baits (ATSBs).: Adults of container *Aedes* sp. attracted to a source of sugar can be killed using ingested toxic compounds (e.g., boric acid, fipronil, Ribonucleic Acid interference or RNAi) [25,26]. Baits can be applied directly to vegetation and other surfaces that are frequented by adult *Aedes* mosquitoes or be contained in a bait station. Floral attractants and fruit juices have been explored as attractants for *Ae. aegypti*. Frikig et al. [27] reported that fruit juices were more effective than water at luring males of *Ae. aegypti*, although none of these lures were effective at attracting male mosquitoes to an insecticidal adult trap. Sippy et al. [28] used a dry ATSB consisting of black/white foam disks sprayed with sugar and boric acid to attract and kill indoor *Ae. aegypti* females. Reported cumulative mortality of adult *Ae. aegypti* released in experimental houses with dry ATSB in Machala, Ecuador varied between 77-100% after 48 h exposure. Dry ATSBs stations that do not rely on chemical attractants or liquid sugar/toxic solutions seem to be advantageous in terms maintenance, price, and persistence.

Sugar utilization of container *Aedes* species in urbanized areas, and therefore the potential usefulness of ATSBs, seems to vary widely depending on location and degree of urbanization [29,30,31]. The use of sugar from plants by *Ae. aegypti* was investigated in two neighborhoods with different degrees of urbanization and availability of sugar sources in Mali. They found 39-40% sugar feeding in sugar-poor sites and 60-65% in sugar-rich sites [32]. They also showed effective control of the local *Ae. aegypti* population during 50 days after spraying the vegetation with ATSB with micro-encapsulated garlic oil. Revay et al. [33] found higher reductions of the *Ae. albopictus* populations in tire sites in Florida by foliar applications of ASTB and eugenol than by using bait stations. More research is required to develop efficient bait stations that would restrict access only to target species. Like other trapping approaches, there is a need to conduct area-wide, cluster randomized trials with entomological and epidemiological outcomes using the ASTB methodology.

Push (repel) - pull (attract/kill).—The basis for this mosquito control approach is to repel mosquitoes away from an area (push) and trap and eliminate pushed-away mosquitoes (pull). The expected benefits from this and other mass-trapping approaches are reducing both biting rate and mosquito abundance to prevent or control exposure to vector-borne pathogens. Recent studies explored the use of various types of traps and the human landing technique to assess protection of a push-pull semi-field evaluation using transfluthrin as the spatial repellent for *Ae. aegypti* [34,35]. Some relevant findings were that the push (repellent) aspect of the system had higher efficacy (protection against bites) than the combined push-pull aspect (repellent + traps) of the trials. They also found that trap efficiency markedly decreased in the presence of humans, which may affect how these types of trials are performed or evaluated with mosquito traps. Area-wide studies on controlling *Ae. aegypti* using the push-pull approach have not been reported so far.

Pull (attract/contaminate/infect) - push (fly away).—Devices attracting container-*Aedes* female mosquitoes are treated with an insect growth regulator (IGR) that adheres to female mosquitoes when they land on the contaminated surface, so that they transfer the chemical to other containers while ovipositing, to suppress immature mosquito development [36]. Thus, the purpose of auto-disseminating devices is not to readily kill the female mosquito but to use it to amplify suppression of mosquito production in nearby containers with water. Commonly, auto-dissemination devices are similar to ovitraps that attract gravid females. One study used an electromechanical trap to disseminate pyriproxyfen for the control of *Ae. aegypti* in Madeira, Portugal [37]. The most used IGR is pyriproxyfen, a juvenile hormone analog that interferes at extremely low dosages with immature development and metamorphosis, preventing the emergence of adult mosquitoes [36]. Accumulation of IGR in containers in time by repeated visits of contaminated female mosquitoes increases the effectiveness of mosquito suppression [38]. A recent review on the use of this technique concluded that it is a promising new approach and a valuable addition to the vector control toolbox [39]. Observed *Aedes* mortality in small field studies ranged 50-92% [38,40,41]. Neighborhood-level studies have shown mixed results varying from relatively ineffective *Aedes* population suppression [42,43] to highly effective control as measured by immature emergence suppression [40], reduced oviposition or adult mosquito abatement [44]. An additional effect of the exposure of *Aedes* to pyriproxyfen is reduced fertility and fecundity [45]. Autodissemination of pyriproxyfen has been combined in one device with spores of the entomopathogenic fungus *Beauveria bassiana*, to reduce the vectorial capacity and slowly kill the adult mosquito [46]. A field trial conducted at the neighborhood level in Florida, USA using these devices showed significant reductions in eggs and larvae in sentinel ovitraps, and a borderline, non-significant reduction of adult mosquitoes captured in electromechanical traps [47].

There are several aspects of this approach that may need more research, such as whether females visiting the traps could still bite people and transmit pathogens as opposed to directly killing the visiting females. A positive expected result of this approach is that contaminated females would be able to reach cryptic aquatic habitats that are not possible to locate or treat using other means, such as source reduction or larvicides. Because this approach depends on the number of contaminated adult mosquitoes visiting the devices, as the mosquito population goes down it is expected to lose effectiveness and perhaps reach a mosquito density threshold below which further suppression is not possible. It would be important to understand if such a theoretical mosquito density threshold is sufficient to prevent local outbreaks of arboviruses or if a combination of this approach along with other mosquito control measures can reduce the mosquito population to safe levels.

Conclusions

There is a growing number of studies aimed at controlling container-*Aedes* species by mass-trapping using a diversity of approaches to lure, capture and eliminate, or to use mosquitoes as means of disseminating control agents to abate its own population. A few mass-trapping non-randomized studies have shown that the density of *Ae. aegypti* can be kept at very low levels for several years and that people living in areas with mass trapping had significantly lower prevalence of arboviral antibodies [20]. Several novel mass-trapping approaches have shown promising results in laboratory and small field studies but there is a need to conduct larger studies, ideally using robust experimental designs with entomological and epidemiological outcomes. Similarly, studies on the cost-effectiveness of mass-trapping are needed to evaluate their feasibility and effectiveness. These needs also apply to other emerging *Ae. aegypti* control tools.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

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References and recommended Reading

Papers of particular interest, published within the period of review, have been highlighted as:

. of special interest

1. Adams LE, Martin SW, Lindsey NP, Lehman JA, Rivera A, Kolsin J, Landry K, Staples JE, Sharp TM, Paz-Bailey G, Fischer M. Epidemiology of dengue, chikungunya, and Zika virus disease in U.S. States and Territories, 2017. Am J Trop Med Hyg 2019, 101:884–890. doi: 10.4269/ajtmh.19-0309. [PubMed: 31436154]
2. Brown JE, McBride CS, Johnson P, Ritchie S, Paupy C, Bossin H, Lutomiah J, Fernandez-Salas I, Ponlawat A, Cornel AJ et al. Worldwide patterns of genetic differentiation imply multiple 'domestications' of *Aedes aegypti*, a major vector of human diseases. Proc Biol Sci 2011, 278:2446–2454. doi: 10.1098/rspb.2010.2469. [PubMed: 21227970]
3. Focks DA, Brenner RJ, Hayes J, Daniels E. Transmission thresholds for dengue in terms of *Aedes aegypti* pupae per person with discussion of their utility in source reduction efforts. Am J Trop Med Hyg 2000, 62:11–18. [PubMed: 10761719]
4. Barrera R 2016. Recomendaciones para la vigilancia de *Aedes aegypti*. Biomédica 2016, 36:454–462. [PubMed: 27869394]
5. Johnson BJ, Ritchie SA, Fonseca DM. The state of the art of lethal oviposition trap-based mass interventions for arboviral control. Insects 2017, 8:5. doi: 10.3390/insects8010005.
6. World Health Organization. (2018). Efficacy-testing of traps for control of Aedes spp. mosquito vectors. World Health Organization. URL: https://apps.who.int/iris/handle/10665/275801.
7. Fay RW, Eliason DA. A preferred oviposition site as a surveillance method for *Aedes aegypti*. Mosq News 1966, 26:531–535.
8. Acevedo V, Amador M, Barrera R. Improving the safety and acceptability of Autocidal Gravid Ovitraps (AGO Traps). J Am Mosq Control Assoc 2021, 37:61–67. doi: 10.2987/21-6996.1. [PubMed: 34184049]
9. Hapairai LK, Mysore K, James LD, Scheel ND, Realey JS, Sun L, Gerber LE, Feng RS, Romero-Severson E, Mohammed A, et al. Evaluation of large volume yeast interfering RNA lure-and-kill ovitraps for attraction and control of *Aedes* mosquitoes. Med Vet Entomol 2021, 35:361–370. doi: 10.1111/mve.12504.. [PubMed: 33377553] . The authors described laboratory and field experiments showing that inactivated yeast interfering RNA formulations that are specific for killing mosquito larvae were effective against larvae of *Aedes aegypti* and *Aedes albopictus*. They also demonstrated that the RNAi tablets were more attractive to ovipositing females of both species than water. These biorational larvicides are welcome additions to other effective organic lavicides that can be used in mass trapping to prevent the production of mosquitoes inside trap containers.
10. Chan KL, Ng SK, Tan KK. An autocidal ovitrap for the control and possible eradication of *Aedes aegypti*. South East Asian J Trop Med Public Health 1977, 8:56–62.
11. Ritchie SA, Long S, Smith G, Pyke A, Knox TB. Entomological investigations in a focus of dengue transmission in Cairns, Queensland, Australia, by using the sticky ovitraps. J Med Entomol 2004, 41:1–4. doi: 10.1603/0022-2585-41.1.1. [PubMed: 14989339]

12. Mackay AJ, Amador M, Barrera R. An improved autocidal gravid ovitrap for the control and surveillance of *Aedes aegypti*. Parasit Vectors 2013, 6:225. doi: 10.1186/1756-3305-6-225. [PubMed: 23919568]
13. Eiras AE, Buhagiar TS, Ritchie SA. Development of the gravid *Aedes* trap for the capture of adult female container-exploiting mosquitoes (Diptera: Culicidae). J Med Entomol 2014, 51:200–209. doi: 10.1603/me13104. [PubMed: 24605470]
14. Heringer L, Johnson BJ, Fikrig K, Oliveira BA, Silva RD, Townsend M, Barrera R, Eiras ÁE, Ritchie SA. Evaluation of alternative killing agents for *Aedes aegypti* (Diptera: Culicidae) in the Gravid *Aedes* Trap (GAT). J Med Entomol 2016, 53:873–879. doi: 10.1093/jme/tjw051. [PubMed: 27247350]
15. Barrera R, Amador M, Acevedo V, Beltran M, Muñoz JL. A comparison of mosquito densities, weather and infection rates of *Aedes aegypti* during the first epidemics of Chikungunya (2014) and Zika (2016) in areas with and without vector control in Puerto Rico. Med Vet Entomol 2019, 33:68–77. doi: 10.1111/mve.12338. [PubMed: 30225842]
16. Eiras AE, Resende MC, Acebal JL, Paixão KS. New cost-benefit of Brazilian technology for vector surveillance using trapping system. From Local to Global Impact of Mosquitoes. IntechOpen Book Series 2018. doi: 10.5772/intechopen.78781.
17. Barrera R, Harris A, Hemme RR, Felix G, Nazario N, Muñoz-Jordan JL, Rodriguez D, Miranda J, Soto E, Martinez S, Ryff K, Perez C, Acevedo V, Amador M, Waterman SH. Citywide control of *Aedes aegypti* (Diptera: Culicidae) during the 2016 Zika epidemic by integrating community awareness, education, source reduction, larvicides, and mass mosquito trapping. J Med Entomol 2019, 56:1033–1046. doi: 10.1093/jme/tjz009. [PubMed: 30753539]
18. Ong J, Chong CS, Yap G, Lee C, Abdul Razak MA, Chiang S, Ng LC. Gravitrap deployment for adult *Aedes aegypti* surveillance and its impact on dengue cases. PLoS Negl Trop Dis 2020, 14:e0008528. doi: 10.1371/journal.pntd.0008528. [PubMed: 32764763]
19. Juarez JG, Chaves LF, Garcia-Luna SM, Martin E, Badillo-Vargas I, Medeiros MCI, Hamer GL. Variable coverage in an Autocidal Gravid Ovitrap intervention impacts efficacy of *Aedes aegypti* control. J Appl Ecol 2021, 58:2075–2086. doi: 10.1111/1365-2664.13951. [PubMed: 34690360] . Non-insecticidal approaches to controlling *Ae. aegypti* are needed given the widespread prevalence of insecticide resistance in this important vector of arboviruses. The authors conducted cluster randomized crossover trials using sticky gravid traps placed at residences in south Texas. They found 77% suppression of the *Ae. aegypti* population when the number of traps per home was around 2.7, with loss of effectiveness with lower trap coverages. This investigation supports previous findings underscoring the importance of achieving high coverage of trapping devices. The issue of coverage of mosquito control is akin to virtually every pest management approach and should be calibrated before deploying large-scale control operations or studies.
20. Sharp TM, Lorenzi O, Torres-Velásquez B, Acevedo V, Pérez-Padilla J, Rivera A, Muñoz-Jordán J, Margolis HS, Waterman SH, Biggerstaff BJ, et al. Autocidal gravid ovitraps protect humans from chikungunya virus infection by reducing *Aedes aegypti* mosquito populations. PLoS Negl Trop Dis 2019, 25;13:e0007538. doi: 10.1371/journal.pntd.0007538.
21. Barrera R, Acevedo V, Felix GE, Hemme RR, Vazquez J, Munoz JL, Amador M. Impact of Autocidal Gravid Ovitraps on chikungunya virus incidence in *Aedes aegypti* (Diptera: Culicidae) in areas with and without traps. J Med Entomol 2017, 54:387–395. doi: 10.1093/jme/tjw187. [PubMed: 28031347]
22. Lega J, Brown HE, Barrera R. A 70% Reduction in mosquito populations does not require removal of 70% of mosquitoes. J Med Entomol 2020,57:1668–1670. doi: 10.1093/jme/tjaa066. [PubMed: 32300803]
23. Hemme RR, Smith EA, Felix G, White BJ, Diaz-Garcia MI, Rodriguez D, Ruiz-Valcarcel J, Acevedo V, Amador M, Barrera R. Multi-year mass-trapping with Autocidal Gravid Ovitraps has limited influence on insecticide susceptibility in *Aedes aegypti* (Diptera: Culicidae) from Puerto Rico. J Med Entomol 2022, 59:314–319. doi: 10.1093/jme/tjab162. [PubMed: 34536077]
24. Johnson BJ, Brosch D, Christiansen A, Wells E, Wells M, Bhandoola AF, Milne A, Garrison S, Fonseca DM. Neighbors help neighbors control urban mosquitoes. Sci Rep 2018, 8:15797. doi: 10.1038/s41598-018-34161-9. [PubMed: 30361483]

25. Xue RD, Ali A, Kline DL, Barnard DR. Field evaluation of boric acid- and fipronil-based bait stations against adult mosquitoes. J Am Mosq Control Assoc 2008, 24:415–418. doi: 10.2987/5683.1. [PubMed: 18939695]

26. Mysore K, Hapairai LK, Sun L, Li P, Wang CW, Scheel ND, Lesnik A, Igiede J, Scheel MP, Wei N, Severson DW, Duman-Scheel M. Characterization of a dual-action adulticidal and larvicidal interfering RNA pesticide targeting the Shaker gene of multiple disease vector mosquitoes. PLoS Negl Trop Dis 2020, 14:e0008479. doi: 10.1371/journal.pntd.0008479. [PubMed: 32687496]

27. Fikrig K, Johnson BJ, Fish D, Ritchie SA. Assessment of synthetic floral-based attractants and sugar baits to capture male and female *Aedes aegypti* (Diptera: Culicidae). Parasit Vectors 2017, 10:32. doi: 10.1186/s13071-016-1946-y. [PubMed: 28095875]

28. Sippy R, Rivera GE, Sanchez V, Heras F, Morejón B, Beltrán E, Hikida RS, López-Latorre MA, Aguirre A, Stewart-Ibarra AM et al. Ingested insecticide to control *Aedes aegypti*: developing a novel dried attractive toxic sugar bait device for intra-domiciliary control. Parasit Vectors 2020, 13:78. doi: 10.1186/s13071-020-3930-9. [PubMed: 32066486] . The authors reported laboratory and semi-field trials where *Ae. aegypti* was attracted by visual means to a black/white surface containing a dry mix of sugars and insecticide, and that landing mosquitoes were killed after probing and ingesting the toxic sugar bait. This is a novel development that merits further field investigations because the use of dry baits avoids dealing with chemical mosquito attractants and liquid formulations of toxic baits. The authors proposed the use of the dry attractive toxic sugar bait indoors for the control of *Ae. aegypti*.

29. Costero A, Attardo GM, Scott TW, Edman JD. An experimental study on the detection of fructose in *Aedes aegypti*. J Am Mosq Control Assoc 1998, 14:234–42. [PubMed: 9813818]

30. Qualls WA, Naranjo DP, Subía MA, Ramon G, Cevallos V, Grijalva I, Gómez E, Arheart KL, Fuller DO, Beier JC. Movement of *Aedes aegypti* following a sugar meal and its implication in the development of control strategies in Durán, Ecuador. J Vector Ecol 2016, 41:224–231. doi: 10.1111/jvec.12217. [PubMed: 27860016]

31. Olson MF, Garcia-Luna S, Juarez JG, Martin E, Harrington LC, Eubanks MD, Badillo-Vargas IE, Hamer GL. Sugar Feeding Patterns for *Aedes aegypti* and *Culex quinquefasciatus* (Diptera: Culicidae) Mosquitoes in South Texas. J Med Entomol 2020, 57(4):1111–1119. doi: 10.1093/jme/tjaa005. [PubMed: 32043525]

32. Sissoko F, Junnila A, Traore MM, Traore SF, Doumbia S, Dembele SM, Schlein Y, Traore AS, Gergely P, Xue RD et al. Frequent sugar feeding behavior by *Aedes aegypti* in Bamako, Mali makes them ideal candidates for control with attractive toxic sugar baits (ATSB). PLoS One 2019, 14:e0214170. doi: 10.1371/journal.pone.0214170. [PubMed: 31206547]

33. Revay EE, Müller GC, Qualls WA, Kline DL, Naranjo DP, Arheart KL, Kravchenko VD, Yefremova Z, Hausmann A, Beier JC et al. Control of *Aedes albopictus* with attractive toxic sugar baits (ATSB) and potential impact on non-target organisms in St. Augustine, Florida. Parasitol Res 2014, 3:73–79. doi: 10.1007/s00436-013-3628-4.

34. Tambwe MM, Moore SJ, Chilumba H, Swai JK, Moore JD, Stica C, Saddler A. Semi-field evaluation of freestanding transfluthrin passive emanators and the BG sentinel trap as a “push-pull control strategy” against *Aedes aegypti* mosquitoes. Parasit Vectors 2020, 13:392. doi: 10.1186/s13071-020-04263-3. [PubMed: 32736580]

35. Tambwe MM, Saddler A, Kibondo UA, Mashauri R, Kreppel KS, Govella NJ, Moore SJ. Semi-field evaluation of the exposure-free mosquito electrocuting trap and BG-Sentinel trap as an alternative to the human landing catch for measuring the efficacy of transfluthrin emanators against *Aedes aegypti*. Parasit Vectors 2021, 14:265. doi: 10.1186/s13071-021-04754-x. [PubMed: 34016149] . The protective efficacy from bites of *Ae. aegypti* of a spatial repellent device was evaluated using human bait landing catches, an electrocuting trap using a human as bait, or an electro-mechanical trap in a large outdoor enclosure. Their results showed similar catches of diverted mosquitoes away from the emanator when each trapping system was used separately (55-66% protection). However, when a second person was introduced in the cage, the highest captures were observed on human bait landing catches and in the electrocuting trap with a human as bait, with very low captures in electro-mechanical traps. They concluded that mosquitoes show a preference for humans over traps. This conclusion underscores the importance of the location of mosquito host-seeking traps in experimental or operational mosquito surveillance systems.

36. Itoh T, Kawada H, Abe A, Eshita Y, Rongsriyam Y, Igarashi A. Utilization of bloodfed females of *Aedes aegypti* as a vehicle for the transfer of the insect growth regulator pyriproxyfen to larval habitats. J Am Mosq Control Assoc 1994, 10:344–347. [PubMed: 7807075]
37. Seixas G, Paul REL, Pires B, Alves G, de Jesus A, Silva AC, Devine GJ, Sousa CA. An evaluation of efficacy of the auto-dissemination technique as a tool for *Aedes aegypti* control in Madeira, Portugal. Parasit Vectors 2019, 12:202. doi: 10.1186/s13071-019-3454-3. [PubMed: 31053095]
38. Devine GJ, Perea EZ, Killeen GF, Stancil JD, Clark SJ, Morrison AC. Using adult mosquitoes to transfer insecticides to *Aedes aegypti* larval habitats. Proc Natl Acad Sci U S A 2009, 106:11530–11534. doi: 10.1073/pnas.0901369106. [PubMed: 19561295]
39. Ngesom AMM, Greenhalgh D, Lasim AM, Sahani M, Hod R, Othman H. A review: autodissemination of pyriproxyfen as novel strategy to control dengue outbreaks. Pertanika J Sci Tech 2020, 28:1117–1140.
40. Abad-Franch F, Zamora-Perea E, Luz SL. Mosquito-disseminated insecticide for citywide vector control and its potential to block arbovirus epidemics: entomological observations and modeling results from Amazonian Brazil. PLoS Med 2017, 14:e1002213. doi: 10.1371/journal.pmed.1002213. [PubMed: 28095414]
41. Caputo B, Ienco A, Cianci D, Pombi M, Petrarca V, Baseggio A, Devine GJ, della Torre A. The "auto-dissemination" approach: a novel concept to fight *Aedes albopictus* in urban areas. PLoS Negl Trop Dis 2012, 6:e1793. doi: 10.1371/journal.pntd.0001793. [PubMed: 22953015]
42. Unlu I, Rochlin I, Suman DS, Wang Y, Chandel K, Gaugler R. Large-scale operational pyriproxyfen autodissemination deployment to suppress the immature Asian tiger mosquito (Diptera: Culicidae) opulations. J Med Entomol 2020, 57:1120–1130. doi: 10.1093/jme/tjaa011. [PubMed: 32006427]
43. Nazni WA, Teoh G, Nordin O, Hasbolah F, Othman S, Angamuthu C, Muhamed KA, Ali N, Muin A, Oman T et al. Field effectiveness of pyriproxyfen auto-dissemination trap against container breeding *Aedes* in high-rise condominiums. Southeast Asian J Trop Med Public Health 2020, 51:937–952.
44. Garcia KKS, Versiani HS, Araújo TO, Conceição JPA, Obara MT, Ramalho WM, Minuzzi-Souza TTC, Gomes GD, Vianna EN, Timbó RV et al. Measuring mosquito control: adult-mosquito catches vs egg-trap data as endpoints of a cluster-randomized controlled trial of mosquito-disseminated pyriproxyfen. Parasit Vectors 2020, 13:352. doi: 10.1186/s13071-020-04221-z. [PubMed: 32665032] . This investigation reports on one of the few cluster randomized trials performed so far on mass trapping to control *Aedes aegypti* and *Culex quinquefasciatus* using entomological endpoints. They employed auto dissemination devices with pyriproxyfen and measured changes in adult and egg mosquito populations. Adult abundance of *Ae. aegypti* was reduced in 60% and of *Cx. quinquefasciatus* in 55.5%. However, they did not observe significant reductions in the mosquito egg population, concluding that changes in egg metrics did not reflect the overall 60% reduction in the adult populations. They proposed that monitoring adult mosquito populations provides a more realistic picture of intervention effects and that there is a need to conduct broader-scale trials with epidemiological endpoints.
45. Ponlawat A, Fansiri T, Kurusarttra S, Pongsiri A, McCardle PW, Evans BP, Richardson JH. Development and evaluation of a pyriproxyfen-treated device to control the dengue vector, *Aedes aegypti* (L.) (Diptera:Culicidae). Southeast Asian J Trop Med Public Health 2013, 44:167–78. [PubMed: 23691625]
46. Snetselaar J, Andriessen R, Suer RA, Osinga AJ, Knols BG, Farenhorst M. Development and evaluation of a novel contamination device that targets multiple life-stages of *Aedes aegypti*. Parasit Vectors 2014, 7:200. doi: 10.1186/1756-3305-7-200. [PubMed: 24766772]
47. Buckner EA, Williams KF, Ramirez S, Darrisaw C, Carrillo JM, Latham MD, Lesser CR. A Field Efficacy Evaluation of In2Care Mosquito Traps in Comparison with Routine Integrated Vector Management at Reducing *Aedes aegypti*. J Am Mosq Control Assoc 2021, 37:242–249. doi: 10.2987/21-7038. [PubMed: 34817613]

Table.

Examples of recent trials on trapping systems for the control of container *Aedes* spp.

Trapping system	Species	Type of study	Location	Type of mosquito control	Results	Reference
Pull (attract/kill)	*Aedes aegypti*	Cluster randomized step-wedge, implemented during a Zika epidemic.	Most residential and commercial building in Caguas city, Puerto Rico.	Mass-trapping with 3 sticky gravid traps/home in 60-80% of homes, and limited community education, larviciding and source reduction.	Achieved steady control below mosquito density threshold (2-3 female *Ae. aegypti*/trap/week. No Zika virus present in *Ae. aegypti* when 60-80% of the houses were treated.	[17]
		Controlled before – after intervention.	34 treatment sites in Singapore.	One sticky gravid trap per 20 households in apartment buildings.	36% reduction in dengue cases.	[18]
		Cluster randomized crossover.	2 low and 2 middle-income communities in Hildalgo and Cameron counties, Texas.	Mass-trapping with sticky gravid traps.	77% reduction of mosquitoes when trap coverage was 2.7 traps/house.	[19]
		Semi-field trials in experimental houses.	Machala, Ecuador.	Dry attractive toxic sugar bait.	54-98% and 77.3-100% mortality of adult *Ae. aegypti* when exposed for 24 and 48 h, respectively. Most mortality occurred within 48 h.	[28]
Push (repel) - pull (attract/kill)	*Ae. aegypti*	Semi-field randomized block design.	Bagamoyo, Tanzania.	Push: 2 Freestanding transfluthrin passive emanator (FTPE) and Pull: 1 Electromechanical trap / block.	Protection efficacy: 61.2% FTPE alone, 2.1% Trap alone, and 64.5% FTPE + Trap.	[34]
Pull (attract/ contaminate/ infect) - push (fly away)	*Ae.* albopictus	Controlled before – after intervention.	3-4 mosquito hot-spot city-blocks in control and interventions areas, Mercer county, New Jersey.	26-28 Autodissemination stations / treatment block.	No significant reductions in egg or adult populations.	[42]
	Ae. aegypti / *Ae. albopictus*	Before – after intervention..	3 dengue hotspot high-rise buildings in Selangor, Malaysia	356 – 552 autodissemination stations.	Ovitrap prevalence was 44.8% before intervention and 53.4% after intervention.	[43]
	Ae. aegypti / *Culex quinquefasciatus*	Cluster-randomized controlled trial.	2 neighborhoods in Federal District, Brazil.	1 autodissemination station per 10 houses. Routine ultra-low volume spraying of insecticides in both neighborhoods.	Reductions of 60.0% in *Ae. aegypti* and 55.5% is adult Cx. *quinquefasciatus* mosquitoes. No measurable effect on *Ae. aegypti* eggs.	[44]
	Ae. aegypti	Comparison of Autodissemination devices with integrated vector management (source reduction, larviciding, adulticiding).	2 suburban neighborhoods in Manatee County, Florida.	15 autodissemination devices/ha and entomopathogenic fungus.	Significantly fewer eggs and larvae were observed in the sites with autodissemination stations.	[47]