Design features of a proposed insecticidal sugar trap for biting midges

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Summary
Insecticidal sugar baits for mosquitoes and houseflies have proven efficacy to reduce insect populations and consequently, disease transmission rates. The new insecticidal sugar trap (IST) is designed specifically for controlling biting midge disease vector populations around livestock and near larval habitats. The trap operates by combining light-emitting diode (LED) technology with insecticidal sugar baits. The positive photo attraction of *Culicoides* elicited by the LEDs, draws the insects to the insecticidal sugar bait, which can be made from various commercial insecticide formulations (pyrethroids, neonicotinoids, etc.) or naturally derived formulations (boric acid, garlic oil, etc.) lethal to *Culicoides*. Insecticidal sugar trap advantages include: customizable LED lights, they can be used with several different oral insecticides that have different modes of action to help combat the evolution of pesticide resistance, screening on the trap reduces non-target insect feeding (for example bees and butterflies), targets males and females of the species because both must feed on sugar, and low energy LEDs and a solar panel reduce trap maintenance to refilling sugar baits, rather than replacing batteries. This article discusses key components of an IST, which increase the traps effectiveness for biting midge control.

Nuova trappola insetticida per Culicoides *spp.*

Parole chiave
Culicoides sonorensis,
Diodo a emissione luminosa (LED),
Esca di zucchero,
Insetticida,
Misure di controllo per *Culicoides*,
Sorveglianza,
Trappola luminosa,
Vettore di malattia.

Riassunto
È stato dimostrato che le esche a base di zucchero e insetticida disegnate per zanzare e mosche riducono la popolazione di insetti e, di conseguenza, il tasso di trasmissione delle malattie. La nuova trappola a base di zucchero e insetticida (IST) descritta in questo studio è stata disegnata in modo specifico per controllare le popolazioni di *Culicoides* possibili vettori di malattie. Questa trappola posizionata negli allevamenti di bestiame e nelle vicinanze di ambienti larvali agisce combinando un diodo a emissione luminosa (LED) con esche a base di zucchero e insetticida. I Culicoidi sono attratti dal LED e quindi entrano in contatto con l'esca. Quest'ultima può essere prodotta con diverse formulazioni commerciali (piretroidi, neonicotinoidi, ecc.) oppure può derivare da formulazioni naturali (acido borico, olio e aglio, ecc.) letali per i *Culicoides*. Tra i vantaggi di una trappola con zucchero e insetticida c'è la possibilità di modulare le emissioni luminose del LED e di impiegare diverse varietà di insetticidi orali con principi di azione differenti e quindi contrastare l'evoluzione di eventuali resistenze ai pesticidi. Questo tipo di trappola, inoltre, è selettiva per *Culicoides* spp. di entrambi i generi, maschile e femminile, in quanto entrambi si nutrono di zucchero. Infine, i LED a basso valore energetico e i pannelli solari riducono la manutenzione della trappola al solo rifornimento di esche, evitando il ricambio costante di batterie. Questo articolo descrive le componenti chiave di una IST ideata per migliorare l'efficacia delle trappole nel controllo dei *Culicoides* spp..

Introduction

Although habitat manipulation for biting midge source reduction is the best method to reduce insect populations (Painter 1927, Jones 1977, Carpenter *et al.* 2008), it can be expensive and logistically difficult. Few chemicals are effective for treatment of larval biting midge (*Culicoides*) habitat. An alternative method is insecticidal sugar traps (IST), these attract male and female emerging biting midges seeking a carbohydrate meal, provided that an appropriate attractant and insecticide are used.

For many years, insecticidal sugar baits (ISB's) have been used on cockroaches (Lofgren and Burden 1958, Gore and Schal 2004) and houseflies (Butler *et al.* 2007) with proven efficacy to reduce insect populations. Recently, insecticidal baits have been registered (Terminix Allclear®, Universal Pest Solutions, Dallas, Texas, USA) for the control of mosquitoes. Attractive Toxic Sugar Baits (ATSB™), or insecticide treated baits (Snyder *et al.* 2016b), are deployed in the environment as a spray on non-flowering vegetation. Mosquitoes feed on the sugar droplets and are orally exposed to the insecticides. The Allclear® product has an olfactory stimulant made from fruit concentrate to increase insect attraction to the sugar drops because sugar solution has no odour. To reduce the impact of spraying synthetic insecticides (such as pyrethroids and imidicloprid) into the environment, less environmentally damaging compounds have been identified. These include boric acid, methyl eugenol, and microencapsulated garlic, however, these are less effective for *Culicoides sonorensis* (Personal observation) as for mosquitoes.

Sugar is not attractive alone; therefore the sugar bait needs to be used in conjunction with an olfactory or visual attractant to draw midges to the bait. Some ultraviolet wavelengths of light are attractive to sugar feeding *Culicoides sonorensis* (Snyder *et al.* 2016a). The lights emitting diode (LEDs) may be tuned to a specific ultraviolet coloured light feeding cue in *C. sonorensis* (Cohnstaedt *et al.* 2008). Insecticidal sugar baits and attractive lights can be combined to make an environmentally friendly insecticidal sugar bait trap that can be deployed around larval habitats. This article discusses key components of an ISB trap to increase its effectiveness for biting midges in addition to the advantages of the ISB trap.

Materials and methods

While designing the insecticidal sugar bait trap, several key features were identified to improve its effectiveness and functionality. These features include a solar panel, battery, LED light source, on/off photo-switch, mesh (400 hpi) to exclude non-target insects, reservoir for the insecticidal sugar bait solution, and collapsible design for easy storage, and shipping (Figure 1). These features were either part of or incorporated into 2 styles of lawn lights (Solar pathway light 009 11 1042; Mini-solar pathway light) from Target® (Manhattan, KS, USA). The lawn lights were modified by replacing the white LED bulb with an ultraviolet LED, which emitted the desired spectra attractive to the *Culicoides* of interest. A rigid wire mesh replaced the clear plastic viewing window as a mechanical exclusionary device for non-target insects and provided physical support for the top, which contained the LED, electronics, and power source. A reservoir was made from 1-inch PVC plastic piping with 2, 1-inch, end caps. The reservoir was designed to hold enough sucrose/pesticide mixture for a week of use, approximately 50 ml. A cotton wick (10 cm in length), which extended from the bottom of the reservoir to its top and ended just beneath the LED bulb, was used to draw out the insecticidal sugar solution for midge consumption. This provided the maximal surface area for feeding.

Figure 1. *Insecticidal sugar trap.* The bait station is a modified lawn light equipped with an ultraviolet light emitting diode (LED) and an insecticidal sugar bait.

The cost of the trap is less than $6.00, as described in Table I.

Table I. *Price table for Insecticidal Sugar Trap.*

Item	Price ($)
Solar Pathway light	3/unit
Reservoir end caps (x2)	0.68/unit
Reservoir pipe (2 in)	0.02/inch
Cotton wick	0.05/wick
UV LED bulb	0.05/bulb
Wire Mesh	1.50/trap
Total	$5.98

Results and discussion

The resulting insecticidal sugar bait trap is a compact structure for durability and ease of assembly in the field. The LED and electronics are rugged and have low energy requirements and therefore, do not need replacing or continual maintenance. The sugar reservoir is easy to manufacture and robust enough to handle a large variety of insecticide formulations. Additional key light trap features improve the ISB trap effectiveness and field deployment for both male and female adult biting midges. Traps of this nature are important because they can serve dual roles of pathogen surveillance and insect control, which are essential for effective entomological surveillance (Cohnstaedt *et al.* 2011).

The solar panel is an important feature that recharges the battery during the day and eliminates the need to manually remove and change batteries. This feature allows the IST to be deployed for long periods of time with minimal maintenance to the electronics. The panel does not have to be large because the LED is highly efficient and uses little power.

The battery can be a small 1.5-volt AAA battery (800-1,200 mAmp hours) or AA battery (1,500-2,000 mAmp hours). It will be recharged daily by the solar panel and at night will provide current to the LED. Typically the current for the LED is 20-25 mAmp/hour, giving the batteries a charge lasting ~ 40-60 hours or 75-100 hours, respectively. Selecting the battery type is important because AA and AAA rechargeable batteries are much cheaper than other batteries, such as the 2/3 AA or 2/3 AAA.

The LED light was a low energy light source based on solid-state electronics, which made for a durable and robust electronic package unlikely to break. Insecticidal sugar traps use colour as a photo-attractant to draw sugar feeding midges to the trap and the sugar solution acted as a phago-stimulant for ingesting the insecticides. An ultraviolet spectrum was the most attractive wavelength for *C. sonorensis* (Snyder *et al.* 2016a) but other colours, or combinations of colours, may be used (Cohnstaedt *et al.* 2008). Furthermore, the colour of light may be changed to attract other species of insects for additional control. There is a history of using lights to attract chironomid midges (Ali *et al.* 1984, Ali *et al.* 1986). The photo-attractant choice is very important because the light is only attractive at short ranges (< 5 meters). Therefore, colour and intensity are important and must be balanced with cost and battery limitations.

The mesh exclusion screen prevents larger non-target insects from feeding by physically impeding their access to the bait. Currently, ATSB™ is used to control mosquito populations by dispersing them on non-flowering vegetation. This technique may work for *Culicoides* population control; however, dispersing insecticides into the environment will always have non-target impacts. The ISB trap equipped with exclusion mesh permits small *Culicoides* to access the bait but physically prevents larger bees, butterflies, moths, ants, etc. from feeding.

The sucrose/insecticide bait reservoir contains the phago-stimulant (sugar, honey, etc.) and the insecticide insects will imbibe. The phago-stimulant is needed to attract insects to the wick and for them to continue feeding until repletion and is typically a 10% sucrose solution by weight. The insecticide can be made from technical grade pesticides or commercial formulations. This type of insecticidal sugar bait was tested; oral application pesticides showed to be extremely toxic to biting midges and resulted in up to 100% mortality (Snyder *et al.* 2016b). The active ingredient can be rotated to expose the target insects to other pesticides with alternative modes of action. Therefore, if pyrethroids are used on the adult insects in an aerial spray program, the ISB traps may be baited with macrocyclic lactones or neonicotinoids. This will help reduce the evolution of pesticide resistance. The sugar baits will target both male and female insects because both must feed on sugar.

Helpful but non-essential characteristics of 'sugar trap for biting midges' include: a mounting stake, used to keep the trap close to the ground but out of the substrate. The stake is easier than hanging traps from objects and allows for a greater density of traps in a perimeter such as around a pond or animal enclosure; the on/off and photo switch are useful because they allow the traps to be shipped and turned on only when needed, conserving battery power. However, the on/off feature is non-essential after the trap is deployed. The photo-switch turns on the light when the ambient light dims, thus permitting to save the battery life. The collapsible nature of the trap allows for the trap to be fully packable and each component including the stake and reservoir nest within the housing of the trap.

This prevents the components from being lost or damaged in transit.

The principle limitation of the IST is the photo-attractive component. The low energy bulb produces only a small amount of light, which limits the attractive distance. Stronger light intensity will increase the attractive range but will come at a cost in battery life. To this end, other light sources around the trap, which create light pollution, will reduce the effectiveness of the trap. Subsequently, reducing other light sources around the emergence area or animal pens will increase trap effectiveness. Optimizing the light to the biting midge species of interest will also increase photo-attraction and UV wavelength lights are recommended (Snyder *et al.* 2016a). Another limitation is the evaporation of the insecticide solution. The reservoirs will need to be refilled weekly to prevent them from drying. Fungus and bacteria will also grow on the wicks and inhibit feeding or in the reservoir, if not treated with antifungals and antibiotics, which will not inhibit sugar feeding by the insects. Honey based baits have natural antibiotic and antifungal properties, which may be preferable. Similarly, wicks may be clogged with dust. The exposed end may be cut and the wick pulled higher to expose a clean feeding surface. Lastly, some insecticides are not soluble in water or do not pass through the wicks. This will prevent the pesticide from moving with the sucrose solution as the insect feeds.

Culicoides may be present in huge numbers and when they feed on the insecticidal sugar baits mortality is likely. Therefore the trap can kill as many midges as can feed on the wicks until the wicks dry. If these situations occur, the trap manager must check and refill the wicks more frequently. This is a benefit to other traps that collect insects and may become blocked, subsequently, reducing effectiveness such as a mosquito magnet (Woodstream Corp., Litiz, Pennsylvania, USA). The trap can be attractive and effective on large numbers of midges because they need sugar meals to fly. The trap is likely most effective at emergence sites because newly emerged male and female biting midges will be looking for sugar meals before seeking blood meals. Snyder and colleagues (Snyder *et al.* 2016b) found that even in the presence of natural non-insecticidal sugar sources the biting midges will feed on the insecticidal sugar baits. Furthermore, the UV light source is attractive to both sugar fed and non-sugar fed biting midges seeking a blood meal (Snyder *et al.* 2016a), although the IST is likely not attractive to blood fed insects. If the UV lights of the trap are placed in a line around the perimeter of an animal enclosure, they can theoretically reduce the number of midges seeking blood meals from enclosed animals. This method should be combined with other methods such as an insecticidal barrier of at least 2 meters high to increase effectiveness.

Insecticidal sugar traps are effective and useful tools, when habitat manipulation is not possible to reduce larval biting midge habitat. The IST can be deployed as a barrier of traps around a perimeter to protect farm animals or located at larval breeding sites to kill newly emerged adults. The traps have several benefits and can easily be manufactured. They should be incorporated as part of an insect control program and not as a stand-alone control measure. If disease detection is required, they may be coupled with genetic material preservation cards for pathogen detection and, therefore, the IST can be a dual function trap for disease surveillance and insect population control.

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