7-1-2021

Development and first evaluation of an attractant impregnated adhesive tape against blood-sucking flies

Junwei J. Zhu

Gwang-Hyun Roh

Yosuke Asamoto

Jen-Chieh Liu

Alexander Lehmann

See next page for additional authors

Authors
Junwei J. Zhu, Gwang-Hyun Roh, Yosuke Asamoto, Jen-Chieh Liu, Alexander Lehmann, Kyle Harrison, David B. Taylor, and Hironao Otake

Insect Science

Insect Science (2022) 29, 603–612, DOI 10.1111/1744-7917.12952

ORIGINAL ARTICLE

Development and first evaluation of an attractant impregnated adhesive tape against blood-sucking flies

Junwei J. Zhu[1], Gwang-Hyun Roh[1,2,3], Yosuke Asamoto[4], Kujtim Bizati[4], Jen-Chieh Liu[4], Alexander Lehmann[1,5], Kyle Harrison[1], David B. Taylor[1] and Hironao Otake[4]

[1]*Agroecosystem Management Research Unit, US Department of Agriculture, Agricultural Research Service, Lincoln, Nebraska, USA;* [2]*US Pacific Basin Agricultural Research Center, US Department of Agriculture, Agricultural Research Service, Hilo, Hawaii, USA;* [3]*Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee, USA;* [4]*Nitto Inc., Teaneck, New Jersey, USA and* [5]*Department of Entomology, University of Nebraska, Lincoln, Nebraska, USA*

Abstract Stable flies are one of the most important arthropod pests of livestock that reduce cattle weight gain and milk production leading to annual economic losses in excess of $2 billion to the US cattle industry. The host-seeking behavior is primarily mediated by associated odors from stable fly larval development environments and host animals. The present paper reports the development and evaluation of attractant-impregnated adhesive tapes to reduce stable fly attacks on cattle. Laboratory bioassays showed that only m-cresol impregnated adhesive tapes caught significantly more stable flies (16 ± 1) than the control tape without attractant added (7 ± 1), with a 77% fly recapture rate. Attractant-impregnated adhesive tapes deployed in cattle feedlots showed significant impacts in reducing fly population, with a total of one million stable flies captured over a period of three weeks (mean catches from 57 596 to 102 088 stable flies per trap per week). It further relieved cattle stress with a significant reduction of biting fly avoidance behavior, (6 ± 0.4 cows observed with tail wagging in control vs. 3 ± 0.4 from the trap-deployed). The efficacy of the developed tapes lasted up to 1-week longevity, although 70% of m-cresol was released starting from the second day. The m-cresol impregnated adhesive tape provided an 80% reduction in cattle stress due to stable fly attack. This is the first report of a technology developed by integrating an attractant compound into an adhesive material on a plastic film with demonstrated effectiveness in trapping biting flies that attack livestock animals.

Key words cattle stress reduction; mass trapping; m-cresol-impregnated adhesive tapes; *Stomoxys calcitrans*

Introduction

Arthropod ectoparasites are endemic to the cattle industry, causing billions of dollars in annual losses due to animal stress. Blood-sucking insects including biting flies induce costly stress responses resulting in skin irritation, blood loss, loss of grazing time in favor of avoidance behavior, and eventually reduced weight gain rate (Pickens & Miller, 1980). Stable flies (*Stomoxys calcitrans* L.) are considered not only as one of the most serious hematophagous pests of livestock, and also causing troubles to wildlife and humans across the temperate and tropical regions of the world. In the United States, stable flies are responsible for economic losses in cattle producers approximating $2 billion per year (Taylor *et al.*, 2012). It has been reported that painful bites further reduce

Correspondence: Junwei J. Zhu, Agroecosystem Management Research Unit, Agricultural Research Service, US Department of Agriculture, Lincoln, NE 68583, USA. Email: jerry.zhu@usda.gov

cattle productivity by disrupting feeding, reproductive, and resting behaviors as well as inducing physiological stress responses with increased heart rate, respiration rate, and body temperature (Schwinghammer *et al*., 1987; Dougherty *et al*., 1993). Stable flies can transmit several diseases in the Old World and South America, such as trypanosomiasis, besnoitiosis, and lumpy skin disease (Capripox) (Baldachino *et al*., 2013; Sharif *et al*., 2019). Some of these diseases have expanded their ranges in recent years and have the potential to invade United States (Blone *et al*., 2020). One of the most important invasive livestock diseases in Europe, the African swine fever, has been reported being transmitted by stable flies either through their bite or via ingestion of infected flies by livestock (Mellor *et al*., 1987; Olsen *et al*., 2018).

In recent years, stable flies have become serious hematophagous pests of livestock animals throughout the world. Several regions have reported devastating outbreaks of stable flies developing in decomposing crop residues. These regions include Australia, Central, and South America (Herrero *et al*., 1991; Koller *et al*., 2009; Dominghetti *et al*., 2015; Solórzano *et al*., 2015). Cattle exposed to stable flies, gain less weight, and utilize feed less efficiently than do fly-free cattle in the United States (Berry *et al*., 1983; Campbell *et al*., 1989). During the last 5 years, frequent outbreaks of stable fly infestation in Costa Rica has reached warning levels of average 1000 stable flies attacking per animal (Herrero *et al*., 1991), as the economic threshold is estimated at 15–20 flies per animal (Berry *et al*., 1983; Campbell *et al*., 1989). In addition to their impact on livestock, stable flies can also affect wildlife and disrupt human recreational activities (Hansens, 1951; Fosbrooke, 1963; Newson, 1977; Merrit & Newson, 1978; Hogsette *et al*., 1987; Urban abd Broce, 1998; Elkan *et al*., 2009). However, there have very few effective methods being developed in control of stable fly infestation, except traditional insecticide applications.

Most of the dipteran insect pests primarily rely on olfactory and visual stimuli for their host seeking behavior. Several studies have shown that various attractant odorants are used by stable flies to locate host animals and oviposition sites (Cilek, 1999; Kristensen & Sommer, 2000; IAEA, 2003; Birkett *et al*., 2004; Tangtrakulwanich *et al*., 2015; Jelvez *et al*., 2017). Four potential behavior-modifying attractant compounds were recently identified from cattle primary manure and urine waste and some larval substrates, which have been demonstrated attractive to adult stable flies. Various trapping systems have been used to monitor and reduce stable fly population density. Alsynite trap is a traditional stable fly traps made of translucent fiberglass panels applied with glue developed by Williams and later being further improved by Broce (Williams, 1973; Broce, 1988). More recently, the Nzi trap developed for controlling savanna tsetse fly (*Glossina* spp.) was investigated for its efficacy in monitoring and controlling stable fly populations, which were shown to be also attractive to stable flies (Mihok, 2002). Several recent studies have further shown that some volatile attractants and visual effects can be added to improve stable fly catches up to 2–5 times more trapping efficiency (Kristensen & Sommer, 2000; IAEA, 2003; Birkett *et al*., 2004; Foil & Younger, 2006; Hogsette *et al*., 2008; Tangtrakulwanich *et al*., 2015; Zhu *et al*., 2015). However, the attractant-added supplement also brings extra costs in labor and materials for trapping system assembling.

The present study reports our first developed attractant-impregnated adhesive tapes for enhanced trapping efficacy in stress reduction of cattle attacked by blood-sucking biting flies. Laboratory and field evaluations of these proto-type attractant-impregnated adhesive tapes were conducted indoors and also in cattle feedlots. By observing the differences in defensive behavioral responses between cattle in treated (with trapping) and untreated (without), we compared their effectiveness in cattle stress reduction achieved by fewer attacks by biting flies via an advanced mass-trapping technique. The outcomes from this study will provide useful info in future development for control strategy via a push–pull strategy in integrated stable fly management.

Materials and methods

Insects

Stable flies used for laboratory tests were obtained from colonies maintained at the United States Department of Agriculture, Agricultural Research Service, Agroecosystem Management Research Unit (Lincoln, NE, USA). The flies were maintained at 23 ± 2°C with variable humidity (30%–50% RH) and a 12 L : 12 D photoperiod. Adults were fed with citrated bovine blood (3.7 g sodium citrate/liter) from a blood-soaked absorbent pad (Stayfree®, McNeil-PPC Inc., Skillman, NJ, USA) placed on top of the screened cage.

Attractant impregnated adhesive tape making

Stable fly attractant-impregnated adhesive tape was manufactured by the R&D Department of Nitto Inc. (NJ, USA). Four different attractant compounds were chosen to develop in patented impregnated adhesive tapes for testing their trapping efficacy, respectively. The selected testing attractant compounds were 1-octen-3-ol, phenol, p-cresol, and m-cresol. These compounds were reported from a study as attractant volatiles identified in cattle manure slush attractive to adult stable flies (Tangtrakulwanich *et al*., 2015). Synthetic standards of these compounds were purchased from Sigma-Aldrich with >95% purity (St. Louis, MO, USA).

The prototype, attractant-impregnated adhesive tape was comprised of three layers (Fig. S1): A plastic paper release cover, an acrylic adhesive which was composed of the rosin ester (tackifier) and one of four synthetic attractants (10%), and a white polyethylene terephthalate-based backing layer. Tape layers had a thickness of 2, 4 (100 μm), and 2 mm, respectively (Bizati *et al*., 2020).

Laboratory cage studies for behavioral activity

Screen cages (64 × 60 × 64 cm) were used as the staging area for evaluating behavioral activity of the attractant impregnated adhesive tapes to adult stable flies under laboratory conditions. Each cage contained one attractant-impregnated adhesive tape (4 × 5 cm) and one control adhesive tape without attractant. The total weight of each attractant compound was about 9.2 mg per sq. cm^2 with approx. 92 mg adhesive glue. The adhesive thickness was 4 mil (100 μm). The tape was 2 mil (white Backing) + 4 mil (adhesive) + 2 mil (paper release) = 8 mil. Each tape strip was hung 10 cm below the cage ceiling and 40 cm apart from each other. A total of 30 adult stable flies (≤5-day-old and normally fed) were released into the cage. The number of stable flies caught on strips on each tape was checked 1, 2, 3, 24, 48, and 72 hr after exposures. Each comparison was replicated at least five times. Treatment locations (cage positions in the room) were randomized throughout the laboratory space (3 × 8 m) to avoid the homogeneity of treatment effect (light intensity and window effect) and the strip position (treated and control) inside the cage was also alternated between tests. Bioassays were carried under the normal indoor light exposure (4 fluorescent lights at the ceiling), with a photo period of 12-h dark and 12-h light. During the bioassay, only water was provided inside each cage.

Dose response tests compared different concentrations of the final selected most active adhesive tapes impregnated with 1%, 3%, 6%, or 10% of m-cresol loaded were further conducted under room temperature with the same bioassay as described above.

Field efficacy trials of m-cresol impregnated adhesive tapes in capturing stable flies

Field trials were conducted from late July to earlier August in 2018. Trials were carried out in a 2500-cow cattle feedlot owned by the University of Nebraska Animal Research Center in Mead, Nebraska (USA). The cattle farm habitat was mixed, with large pasture lands and confinement-type feedlots (5 × 40 m). Cows and calves (Red and Black Angus) were maintained in dirt lots with access to shade structures, water, hay, and corn-based feed. Cows were randomly organized into 15–20 cow herds released in each pen. There were a total of 12 pens of animals in the experimental site. We first conducted a preliminary field test to compare the differences in trap catches of stable flies between the insect tapes with impregnated attractant compound (10% of m-cresol) and ones without (control) followed the methods described in Zhu *et al*. (2015). The results showed that the attractant-impregnated tapes caught average 17 ± 2 stable flies per trap per day, relative to 10 ± 2 flies from the control ($t = 2.06$, $P = 0.011$, $P < 0.05$). Therefore, 10% m-cresol impregnated insect tapes were used for a late comparison tests of stable fly population and animal stress reduction field trial described below.

A total of 12 rolls of m-cresol-impregnated (10% wt) adhesive tapes were placed in mown grassy areas next to the cattle pens. Strips of adhesive tapes (with an exposed surface of 0.66 × 3.66 m) were kept taut under windy conditions by securing it with plastic spring clips to a long carriage bolt threaded through locking holes by two 1.5-m height of PVC pipes (see Fig. S2). The tape strips were oriented with the side containing the m-cresol-impregnated adhesive surface facing to the cattle pens. The distance between each tested adhesive tape was about 5 m apart. The number of stable flies captured was photographically recorded per check (every other day). When tape surfaces became saturated with insects and debris, they were replaced with new surfaces of the adhesive tape. The trapping efficacy trials were repeated three times with three replicates, and each lasted one week (tape catches were checked at least three times per week).

Cattle defensive behavior observation

Animal behavior was observed and recorded before and during the trials from cows located in pens with attractant-impregnated adhesive tapes deployed (treatment) and those with no traps placed (control). The pens with treatments and control were separated at least 50 m apart. These tests were repeated three times during a

3-week period ($N = 3$). Videos were recorded using Canon DVD camcorders (DC210 with 35× optical zoom, Cannon Ltd., Japan) with the approval permit issued by the University of Nebraska IACUC committee (UNL4872-001). Recordings of cow's behavior in the treated and control pens usually lasted about 1 h from 11 am to 12 pm (i.e., when stable flies were most active) on Monday, Wednesday, and Friday every week.

We used a focal animal sampling method reported by Colgan for this study (Colgan, 1978). Among the four previously identified cow defensive behaviors, we selected the tail-wagging rate as an indicator of cattle stress caused by biting flies (Todd, 1964; Okumura, 1977; Harris *et al*., 1987; Warnes & Finlayson, 1987). The number of cows observed wagging their tails and the number of cows with tail-wagging observed within a herd of cows were analyzed from the recorded video taken during the trials. We selected a 3-min time frame of recordings, and randomly selected five recordings from the 1-h recording to obtain defensive behavioral measures for comparisons between cows in the treated and control pens.

Longevity of m-cresol impregnated adhesive tapes

The longevity of the m-cresol-impregnated (10%) adhesive tape across time was further evaluated in a grass field in the feedlot. Fresh adhesive tape strips were wrapped outside of the USDA-style stable fly corrugated panel traps and preaged for 1, 2, 3, 4, 5, and 6 days under Midwest summer field conditions (Zhu *et al*., 2015). Traps with different aged adhesive tapes were placed ∼10 m apart from each other at a height of ∼50 cm above ground level. Five replicates were spaced ∼30 m apart and randomly distributed throughout the field. Traps were monitored daily and caught stable flies were removed with forceps after each check. Aged traps were deployed in mid of August for three consecutive days.

Volatile collection and analyses of m-cresol absorption on SPME fibers

Solid-phase microextraction (SPME) method was used for comparing the relative release of m-cresol from adhesive tapes to understand relationships between the longevity of the tape efficacy and attractant compound release. A piece of the strip (4 × 5 cm) was cut from the above tested different aged adhesive tapes placed in the field and placed inside an aluminum foil box for transport to the laboratory for odor release-collection tests. For each aged groups of adhesive tapes, five replicates were sampled across time. Atmospheric concentrations of m-cresol absorbed onto the SPME fibers (100 μm polydimethylsiloxane (PDMS) fiber, Supelco, St. Louis, MO, USA) were measured. The SPME fibers were preconditioned in a gas chromatography (GC) inlet held at 250°C for 30 min before collecting. SPME holders were placed 2 cm next to each cut tape standing vertically on a clip base in the center of a 100 mL glass beaker. SPME fibers were exposed next to the surface of a tape for a 15-min time period of each sample. Relative absorptions of m-cresol onto SPME fibers were analyzed in an Agilent GC system equipped with an FFAP column (30 m × 0.25 mm i.d., J & W Scientific, Agilent). Helium was used as the carrier gas, and the flow rate maintained at 1.5 mL/min. Samples were injected under the splitless mode. The temperature program for the GC analysis was set at 50°C for 3 min, rising by 10°C/min to 280°C. Quantities of m-cresol were assessed by the autointegrated method of peak areas. We used a relative % of the absorbed amount of m-cresol onto the SPME fiber detected on the first day (100) to those of the rest of the aged adhesive tapes.

Data analyses

For comparisons between the recapture rates of stable flies responded to different attractant impregnated adhesive tapes inside the cage, we used the Student's *t*-test. Student's *t*-tests were also used to compare the cows' tail-wagging behavioral response comparison between the treatment and control. ANOVA tests followed by PLSD were used for comparisons of captures among different doses of the attractant-impregnated tapes, the efficacy of different ages of tapes, and m-cresol absorption rates of adhesive tapes.

Results and discussion

Semiochemical-based pest management technology has been used to monitor and control insect pests in worldwide agricultural, forestry, and public health sectors. In the past half-century, tremendous advances have been achieved in developing semiochemical-based control strategies, especially in the use of attractants. One of the most common applications is attractant-based mass trapping for pest population suppression, which covers millions of acres of agricultural crops worldwide (Steiner, 1952; Howse *et al*., 1998; Baker & Heath, 2004). More than 20 million attractant lures are produced for monitoring and mass trapping annually (Witzgall *et al*., 2010). Volatiles isolated from cattle rumen digesta (i.e., dimethyl trisulfide, butanoic acid, p-cresol, skatole, and especially 1-octen-3-ol) are attractive to stable

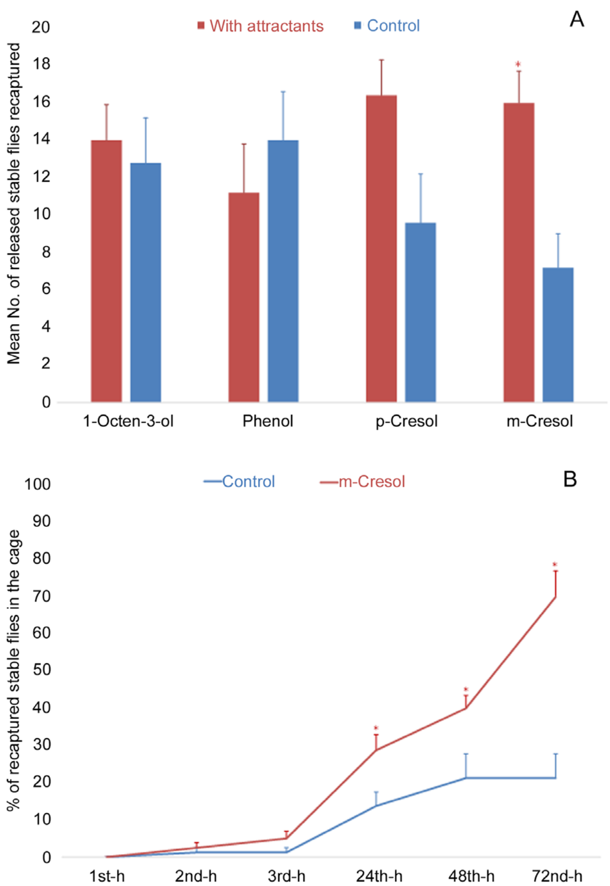

Fig. 1 Recapture efficacy tests of stable fly attractant-impregnated adhesive tapes conducted under laboratory conditions. (A) Mean numbers of stable fly recaptures on adhesive tapes of 4 different-attractant attractants. (B) Mean % of recapture rates of m-cresol impregnated adhesive tapes at different times. Stars on tops of bars and lines indicate significant differences between the treatments and controls (t-test, $P < 0.05$).

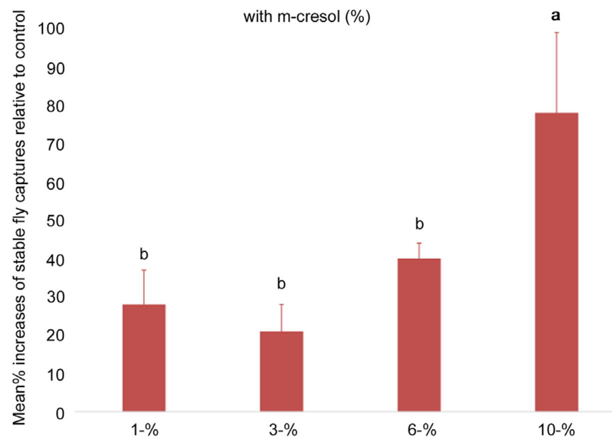

Fig. 2 Mean numbers of recaptured stable flies from m-cresol impregnated adhesive tapes at four different doses tested (ANOVA, df = 3,16; $F = 4.16$, $P < 0.05$). Different letters on top of bars indicate significant differences.

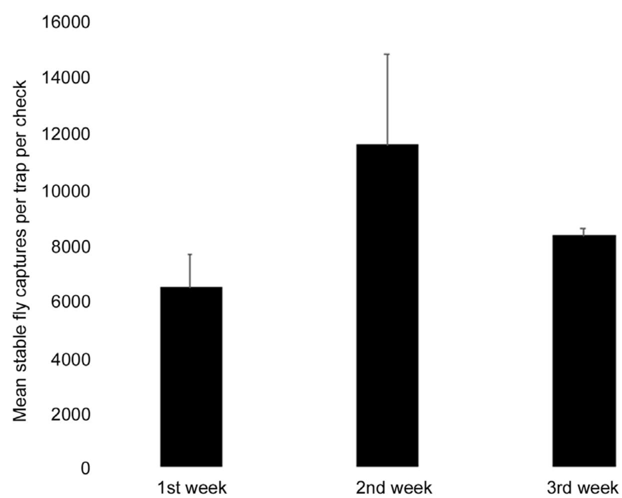

Fig. 3 Mean number of stable flies caught from m-cresol impregnated adhesive tapes per trap per check in cattle feedlot during a 3-week period ($F = 1.10$, df = 11,93; $P > 0.05$).

flies (Jeanbourquin & Guerin, 2007). Tangtrakulwanich *et al.* (2015) have characterized several additional attractant compounds from cattle manure slurry (i.e., phenol, p-cresol, and m-cresol) attractive to stable flies. Recently in Brazil and Australia, stable fly outbreaks have been associated with crop residues and waste products, including pineapple, vegetables, sugarcane, and several of the above-mentioned compounds were also presented in these plant-based substrates (Herrero *et al.*, 1991; Koller *et al.*, 2009; Dominghetti *et al.*, 2015; Tangtrakulwanich *et al.*, 2015). Various trap designs including alsynite traps, Nzi traps, white panel traps, and black-blue cloth baited with several biting fly attractants, CO_2 malaise, and cattle urine have demonstrated their enhanced attraction to stable flies (Cilek, 1999; Mihok *et al.*, 2007; Mihok & Mulye, 2010; Tangtrakulwanich *et al.*, 2015; Tunnakundacha *et al.*, 2017). However, all of trapping systems were consisted of a trapping device with an individual dispenser containing the attractant compound that needs to be added additionally. This obviously increases the costs not only in labor, as well as materials, which is not very practical for animal producers.

We evaluated the catch efficacy of stable flies by adhesive tapes that were impregnated with four selected attractant compounds including 1-octen-3-ol, phenol, p-cresol, and m-cresol at a 10% concentration under the laboratory conditions. The results showed only m-cresol

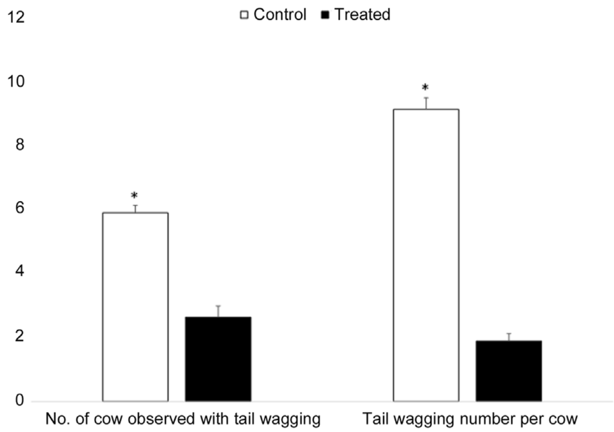

Fig. 4 Comparisons of cattle defensive behaviors between the treated and control pens (Left: mean number of cows observed with tail wagging. Right: mean tail wagging numbers of cows between the treated and control). Stars on top of bars indicate significant differences between the comparisons (t-test, $P < 0.05$).

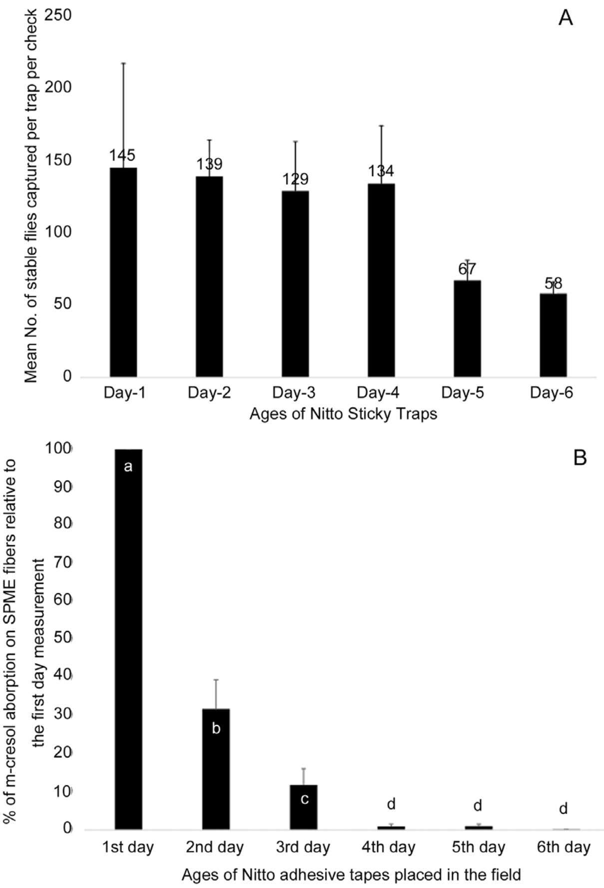

Fig. 5 Efficacies in stable fly attraction from different ages of m-cresol impregnated adhesive tapes in feedlot (A, ANOVA test, $F = 2.0$, df $= 5{,}18$; $P > 0.05$); m-Cresol absorption rates from SPME fibers analyzed from Day 1 to Day 6 of m-cresol impregnated adhesive tapes (B). Different letters within the bars indicate significant differences among ages (ANOVA, $F = 3.1$, df $= 5{,}12$; $P < 0.0001$).

contained adhesive tapes caught significantly more stable flies relative to those with no attractant added (Fig. 1A, $t = 2.2$, $p = 0.04$), although the other three attractant compounds tested were previously shown to induce stable fly host-seeking behavior, no significant increases were demonstrated relative to the controls ($p = 0.06$–0.42). The discrepancy could be explained due to differences in doses released from the adhesive tapes compared to different lure types used (rubber septa, cotton rolls, etc.) from previous studies, which further investigation may be necessary. Furthermore, Tangtrakulwanich *et al.* (2015) demonstrated that 1-octen-3-ol acting as a strong attractant to stable flies from both laboratory assays and field trapping tests, with similar results have also been reported from various other hematophagous insects, including stable flies (Hall *et al.*, 1984; French & Kline, 1989; Gibson & Torr, 1999). However, while conducted in the triple cages, Alzogaray & Carlson (2000) found that 1-octen-3-ol tested was not attractive to stable flies, which it might be due to different experimental designs and lure concentrations used. Another interesting finding shows that significant differences in stable fly recapture rates with m-cresol impregnated adhesive tapes in cage studies start to show after 24 hr (Fig. 1B, $t = 2.35$–2.38, $p < 0.05$), with further increases >50% after 72 hr. This may suggest a behavioral inhibition due to a relatively higher concentrated m-cresol released from the tapes at earlier stages. We further conducted a dose-response test on efficacy of adhesive tapes with 1%, 3%, 6%–10% amounts of m-cresol to investigate whether a lower dose would lead to a similar level of recapture as that of 10%. The results revealed that significant more stable flies were caught from those with the highest attractant dose impregnated only (Fig. 2, df $= 3{,}16$, $F = 4.15$, $p = 0.02$, $p < 0.05$). Therefore, 10% of m-cresol was selected as an optimal dose for manufacturing the prototype attractant-impregnated adhesive tapes for field trials.

Further field trials carried out in the University of Nebraska feedlots with m-cresol impregnated adhesive tapes placed outside of the cattle pens caught almost one million of stable flies (979 580) during a 3-week trial period of the summer in 2018. Mean total catches from each trap ranged from 57 596 to 102 088 stable flies, but no significant differences in mean captures per trap were found during the tested period (Fig. 3, df $= 2{,}6$; F

= 0.84, $P > 0.05$). The attractant-baited mass-trapping technology has been successfully implemented in reducing pest population densities (El-Sayed *et al.*, 2006). Rugg (1982) reported a significant reduction in stable fly number (79% in 7.5 days) via the deployment of Williams traps with clear adhesive surfaces in an Australian zoo. Alsynite traps or white panel traps baited with attractants have been demonstrated with significant increases in stable fly captures compared to those without attractants (Tangtrakulwanich *et al.*, 2015; Zhu *et al.*, 2015). However, the extra labor and costs in trap assembling, bait making (e.g., rubber septum, plastic tube, sachet, or other forms of dispensers), and additional sticky glue materials needed make it inefficient in practical use. The m-cresol-impregnated adhesive tapes developed in the present study is not only a novel approach to overcome these shortcomings, it is also the first time for a trapping device to combine attractant compounds together with glue materials together in mass trapping technology development.

Estienne *et al.* (1991) reported that steers exposed to over 10 stable flies displayed behavioral changes (including rapid tail wagging, panniculus reflex, and head shaking). All of these behavioral changes are considered major defense strategies against parasitism (Poulin, 1995; Agnew *et al.*, 2000). Animals fight against ectoparasites by flicking ears, wagging tail, stamping foot, shaking the head and body, sneezing, and biting parasites (Bergman, 1917; Hart, 1994). In this study, we found out significantly higher numbers of cattle observed with tail-wagging in the control pen (~6 cows in a 12-cow herd) versus those from the pen deployed with the attractant impregnated adhesive tapes (~2 cows in a 15-cow herd) (Fig. 4, $t = 0.003$, $P < 0.05$), with increases in tail wagging frequencies from cattle in those pens with no adhesive tapes deployed outside (9.2 ± 0.4 in the control pen versus 1.9 ± 0.2 from the treated pen). Cattle engaged in significantly higher rates of defensive behaviors (an average of four to five times more tail-wagging observed, $t = 0.0001$, $P < 0.05$). Although tail-wagging is ineffective for repelling stable flies, it remains the simplest method for quantifying and monitoring pest intensity and animal stress levels (Mullens *et al.*, 2006). An average of 60%–80% of reduction in cattle defensive responses was observed from animals in pens with adhesive tapes deployed, compared to those without.

The attractiveness of different aged m-cresol impregnated adhesive tapes was further evaluated under hot summer US Midwest conditions. We found no significant differences in stable fly catches from adhesive tapes aged from 1 to 6 days old (Fig. 5A; df = 5,12; $F = 1.01$, $P > 0.05$). However, SPME absorption rates of m-cresol analyzed from different aged adhesive tapes differed significantly. (Fig. 5B; df = 5,12; $F = 3.1$, $P < 0.05$). These results suggest a fast release of the attractant compound from the adhesive tape in just 24 h, which implies that more work needs to be improved with a slower and more stable release of the attractant compound in future development. Furthermore, loss of stickiness after 7 days under heat exposure needs to be investigated by selecting more suitable and long-lasting glue materials. Our first evaluation trial with a displayed distance between each attractant-impregnated adhesive tape at 5 m showed no significant differences in trap catches of stable flies, we indicated at least no interaction caused due to this relative short distance deployed. However, more studies are needed to explore whether a great distance would result a similar effectiveness, or not.

In conclusion, the present study is the first attempt for a development of combining the stable fly attractant compound together with a glue material for an insect trapping system, although this concept is not new as patent disclosures about aerosol foam containing both insect bait composition and a toxicant for crawling insect control were published in the 1970–1980s (Hagarty, 1989) and a Spider Web large white sticky trap was developed for controlling house flies was reported (Kaufman *et al.*, 2005). The approach of developing a stable fly attractant impregnated adhesive tape would dramatically reduce the cost for deploying trapping systems in large numbers, by saving material and labor costs for a practical control program that will benefit pest control professionals and customers. If this technology is proven to be effective, it may have broad applications in various environments against other economically important agricultural pests. However, the results from this proto type of adhesive tapes reveal that it is still in its earlier stage of development, with further improvements are much needed. In addition, the cost for recycling sticky plastic forms and its potential environmental pollution should also be considered, and seek for self-degradable materials to replace it.

Acknowledgments

We express our deep gratitude to Brad Voelker and Dennis Berkebile for their technical help with this study. Special thanks to several student helpers for their contributions to our stable fly colony. The ENREC staff and University of Nebraska-Lincoln, especially the cow/calf unit, assisted with aspects of these studies and provided access to their facilities. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture. USDA is an equal opportunity provider and employer.

Disclosure

The authors declare that they have no conflict of interest.

References

Agnew, P., Koella, J.C. and Michalakis, Y. (2000) Host life history responses to parasitism. *Microbes and Infection*, 2, 891–896.

Alzogaray, R.A. and Carlson, D.A. (2000) Evaluation of *Stomoxys calcitrans* (Diptera: Muscidae) behavioral response to human and related odors in a triple cage olfactometer with insect traps. *Journal of Medical Entomology*, 37, 308–315.

Baker, T.C. and Heath, J.J. (2004) Pheromones—function and use in insect control. *Molecular Insect Science* (Vol. 6) (eds. L.I. Gilbert, K. Iatro & S.S. Gill), pp. 407–460. Elsevier.

Baldacchino, F., Muenworn, V. and Desquesnes, M. (2013) Transmission of pathogens by *Stomoxys* flies (Diptera, Muscidae): a review. *Parasite*, 20, 1–13.

Bergman, A.M. (1917) Om renens oestrider. *Entomologisk Tidsskrift*, 38, 113–146.

Berry, I.L., Stage, D.A. and Campbell, J.B. (1983) Populations and economic impacts of stable flies on cattle. *Transactions-American Society of Agricultural Engineers*, 26, 873–877.

Birkett, M.A., Agelopoulos, N. and Jensen, K.M.V. (2004) The role of volatile semiochemicals in mediating host location and selection by nuisance and disease-transmitting cattle flies. *Medical and Veterinary Entomology*, 18, 313–322.

Bizati, K., Asamoto, Y. and Zhu, J.J. (2020) *Insect Tape Trap*. World Intellectual Property Organization. (WO2020087055).

Blone, S., Franzke, K. and Beer, M. (2020) African swine fever—a review of current knowledge. *Virus Research*, 287, 198099.

Broce, A. (1988) An improved alsynite trap for stable flies (Diptera: Muscidae). *Journal of Medical Entomology*, 25, 406–409.

Campbell, J.B. and Berry, I.L. (1989) Economic threshold for stable flies on confined livestock, pp. 18–22. In Petersen J.J., Greene G.L. (eds.), *Current status of stable fly (Diptera: Muscidae) research*. Miscellaneous Publications of Entomological Society of America Vol. 74. Publisher is The Entomological Society of America.

Cilek, J.E. (1999) Evaluation of various substances to increase adult *Stomoxys calcitrans* (Diptera: Muscidae) collections on alsynite cylinder traps in north Florida. *Journal of Medical Entomology*, 36, 605–609.

Colgan, P.W. (1978) *Quantitative Ethology*. Wiley-Interscience, New York.

Dominghetti, T.F.S., de Barros, A.T.M. and Cançado, P.H.D. (2015) *Stomoxys calcitrans* (Diptera: Muscidae) outbreaks: current situation and future outlook with emphasis on Brazil [Surtos por *Stomoxys calcitrans* (Diptera: Muscidae) no Brasil: Situação atual e perspectivas]. *Revista brasileira de parasitologia veterinaria*, 24, 387–395.

Dougherty, C.T., Knapp, F.W. and Burrus, P.B. (1993) Face flies (*Musca autumnalis* De Feer) and the behavior of grazing beef cattle. *Applied Animal Behavioral Science*, 35, 313–326.

Elkan, P.W., Parnell, R. and Smith, J.L.D. (2009) A die-off of large ungulates following a *Stomoxys* biting fly out-break in lowland forest, northern Republic of Congo. *African Journal of Ecology*, 47, 528–536.

El-Sayed, A.M., Suckling, D.M. and Wearing, C.H. (2006) Potential of mass trapping for a long-term pest management and eradication of invasive species. *Journal of Economic Entomology*, 99, 1550–1564.

Estienne, M.J., Knapp, F.W. and Boling, J.A. (1991) Physiological and nutritional responses of beef steers exposed to stable flies (Diptera: Muscidae). *Journal of Economic Entomology*, 84, 1262–1271.

Fiol, L.D. and Younger, C.D. (2006) Development of treated targets for controlling stable flies (Diptera: Muscidae). *Veterinary Parasitology*, 137, 311–315.

Fosbrooke, H. (1963) The *Stomoxys* plague in Ngorongoro 1962. *East African Wildlife Journal*, 1, 124–126.

French, F.E. and Kline, D.L. (1989) 1-Octen-3-ol, an effective attractant for Tabanidae (Diptera). *Journal of Medical Entomology*, 26, 459–461.

Gibson, G. and Torr, S.J. (1999) Visual and olfactory responses of haematophagous Diptera to host stimuli. *Medical and Veterinary Entomology*, 13, 2–23.

Hagarty, J.D. (1989) Aerosol foam bait insecticide. *US Patent 4*, 889,710.

Hall, D.R., Beevor, P.S. and Cork, A. (1984) 1-Octen-3-ol, a potent olfactory stimulant and attractant for tsetse isolated from cattle odours. *Insect Science and Its Application*, 5, 335–339.

Hansens, E.J. (1951) The stable fly and its effect on seashore recreational areas in New Jersey. *Journal of Economic Entomology*, 44, 482–487.

Harris, J.A., Hillerton, J.E. and Morant, S.V. (1987) Effect on milk production of controlling muscid flies, and reducing fly avoidance behaviour by the use of fenvalerate ear tags during the dry period. *Journa of Dairy Science*, 54, 165–171.

Hart, B.L. (1994) Behavioural defence against parasites: interaction with parasite invasiveness. *Parasitology*, 109, 139–151.

Herrero, M.V., Montes, L. and Hernández, R. (1991) Abundancia relativa de *Stomoxys calcitrans* (L.) (Diptera: Muscidae) en seis localidades del Pacífico Sur de Costa Rica. *Revista de Biología Tropical*, 39, 309–310.

Hogsette, J.A., Ruff, J.P. and Jones, C.J. (1987) Stable fly biology and control in northwest Florida. *Journal of Agricultural Entomology*, 4, 1–11.

Hogsette, J.A., Nalli, A. and Foil, L.D. (2008) Evaluation of different insecticides and fabric types for development of treated targets for stable fly (Diptera: Muscidae) control. *Journal of Economic Entomology*, 101, 1034–1038.

Howse, P.E., Stevens, I.D.R. and Jones, O.T. (1998) *Insect Pheromones and Their Use in Pest Management*. Chapman and Hall, London.

International Atomic Energy Agency (IAEA). (2003) *Improved attractants for enhancing tsetse fly suppression: final report of a coordinated research project 1996–2002*. IAEA-TECDOC-1373 FAO/IAEA. IAEA, Vienna, Austria.

Jeanbourquin, P. and Guerin, P.M. (2007) Sensory and behavioural responses of the stable fly *Stomoxys calcitrans* to rumen volatiles. *Medical and Veterinary Entomology*, 21, 217–224.

Jelvez-Serra, N.S., Fonseca-Goulart, H. and Zhu, J.J. (2017) Identification of stable fly attractant compounds from vinasse, a sugarcane ethanol distillation byproduct. *Medical and Veterinary Entomology*, 31, 381–391.

Kaufman, P.E., Rutz, D.A. and Frisch, S. (2005) Large sticky traps for capturing house flies and stable flies in dairy greenhouse facilities. *Journal of Dairy Science*, 88, 176–181.

Kristensen, P.K. and Sommer, C. (2000) Ammonia and 1-octen-3ol as attractants for *Haematopota pluvialis*, *Hybomitra expollicata* (Diptera: Tabanidae) and Morellia spp. (Diptera: Muscidae). *Journal of Medical Entomology*, 37, 984–985.

Koller, W., Catto, J.B. and Graciolli, G. (2009) Surtos da mosca-dos-estábulos, *Stomoxys calcitrans*, em Mato Grosso do Sul: novo problema para as cadeias produtivas da carne e sucroalcooleira? *Documentos*, 175, Embrapa Gado de Corte, Campo Grande, MS, Brazil, pp. 31.

Mellor, P.S., Kitching, R.P. and Wilkinson, P.J. (1987) Mechanical transmission of capripoxvirus and African swine fever virus by *Stomoxys calcitrans*. *Revista brasileira de parasitologia veterinaria*, 43, 109–112.

Merritt, R.W. and Newson, H.D. (1978) Ecology and management of arthropod populations in recreational lands. *Perspectives in Urban Entomology* (eds. G.W. Frankie & C.S. Koehler), pp. 125–162. Academic Press Inc., New York, NY.

Mihok, S. (2002) The development of a multipurpose trap (the Nzi) for tsetse and other biting flies. *Bulletin of Entomological Research*, 92, 385–403.

Mihok, S., Carlson, D.A. and Ndegwa, P.N. (2007) Tsetse and other biting fly responses to Nzi traps baited with octenol, phenols and acetone. *Medical and Veterinary Entomology*, 21, 70–84.

Mihok, S. and Mulye, H. (2010) Responses of tabanids to Nzi traps baited with octenol, cow urine and phenols in Canada. *Medical and Veterinary Entomology*, 24, 266–272.

Mullens, B.A., Lii, K.S. and Mao, Y. (2006) Behavioural responses of dairy cattle to the stable fly, *Stomoxys calcitrans*, in an open field environment. *Medical and Veterinary Entomology*, 20, 122–137.

Newson, H.D. (1977) Arthropod problems in recreational areas. *Annual Review of Entomology*, 22, 333–353.

Okumura, T. (1977) The relationship of attacking fly abundance to behavioral responses of grazing cattle. *Japanese Journal of Applied Entomology and Zoology*, 21, 119–122.

Olesen, A.S., Hansen, M.F. and Rasmussen, T.B. (2018) Survival and localization of African swine fever virus in stable flies (*Stomoxys calcitrans*) after feeding on viremic blood using a membrane feeder. *Veterinary Microbiology*, 222, 25–29.

Pickens, L.G. and Miller, R.W. (1980) Biology and control of the face fly, *Musca Autumnalis* (Diptera: Muscidae). *Journal of Medical Entomology*, 17, 195–210.

Poulin, R. (1995) Adaptive changes in the behaviour of parasitized animals: a critical review. *Intational Journal Parasitology*, 25, 1371–1383.

Rugg, D. (1982) Effectiveness of Williams traps in reducing the numbers of stable flies (Diptera: Muscidae). *Journal of Economic Entomology*, 75, 857–859.

Schwinghammer, K.A., Knapp, F.W. and Boling, J.A. (1987) Physiological and nutritional response of beef steers to combined infestations of horn fly and stable fly (Diptera: Muscidae). *Journal of Economic Entomology*, 80, 120–125.

Sharif, S., Jacquiet, P. and Prevot, F. (2019) *Stomoxys calcitrans*, mechanical vector of virulent *Besnoitia besnoiti* from chronically infected cattle to susceptible rabbit. *Medical and Veterinary Entomology*, 33, 247–255.

Solórzano, J.A., Gilles, J. and Taylor, D.B. (2015) Biology and trapping of stable flies (Diptera: Muscidae) developing in pineapple residues (*Ananas comosus*) in Costa Rica. *Journal of Insect Science*, 15, 145–152.

Steiner, L.F. (1952) Methyl eugenol as an attractant for oriental fruit fly. *Journal of Economic Entomology*, 45, 241–248.

Tangtrakulwanich, K., Albuquerque, T.A. and Zhu, J.J. (2015) Behavioural responses of stable flies to cattle manure slurry associated odourants. *Medical and Veterinary Entomology*, 29, 82–87.

Tunnakundacha, S., Desquesnes, M. and Masmeatathip, R. (2017) Comparison of Vavoua, Malaise and Nzi traps with and without attractants for trapping of *Stomoxys* spp. (Diptera: Muscidae) and tabanids (Diptera: Tabanidae) on cattle farms. *Agriculture and Natural Research*, 51, 319–323.

Taylor, D.B., Moon, R.D. and Mark, D.R. (2012) Economic impact of stable flies (Diptera: Muscidae) on cattle production. *Journal of Medical Entomology*, 49, 198–209.

Todd, D.H. (1964) The biting fly *Stomoxys calcitrans* (L.) in dairy herds in New Zealand. *New Zealand Journal of Agricultural Research*, 7, 60–79.

Urban, J.E. and Broce, A.B. (1998) Flies and their bacterial loads in greyhound kennels in Kansas. *Current Microbiology*, 36, 164–170.

Warnes, M.L. and Finlayson, L.H. (1987) Effect of host behavior on host preference in *Stomoxys calcitrans*. *Medical and Veterinary Entomology*, 1, 53–57.

Williams, D.F. (1973) Sticky traps for sampling populations of *Stomoxys calcitrans*. *Journal of Economic Entomology*, 66, 1274–1280.

Witzgall, P., Kirsch, P. and Cork, A. (2010) Sex pheromones and their impact on pest management. *Journal of Chemical Ecology*, 36, 80–100.

Zhu, J.J., Zhang, Q. and Taylor, D.B. (2015) Visual and olfactory enhancement of stable fly trapping. *Pest Management Science*, 72, 1765–1771.

Manuscript received March 31, 2021
Final version received June 25, 2021
Accepted July 1, 2021

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Fig. S1. The schematic diagram of the developed attractant-impregnated adhesive stable fly tapes.

Fig. S2. m-Cresol impregnated adhesive tapes placed near a cattle feedlot (a yellow framed insert showed caught stable flies on the surface).