Biology and trapping of stable flies (Diptera, Muscidae) developing in pineapple residues (Ananas comosus) in Costa Rica

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Stable flies (Stomoxys calcitrans (L.), Diptera: Muscidae) are important pests of livestock worldwide with heavy economic impact (Kunz et al. 1991, Foil and Hogsett 1994, Taylor and Berkebile 2006). Annual losses in the United States have been estimated to exceed $2 billion (Taylor et al. 2012). This pest reproduces in decomposing organic matter including crop residues and animal manure. Adults require multiple blood meals to complete sexual maturation and ovarian development (Anderson 1978, Axtell 1986). Outbreaks of stable flies affecting cattle in Costa Rica were first observed in 1987 (Herrero et al. 1989, 1991) in pineapple (Ananas comosus (L.) Merrill) producing regions of the country. Populations of this pest have increased in the last 15 yr, mainly on dairies and farms near pineapple fields in the northern and Caribbean coastal regions of the country. Infestations in excess of 700 flies per animal are not uncommon (J.-A.S., unpublished data). The accepted economic threshold for stable flies is 5 per front leg (Campbell and Berry 1989), which is equivalent to 14 flies per animal (Berry et al. 1983). High infestations cause stress, which manifests defensive behavior and significant production losses (Taylor et al. 2012). Tropical conditions in Costa Rica with high temperatures and humidity shorten the life cycle of stable flies to 15–27 d (Lysyk 1998, Taylor and Berkebile 2011, Vargas and Solórzano 2015). The number of stable fly outbreaks has increased significantly in recent years with 230 reported in 2012 (Servicio Nacional de Salud Animal [SENASA] 2012).

Since the introduction of the pineapple variety MD-2 (“Golden” or “Sweet yellow”), acreage dedicated to pineapple production in Costa Rica has increased 4-fold, from ≈8,000 ha in 2001 to >45,000 in 2008 (Secretaría Ejecutiva de Planificación Agropecuaria [SEPSA] 2009). MD-2 plants are larger and more succulent than other commercial varieties of pineapple. In Costa Rica, pineapples are grown with a 1.5–2-yr crop cycle. The first crop of fruit is harvested approximately 1 yr after planting. A second is harvested 6 mo later. After the second harvest, plants are chopped and incorporated into the soil in preparation for replanting. The chopped plant residues, ≈230 tons/ha, combined with the warm, humid climate, and high precipitation make an excellent substrate for the development of stable fly larvae.

Pineapple producers in Costa Rica are mandated to control stable flies developing in their fields and adult trapping is widely used. White plastic bags with a brushed on adhesive are a primary tool. Traps are mounted on wooden stakes and placed every 10–20 m surrounding fields with fresh chopped pineapple residues and in surrounding pastures (Solórzano et al. 2013). While these traps collect large numbers of flies, their efficacy in reducing the intensity of the stable fly outbreaks remains questionable. The traps are not considered to be environmental friendly and efficacy decreases quickly with time. During the rainy season, traps must be serviced twice a week. Finally, they are of little use for monitoring fly populations because removal of insects from the traps for sexing and identification is very difficult.

Since 1970s, various types of traps have been developed for the study and control of stable flies. Classical examples are sticky traps using Alysynite such as the Williams (1973) and Broce (1988) traps. Meiffert et al. (1978) and Rugg (1982) evaluated these traps for stable fly control. More recently, blue fabric traps (Vavoua and F3 trap) initially designed for tse-tse fly (Glossina spp.) have been evaluated for
Stomoxys spp. (Gilles et al. 2007). In parts of Africa, they are being used for the control of diverse species of Stomoxys (Holloway and Phelps 1991, Mihok et al. 1995). Gilles et al. (2005) collected up to 1,250 stomoxyines per day in Vavoua traps.

In this study, we compare five different types of traps using a Latin square design to assess their efficacy for capturing stable flies and usefulness as monitoring tools to increase our understanding of their biology in Costa Rica.

Materials and Methods

Study Site. The study was conducted on a PINDECO, Del Monte Co., plantation with MD-2 pineapples near Pital, San Carlos, Costa Rica.

Fig. 1. Traps. (A) Vavoua, (B) Nzi, (C) Model H, (D) Ngu, and (E) white sticky.
Rica (10.454 N, 84.265 W). The site has an annual rainfall of 2,450 mm, red (Ultisol) soils, and is classified as tropical wet forest (Holdridge 1967). The study was conducted in February and March 2013. A 300 by 6 m strip of 2 yr-old pineapple was chopped with a Seppi Midiforst Mdt 150 at 5,000 revolutions per minute pulled by a John Deere 150 HP tractor at 0.5 km/h on 2 February 2013, 2 d before the setup of traps.

Climate Record. An automated weather station (Davis Vantage Pro, Vernon Hills, IL) was placed near the study site. Daily data with readings every 30 min for precipitation, relative humidity, temperature, sunshine (solar radiation), and wind speed and direction were recorded. Degree-days (DD10) were calculated from daily maximum-minimum temperatures using sine-wave integration (Allen 1976) with a threshold of 10°C (Lysyk 1993).

Traps. Efficacy of four models of blue-black polyester and polyethylene fabric traps, Vavoua (Laveissière and Grébaut 1990), Nzi (Mihok 2002), H (Kappmeier 2000), and Ngu (Brightwell et al. 1987, 1991) obtained from Vestergaard Frandsen S.A. (Lausanne, Switzerland), was compared with that of standard white sticky traps for trapping stable flies (Fig. 1). Fabric traps were fitted with transparent plastic 2-liter bottles for collection chambers. Flies collected in the two collection chambers of the model H trap were combined for analysis. White sticky traps were made from white plastic bags 0.80 by 0.95 m high, coated with Zapicol adhesive (Zapi, San Jose, Costa Rica) diluted with gasoline, placed with the bottom 10 cm above the ground and supported by two wooden stakes (Fig. 1E). Stable flies collected in the fabric traps were sexed, but flies collected on the white sticky traps could not be removed for sexing because of the strength of the adhesive.

Experimental Design and Statistical Analysis. A Latin Square design with daily rotation of traps among sites was used. Traps were set in a row 300 m long, ~50 m between trap sites. Flies were collected and traps relocated daily at 8 a.m. A complete rotation of traps through sites was completed each week for four consecutive weekly blocks. Daily trap catches were evaluated with General Mixed Linear Models (Proc GLIMMIX, SAS 2012) using a log transformation and negative binomial distribution. Differences between LSMeans were determined with Tukey’s adjustment for multiple comparisons ($\alpha = 0.05$ for all comparisons). Sex ratio was analyzed with logistic regression. For those collections with 0 for either sex, one of each sex was added to the observed values. Block was considered a random variable.

Results

In total, 6,777 stable flies were collected in five traps over the 20 trapping days of this study (Fig. 2). Temperature ranged from 17.1 to 32.6°C with an average of 23.7°C and relative humidity was 75–98%. During the first 3 wk, precipitation was low, in the 4th week daily

![Fig. 2](http://jinsectscience.oxfordjournals.org/) Summary of stable fly collections and weather conditions during study period. Stable flies are total daily collections of the five traps combined. Temperatures (°C) are daily average and range. Precipitation is daily total in mm.

<table>
<thead>
<tr>
<th>Trap</th>
<th>Catch/day</th>
<th>95% CI</th>
<th>%♂</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>White sticky</td>
<td>140a</td>
<td>113–173</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nzi</td>
<td>57b</td>
<td>46–71</td>
<td>73a</td>
<td>70–75</td>
</tr>
<tr>
<td>Vavoua</td>
<td>44bc</td>
<td>35–55</td>
<td>72a</td>
<td>69–75</td>
</tr>
<tr>
<td>Model H</td>
<td>31c</td>
<td>25–38</td>
<td>71a</td>
<td>67–74</td>
</tr>
<tr>
<td>Ngu</td>
<td>17d</td>
<td>14–22</td>
<td>81b</td>
<td>77–86</td>
</tr>
</tbody>
</table>

Means followed by the same letter within a column do not differ ($\alpha = 0.05$).

Discussion

Climatic conditions observed during this study were conducive to survival and reproduction of stable flies (Lysyk 1998, Gilles et al. 2005). Stable flies were not observed in the pineapple fields prior to chopping and, based upon degree-day accumulations, eggs deposited in the chopped substrate would not be expected to complete development and begin emerging as adults for 16 d (Lysyk 1993). Therefore, we assume that the flies collected prior to 16 d were immigrants from outside the field. These flies were primarily females (Fig. 4) and were presumably attracted to the fields for oviposition. Odors from freshly chopped pineapple plants are highly attractive for female stable flies (unpublished data).

White sticky traps caught more stable flies than any of the fabric traps. During the study, we frequently observed stable flies attracted to,
and landing on, the fabric traps without entering them. Similar observations were reported for fabric traps used for tsetse fly (Glossina spp.) control in West Africa (Rayaisse et al. 2012). Insecticide-treated fabric traps or targets may be more efficacious than the untreated traps used for this study. Also, during the study, sticky traps were replaced daily, not every 2 wk as is the usual practice. Therefore, only first-day collections were evaluated. It is likely that the efficacy of sticky traps drops with time due to degradation of the adhesive and saturation of the surface.

The number of flies collected on the white sticky traps increased and sex ratio (females per male) of the flies collected in the fabric traps decreased at ≈16 d after chopping, when, according to degree-day accumulations, flies developing in the residues were expected to start emerging. This observation validates the degree-day models of Lysky (1993, 1998). Unexpectedly, collections in the fabric traps decreased during this time frame. Previous studies found that sticky traps, both Alsynite and white coroplast, tend to collect young, nulliparous flies (Hogsett et al. 1989, Beresford and Sutcliffe 2006) and that blue-black fabric traps tend to catch an older component of the stable fly population (Taylor and Berkebile 2006). Results of this study are in accord with those findings. The fabric and white sticky traps collected similar numbers of stable flies when the population was expected to be dominated by older, presumably gravid, females seeking oviposition sites. However, once flies completed development and young, presumably nulliparous, adults began to emerge from the pineapple substrate, collections on the white sticky traps increased.

Fabric traps, especially the Nzi and Vavoua, collected significant numbers of female stable flies attempting to colonize the freshly cut pineapple residues. Use of fabric traps for 2 wk after chopping the pineapple residues in the fields reduces the number of ovipositing females and hence the number of flies developing in the fields. The fabric traps have advantages for use in bio-ecological studies as well because flies can be easily removed for species identification and sexing. Although the white sticky traps collected more flies than the fabric traps, they remain labor intensive and environmentally unsound because of their disposable and nonbiodegradable nature. Further studies on these traps are warranted to evaluate effects of long lasting insecticide treatment of traps, possible age and sex biases trap positioning, timing, and number of traps required per hectare.

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