Harvesting Sugar From Nonflowering Plants: Implications of a Marked Sugar Bait on Honey Bee (Hymenoptera: Apidae) Whole Hive Health

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Abstract

Honey bees (Apis mellifera) are effective foragers for floral and extra-floral sources of sugars and as a result may easily be exposed to toxicants in the environment, such as pesticides. Toxic sugar baits (TSB) or insecticide-laced baits are designed for insect vector management but may be a danger to foraging honey bees and their hives. During a mosquito movement study at a zoological institution, nonflowering foliage surrounding the zoo was marked with sugar solution dyed with over the counter food-coloring. Mosquitoes and other insects foraged on the marked sugar and were collected within the zoo. Additionally, four of six honey bee hives within the zoo had workers that also foraged the dyed sugar and consequently colored approximately 57 kg of honey within the hives. This observation identifies a possibility route of toxicant accumulation within the hives from TSB and possible exposure may have whole hive health implications not previously described on an individual bee level.

Key words: ATSB, honey bee, vector control, Apis, pesticide

Effective and efficient foraging for nectar, pollen, and water by honey bees (Apis mellifera) (L.) is essential for whole hive health. Bees will exploit any carbohydrate including alternatives to floral sources such as from both natural (e.g., honey dew) and human-associated sugar sources (Penick et al. 2016). Relatively recent reports of honey bees taking advantage of human-associated sugar sources include cultivated honey bee colonies foraging at a maraschino cherry factory, from discarded human food, and human waste bins (Dominus 2010, Chandrasekaran et al. 2011, Anderson et al. 2014, Penick et al. 2016). Implications of honey bees exploiting atypical food sources are largely unknown and under investigated; however, such behavior may expose honey bees to potential dangers (e.g., pesticide exposure).

Pesticides applied to facilitate agricultural crop yields can negatively impact honey bee and other pollinator species’ performance even at sublethal levels (Mommaerts et al. 2010, Cresswell 2011, Goulson et al. 2015). Neonicotinoids (e.g., imidacloprid) are the most commonly applied pesticide to agricultural crop species (Elbert et al. 2008). Honey bee exposure to neonicotinoids in field conditions may result in both sublethal and lethal effects (Cresswell 2011). While lethal effects increase mortality of exposed bees sublethal effects may decrease individual performance, as indicated by altered behavior, reduced foraging efficiency, or decreased fecundity (Colin et al. 2004, Mommaerts et al. 2010, Cresswell 2011, Krupke et al. 2012, Whitehorn et al. 2012). Impacts of these exposures may have significant negative effects on whole hive productivity and long term health.

Other avenues of honey bee exposure to pesticides include those dispersed for the goal of arthropod vector control (e.g., mosquitoes). A relatively new method for vector control is attractive toxic sugar bait (ATS systems). These ATSB systems have been increasing in their application due to technological simplicity, ease of dispersal, and the ability to change active ingredients from known insecticides to insecticidal natural products. The ATSB system consists of a solution with the components of a phagostimulant (i.e., sugar source), an oral toxin, and may also contain a floral scent or kairomone for attraction (Beier et al. 2012, Fiorenzano et al. 2017). Sugar baiting takes advantage of the biologic requirements of mosquitoes (both male and female) to take in carbohydrate meals (e.g., nectar, fruits, and honeydew) (Foster 1995, Ferguson et al. 2010, Gouagna et al. 2010, Allan 2011, Fiorenzano et al. 2017).

Application of ATSB solutions involves spraying areas of vegetation, attracting local mosquito populations (competing for local sugar sources), which upon feeding on the aqueous or crystalized ATSB solution, mosquitoes are killed (Müller et al. 2010a, Beier et al. 2012, Fiorenzano et al. 2017). Significant mosquito capture...
reductions have been reported in areas following application of ATSB solutions (Müller et al. 2008; Müller and Schlein 2008; Müller et al. 2010a,b,c; Beier et al. 2012). ATSB solutions rely on oral ingestion rather than contact like traditional vector control methods; therefore, numerous pesticide classes including avermectins, neonicotinoïds, phenylpyrazoles, pyrethroids, pyrroles, spinosyns, and other EPA exempt and more environmentally favorable pesticides (e.g., borates, botanicals) have been investigated and shown to be effective (Allan 2011, Xue et al. 2011, Revay et al. 2014, Qualls et al. 2014, Revay et al. 2015, Fiorenzano et al. 2017).

Concerns with any mode of pesticide dispersal for agricultural use or vector control include both environmental impacts and impacts on nontarget insects such as local predators or pollinator species (e.g., honey bees). To-date, several ATSB impact studies have shown little to no impact on beneficial and nontarget insects (Khallaayoune et al. 2010a,b,c; Beier et al. 2012). ATSB solutions rely on oral ingestion rather than contact like traditional vector control methods; therefore, numerous pesticide classes including avermectins, neonicotinoïds, phenylpyrazoles, pyrethroids, pyrroles, spinosyns, and other EPA exempt and more environmentally favorable pesticides (e.g., borates, botanicals) have been investigated and shown to be effective (Allan 2011, Xue et al. 2011, Revay et al. 2014, Qualls et al. 2014, Revay et al. 2015, Fiorenzano et al. 2017).

The impact on honey bees of a single application of a dyed sugar bait (DSB) solution to nonflowering plants (as a visual marker for a mosquito movement study at a zoological park) are reported here and discussed are the unexpected findings and possible implications of sugar bait systems to honey bee hives.

Materials and Methods

The Sunset Zoo (SSZ) is in the city of Manhattan, Kansas (N 39° 10′, W 96° 35′), in the northeastern region of Kansas. The SSZ is atop a hill and is surrounded immediately by a city cemetery (North), heavily forested riverine area (West), and forested residential areas (South and East).

Three DSB solutions were prepared, each with 3.8-liter tap water combined with 1 kg granular sugar (Kroger brand, Manhattan, KS). Food coloring (7.4 ml; e.g., red, blue, and green [McCormick, Manhattan, KS]) was added to each of the three solutions, respectively. Solutions were dispersed using hand-held 3.8-liter sprayers (Flo-Master, Michigan).

Application of the DSB was over three predetermined areas outside of the SSZ during the month of June (2015). Each predetermined area had a single color sprayed over nonflowering foliage, present 10–100 m outside the SSZ’s boundaries. The three locations included a forested residential area (Fig. 1A) South of the SSZ (red dye), a forested lower riverine area (Fig. 1B) West of the SSZ (blue dye), and broken areas of nonflowering foliage present within a local cemetery north of the SSZ (green). Nonflowering plant species primarily consisted of Acer rubrum, Cercis canadensis, Gleditsia triacanthos, Juncus sp., Juniperus virginiana, Lonicera sp., ornamental landscape species (present within cemetery), Pinus strobus, Quercus palustris, Sambucus canadensis, and various stumps and tree trunks.

Sampling of mosquitoes within the SSZ for the targeted migration study occurred over three consecutive days following DSB application. Mosquitoes from two species were identified with dyed foreguts (e.g., red and blue); however, seven families of insects were identified within the SSZ with dyed foreguts (data not presented here).

The SSZ, at the time of the study retained six hives containing mixed populations of Apis mellifera ligustica and Apis mellifera carnica. Sampling of the honey was not predetermined and occurred as routinely conducted by local apiculturist managing the SSZ’s hives, approximately 1 mo following DSB application outside of the SSZ. Photographic documentation of dyed honey cells in frames, not previously harvested by the apiculturist, was conducted following primary harvesting and processing of initially identified dyed honey. Per the apiculturist’s protocol, honey was processed after harvesting, limiting further analysis.

Results

During routine harvest, 1 mo following DSP application, of the SSZ’s hives, four of six honey bee hives within the SSZ were found to have frames containing dyed honey within the cells. Affected hives were the southernmost within the SSZ and in close proximity to each other (i.e., < 5 m) and closest in proximity to the Southern red DSP application area. Of the four-affected hives, the majority of honey in the cells was reported to be bright red in color, with fewer cells noted to be bright green in color, from the apiculturist’s report. Of the 133 kg of harvested honey at time of collection, approximately 57 kg were dyed bright red. During secondary documentation of the honey bee hives, frames not previously harvested were revealed to have numerous cells noted to be red in color; however, the apiculturist reported the color to have faded from initial observations and no other color other than red was identified at this time (Fig. 2A and B).

Fig. 1. Forested residential (A) and riverine (B) areas located outside of the Sunset Zoo to the South and West, respectively, where red and blue attractive sugar bait solutions were dispersed over nonflowering foliage, respectively, for the intended mosquito migration study conducted in June, 2015. Not pictured in this figure are example nonflowering foliage from North of the Sunset zoo where attractive sugar bait dyed with green was dispersed within the local cemetery. Plant species present in these attractive sugar bait dispersal areas included include Acer rubrum, Cercis canadensis, Gleditsia triacanthos, Juncus sp., Juniperus virginiana, Lonicera sp., ornamental landscape species (present within cemetery), Pinus strobus, Quercus palustris, and Sambucus Canadensis, and various stumps and tree trunks.
Discussion

The present observations suggest the SSZ’s honey bee colonies identified and foraged the DSB solution applied to predetermined nonflowering areas. Reasons for these observations may include inadvertent dispersal of the DSB solution on flowering foliage or honey bees foraging—for either floral or extra-floral sugar sources (e.g., honey-dew), resulting in the harvest of the dyed sugars. Cultivated honey bees foraging on extra-floral sources of food is not a new finding in itself; however, the present observations bring to light certain considerations when considering ATSB systems (Dominus 2010, Chandrasekaran et al. 2011, Anderson et al. 2014, Vidal-Naquet considerations when considering ATSB systems (Dominus 2010, Chandrasekaran et al. 2011, Anderson et al. 2014, Vidal-Naquet 2015). The authors note that the implications of the present findings are significant when considering the increasing application of ATSB systems for vector control and previous ATSB studies indicating minimal impact on nontarget insects.

Five studies to-date have been conducted evaluating ATSB’s impact on nontarget insects. Impacts on nontarget insects were evaluated through the application of both DSB and ATSB solutions on flowering and nonflowering flora, followed by the collection of insects within the application areas using malaise and pitfall traps, entomological nets, and ultra-violet light traps (Khallaayoune et al. 2013, Qualls et al. 2014, Revay et al. 2014, Qualls et al. 2015, Revay et al. 2015). The authors note that collection methods used in these studies may inherently be insensitive for some species (i.e., honey bees) resulting in a lack of sensitivity to evaluate ATSB’s impact on honey bees. Honey bee hives were not assessed in these studies. Impacts on insects belonging to Hymenopteridae, did show variable effect when attractive sugar bait (ASB) or ATSB solutions were applied to flowering versus nonflowering foliage, resulting in up to a 22-fold increase in affected hymenopterids collected within flowering areas versus nonflowering (Schlein and Müller 2010, Qualls et al. 2014, Revay et al. 2014, Qualls et al. 2015). The latter findings resulted in the recommendations and limitations that ATSBs to be applied to only nonflowering foliage (Fiorenzano et al. 2017).

The current observations of the dyed honey within the SSZ hives suggest similar solutions—as those applied for vector control—containing both toxicants, attractants, or dye may similarly or more significantly result in exposure to individual foraging bees and secondarily the local hives. Inherent to a number of pesticides used in both agricultural use and vector control (e.g., neonicotinoids, phenylpyrazoles) is the attribute of not invoking antifeeding or food aversion behaviors when ingested (Colin et al. 2004). The latter suggesting accumulation of a pesticide may be achieved to a sublethal dose. Sublethal effects may have significant impacts on a hive’s performance. Impacts may be attributed to individual performance, where exposure to sublethal doses of a neonicotinoids have been associated up to 20% reduction in performance, affecting locomotor skills, sense perceptions, memory, and ability to orient (Mommaerts et al. 2010, Cresswell 2011). Subsequent to these conclusions, when evaluating toxic effects of pesticides (i.e., in the area of ATSB dispersal), the authors suggest a simple mortality assessment may not accurately represent the impact of exposure and relies on the assumption of exposure dosage being of lethal level.

Due to taking advantage of oral ingestion rather than contact toxicity—as many vector control strategies currently rely on—many additional pesticide classes have been investigated for use through ATSB systems (Fiorenzano et al. 2017). Pesticides exempt from EPA regulations or deemed as low-environmental risk such as borates, or various botanicals (e.g., eugenol, cinnamon, garlic, etc.) have been investigated and found effective for vector control through ATSB systems (Khallaayoune et al. 2013, Revay et al. 2015). However, these exempt pesticides have not been investigated when considering their sublethal or lethal impacts on honey bees. The honey (57 kg) was not dyed from a single visit, but the accumulation of dye from subsequent visits likely by multiple individuals from various hives, foraging areas versus nonflowering (Schlein and Müller 2010, Qualls et al. 2014, Revay et al. 2014, Qualls et al. 2015). The latter findings resulted in the recommendations and limitations that ATSBs to be applied to only nonflowering foliage (Fiorenzano et al. 2017).

In conclusion, we present unique observations of dye accumulation following dispersal of a dyed sugar solution, similar to solutions used in ATSB systems. We suggest that possible accumulation of pesticides may occur in honey following application of an ATSB solution, despite current recommendations for the application of ATSB systems to be on nonflowering foliage only. Additionally, previous work suggests ATSB systems to have minimal impacts on nontarget insects such as honey bees; however, the authors suggest that methods used to assess impact may be inherently insensitive to identifying sublethal impacts to honey bees. The ATSB systems have proven to be an effective means for vector control; however, there is a need for prospectively planned studies evaluating both EPA exempt pesticide impacts on honey bees and studies clarifying potential implications of pesticide exposure and accumulation in honey through the application of ATSB systems.
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