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Sweet waste extract uptake by a mosquito vector: Survival, biting, fecundity responses, and potential epidemiological significance

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ABSTRACT

In nature, adult mosquitoes typically utilize nectar as their main energy source, but they can switch to other as yet unidentified sugary fluids. Contemporary lifestyles, with their associated unwillingness to consume leftovers and improper disposal of waste, have resulted in the disposal of huge amounts of waste into the environment. Such refuse often contains unfinished food items, many of which contain sugar and some of which can collect water from rain and generate juices. Despite evidence that mosquitoes can feed on sugar-rich suspensions, semi-liquids, and decaying fruits, which can be abundant in garbage sites, the impacts of sweet waste fluids on dengue vectors are unknown. Here, we investigated the effects of extracts from some familiar sweet home waste items on key components of vectorial capacity of *Aedes aegypti*. Adult mosquitoes were fed one of five diets in this study: water (WAT); sucrose (SUG); bakery product (remnant of chocolate cake, BAK); dairy product (yogurt, YOG); and fruit (banana (BAN). Differences in survival, response time to host, and egg production were examined between groups. For both males and females, maintenance on BAK extract resulted in marked survival levels that were similar to those seen with SUG. Sweet waste extracts provided better substrates for survival compared to water, but this superiority was mostly seen with BAK. Females maintained on BAK, YOG, and BAN exhibited shorter response times to a host compared to their counterparts maintained on SUG. The levels of egg production were equivalent in waste extract- and SUG-fed females. The findings presented here illustrate the potential of sweet waste-derived fluids to contribute to the vectorial capacity of dengue vectors and suggest the necessity of readdressing the issue of waste disposal, especially that of unfinished sweet foods. Such approaches can be particularly relevant in dengue endemic areas where rainfall is frequent and waste collection infrequent.

1. Introduction

Several outbreaks of dengue and related diseases, such as Zika fever, have been reported in recent years, mostly from urban centers, with smaller numbers of cases from rural areas (Banerjee et al., 2015). Urbanization and globalization have led to overcrowding of cities (Kang, 2014). Urban centers are also characterized by the gradual replacement of traditional foods by processed and ready-made foods (Hurtig, 2009), excessive purchasing, over-preparation

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and unwillingness to consume leftovers (Gustavsson et al., 2011), increased usage of plastic and glass containers in various forms (Asian Productivity Organization (2007), improper disposal attitudes (Anomanyo, 2004; Da et al., 2008), insufficient disposal facilities (Gregory et al., 1996), and inadequate waste management (Jacobi and Besen, 2011). These attitudes and management issues have resulted in huge amounts of household waste being discarded into the environment (Banerjee et al., 2015). Leftover food items, packaging (Gustavsson et al., 2011; Jacobi and Besen, 2011), and containers made of plastic or glass constitute the bulk of household waste (Banerjee et al., 2015).

Dengue vectors typically thrive in artificial container habitats (Higa, 2011) and can colonize any container flooded by rainfall (Liehne, 1988; Juliano et al., 2002). When glass and plastic containers are discarded, they can retain rainwater, and become potential breeding sites for container-inhabiting *Aedes* mosquitoes (Barrera et al., 1993). Over 26 types of waste containers have been found positive for immature stages of *Aedes* (Banerjee et al., 2013, 2015). In addition to providing breeding habitats, discarded household products can contain nutrients in readily available quantities. Globally, around one third of the edible parts of food produced for human consumption are discarded as waste (UN/FAO, 2011). In industrialized Asia, food waste per person per year is around 80 kg (Gustavsson et al., 2011). Malaysians throw away 9000–15000 t of unfinished food daily (Nation, 2016). In urban areas where rainfall is frequent and waste collection infrequent, sweet waste can have an important impact on the mosquito community and significant epidemiological implications. There is evidence that food waste contains many sweet products: bakery (cakes and desserts), parts of fruits (bananas, apples, pineapples, plums, peaches), canned drinks, dairy products (yogurt), and jams (WRAP, 2009). In situations similar to those reported by WRAP (2009), juicy, sweet, and fragrant fruits, such breadnuts, durians, breadfruits, and jackfruits, are commonly observed discarded in Malaysia. In a garbage survey carried out in 2016 in Kota Samarahan, partly eaten apples and Kit Kat chocolate bars were found in some garbage sites near residences.

The sugar contents of the foods used in homes that are later discarded uneaten is diverse and appreciable. For example, some sweet beverages contain sweeteners, such as sucrose (50% glucose, 50% fructose), high-fructose corn syrup (HFCS; most often 45% glucose and 55% fructose), or fruit juice concentrates (Malick and Hu, 2012). A can of cola contains 33 g of sugar (Brown, 2016). Syrups (67% granulated sugar dissolved in water) are commonly used in a range of baked goods and confectionery (British Sugar, 2012). One hundred grams of pineapple, apple, or banana contains 9.9, 10.4, and 12.2 g of sugar, respectively (NAL USDA, 2016). Fructose occurs naturally in fruits (Park and Yetley, 1993) and apple juice contains high concentrations of free fructose (Riby et al., 1993). Glucose occurs in fruits and its syrup is widely used in the manufacture of foodstuffs (Ushijima et al., 1991). Sucrose is found in some fruits and some roots, *e.g.*, carrot (Buss and Robertson, 1976), and lactose is found primarily in many dairy products (Kimball, 2012).

Fructose, glucose, sucrose, starch, and a few unknown sugars have been found in wild female mosquitoes (Burkett et al., 1998). In fact, sugar is a staple of mosquitoes (Gary and Foster, 2004), as illustrated by behavioral, structural, and physiological specializations for finding, feeding on, and assimilating it in both sexes (Foster, 1995). In the wild, finding a suitable sugar meal is one of the most critical challenges faced by mosquitoes (Gary and Foster, 2004; Clements, 1992). An adequate dietary sugar supply is a critical aspect of survival (Burkett et al., 1998), longevity, and population maintenance (Thorsteinson and Brust, 1962). Energy gained from sugar intake is necessary to maintain male sexual performance (Clements, 1955; Nayar and Van Handel, 1971) and female vectorial capacity (Gouagna et al., 2010; Gu et al., 2011). Sugar-fed females show enhanced survival, host-finding ability (Foster and Eischen, 1987; Walker and Edman, 1985), and increased possibility of vectoring pathogens than those that have been starved or fed on water (Kelly and Edman, 1996; Burkett et al., 1998). Sugar-deprived males or females typically die within a few days (Foster, 1995). Ingested sugars increase flight activity and range for mosquitoes of both sexes, (Abraham, 2013). Male mosquitoes rely mostly on sugar-rich diets to engage in the energetically costly swarming (Kaufmann et al., 2013) and gamete production (Foster, 1995). Some mosquitoes do not seek blood until they take at least one sugar meal (Renshaw et al., 1994; Briegel et al., 2001). A sugar meal is necessary to initiate the development of ovarian follicles (Abraham, 2013) and the first batch of eggs (O'Meara, 1985). The occurrence of sugar feeding during an ovarian cycle promotes the rate of egg development (Nayar and Sauerman, 1975). Sugar feeding also influences offspring quality through a maternal effect (Fernandes and Briegel, 2005). The deprivation of sugar after completion of egg development results in eggs with depleted glycogen deposits (van Handel, 1992). Without sugar, mosquitoes can die rapidly, despite frequent access to blood (Nayar and Sauerman, 1971; Fernandes and Briegel, 2005). In the laboratory, it is standard practice to provide mosquito colonies with a variety of sugar solutions, and female *Ae. aegypti* mosquitoes lived much longer in the laboratory when fed with both sugar and blood than when fed with blood alone (Clements, 1992). In fact, such practices mimic the availability of natural sugars in the wild (Gillett et al., 1962; Gouagna et al., 2010).

To supplement their energy reserves and sustain life in nature, both sexes feed almost exclusively on plant-derived sugary fluids, including sap, nectar, honeydew, and fruits (Clements, 1992; Foster, 1995; Foster and Takken, 2004). There is evidence that mosquito populations prevail mostly in environments where sugar resources are available. Gu et al. (2011) found a 250-fold difference in the malarial vectorial capacity between sugar resource-rich and sugar-poor sites, where the vector could not maintain a viable population. Despite immense diversity of flowering plants that can serve *a priori* as sugar sources (Gouagna et al., 2010), it has been reported that mosquitoes do not acquire sugar meals from all flowering plants (Müller and Schlein, 2005). *Ae. aegypti* and other aedines were reported to feed on only three of 24 native plant species offered to them in Canada (Abdel-Malek and Baldwin, 1961). In the absence of favorable sugar sources, mosquitoes can switch to other sources (Müller and Schlein, 2005). There is evidence that mosquitoes can feed on sugar-rich sticky suspensions (Abraham, 2013), semi-liquids (Eliason, 1963), dry food (Downs and Arizmendi, 1951), healthy plant tissues (Schlein and Müller, 1995), and damaged or decaying fruits (Foster, 1995). Although confirmed to be of plant origin (Gary and Foster, 2004; Gouagna et al., 2010), the actual sources of sugary fluids upon which mosquitoes feed in nature are still unknown (Gouagna et al., 2010). Thus, further studies are needed to identify the cryptic sources of sugar of wild mosquitoes.

Although some household wastes have been reported to act as larval development sites for dengue vectors (Banerjee et al., 2013) and another study addressed their seasonal productivity relative to urbanization level (Banerjee et al., 2015), there have been no studies regarding the potential of discarded household products as sources of energy for adult dengue mosquitoes. Here, we evaluated the capacity of the extracts of some common sweet home wastes on key components of the vectorial capacity of *Ae. aegypti*.

2. Materials and methods

2.1. Ethical statement

This study was approved by the Biological Research Ethics Committee at University Malaysia Sarawak (UNIMAS).