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Excito-Repellent Responses between *Culex quinquefasciatus* Permethrin Susceptible and Resistant Mosquitoes

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Abstract The behavioral responses exhibited between four permethrin-resistant field-derived populations and a long-established, permethrin susceptible colony population of *Culex quinquefasciatus* mosquitoes was assessed for behavioral responses to permethrin in an excito-repellency (ER) test system. After a 30-min exposure to two different insecticide concentrations (200 and 500 mg/m^2) in paired contact and noncontact test designs, the initial knockdown and escape (exit) responses were recorded followed by mortality after 24-h. All five test populations rapidly escaped from the chambers treated with permethrin regardless of background insecticide susceptibility status or chemical concentration. The greatest contact escape response was seen from the colonized population with 88 % of specimens escaping the chamber within 30-min. Contact irritancy was the predominant response compared to relatively

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weak noncontact spatial repellency in all test populations at both low and high concentrations. At the lower concentration, the contact escape responses did not appear influenced by background susceptibility status, whereas at the higher concentration the permethrin-resistant field populations exhibited significantly reduced avoidance behavior compared to the laboratory susceptible strain.

Keywords Excito-repellency · susceptibility · permethrin · *Culex quinquefasciatus*

Introduction

Culex quinquefasciatus Say, a cosmopolitan mosquito with wide global distribution, is an important pest species and vector of arthropod-borne viruses (arbovirus) and lymphatic filariasis in humans (Sasa 1976). Transmissible arboviruses include West Nile virus (Turell et al. 2005; Kilpatrick et al. 2005; Kwan et al. 2010), St. Louis encephalitis virus (Savage et al. 1993), Chikungunya virus (Bessaud et al. 2006), and Rift Valley fever virus (Sang et al. 2010; Turell et al. 2008). This mosquito species can also transmit avian malaria parasites (LaPointe et al. 2005; Woodworth et al. 2005; Ejiri et al. 2009). In Asia, *Cx. quinquefasciatus* is the predominant urban mosquito species and has been shown experimentally capable of transmitting Japanese encephalitis virus (JEV) (Banerjee et al. 1977) and reported naturally infected with JEV in Vietnam (Thao et al. 1974; Lindahl et al. 2013), India (Kanojia 2007), and Thailand (Nitatpattana et al. 2005). In addition to its capabilities as a pathogen vector, this mosquito is a prime nuisance species with a high reproductive capacity and strong anthropophilic feeding behavior in urban areas (Yang and Liu 2013).

Several vector control strategies are available for disease control and prevention. The use of insecticide remains the primary method for controlling adult and larval mosquitoes in many operational programs (Matthews 2011). Over many decades, four classes of synthetic compounds, the organochlorines, organophosphates, carbamates, and pyrethroids, have been used in public health vector control programs in Thailand (Chareonviriyaphap et al. 1999, 2013; Thanispong et al. 2008). Among these, the synthetic pyrethroids are the most common active ingredients used as mosquito adulticides for outdoor space spray and indoor residual applications along with the impregnation of fabric materials (e.g., bed nets) to prevent mosquito blood feeding. For decades, various pyrethroid formulations have dominated the market due to their high efficacy against mosquitoes at low dosage, rapid knockdown and killing action, and relatively low toxicity for humans and other mammalian species (Hemingway et al. 2004; Grieco et al. 2007). However, extensive and long-term use of pyrethroids has resulted in the development of insecticide resistance in many medically important mosquito populations, including *Cx. quinquefasciatus* (Chandre et al. 1998; Yang and Liu 2013; Chareonviriyaphap et al. 2013). To mitigate or avoid the development of insecticide resistance, chemicals that elicit a strong behavioral avoidance ('excito-repellency') response (in addition to toxic properties) that result in reduced human-vector contact and blood feeding retain merit in disease control strategies.

A better understanding of the behavioral responses of *Cx. quinquefasciatus* to insecticides can assist vector control programs in selecting the most effective and appropriate methods for disease control. The non-toxic actions of insecticides have