Comparative Behavioral Responses of Pyrethroid–Susceptible and –Resistant *Aedes aegypti* (Diptera: Culicidae) Populations to Citronella and Eucalyptus Oils

SUNAIYANA SATHANTRIPHOP,[1] KANUTCHAREE THANISPONG,[2] UNCHALEE SANGUANPONG,[3] NICOLE L. ACHEE,[4] MICHAEL J. BANGS,[1,5] AND THEERAPHAP CHAREONVIRIYAPHAP[1,6]

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ABSTRACT The objective of this study was to compare the behavioral responses (contact irritancy and noncontact spatial repellency) between susceptible and resistant populations of *Aedes aegypti* (L.) (=*Stegomyia aegypti*) to essential oils, citronella, and eucalyptus, *Eucalyptus globulus*, extracts, using an excito-repellency test system. N, N-diethyl-meta-toluamide (DEET) was used as the standard reference repellent. Mosquitoes included two long-standing insecticide susceptible colonies (U.S. Department of Agriculture and Bora Bora) and two pyrethroid-resistant populations recently obtained from Phetchabun and Kanchanaburi provinces in Thailand. Both DEET and citronella produced a much stronger excitation ("irritancy") and more rapid flight escape response in both pyrethroid-resistant populations compared with the laboratory populations. Noncontact repellency was also greater in the two resistant populations. Eucalyptus oil was found to be the least effective compound tested. Differences in responses between long-established pyrethroid-susceptible colonies and newly established and naturally resistant colonies were clearly demonstrated. These findings also demonstrate the need for further comparisons using natural pyrethroid-susceptible populations for elucidation of factors that might contribute to different patterns of escape behavior.

KEY WORDS *Aedes aegypti*, behavior, DEET, citronella oil, eucalyptus oil

Dengue viruses are responsible for one of the most prevalent and important vector-borne diseases (dengue fever and dengue hemorrhagic fever) of public health importance in the tropical and subtropical world (Gubler 1998). It is estimated that ≈400 million dengue infections occur annually, of which close to one-quarter will manifest with some form of clinical or subclinical severity (Bhatt et al. 2013). This represents a threefold increase in the number of estimated cases by the World Health Organization (WHO 2012), but likely still represents half of the world population live in the dengue-endemic countries (WHO 2012). Thailand has long had persistent dengue transmission with all four serotypes circulating in urban and rural settings. The principal vector of dengue viruses is *Aedes aegypti* (L.) (=*Stegomyia aegypti*), which is a common resident in urban areas, whereas *Aedes albopictus* (Skuse) (=*Stegomyia albopicta*), a dengue vector of generally secondary importance, is more prevalent in more open suburban and rural settings (Pethuan et al. 2007). Both species have proven difficult to control because of their bionomics and behavioral traits in close association with human activities. Years of research and significant financial support have yet to provide an effective vaccine to protect against dengue. Thus, the prevention and control of dengue remains almost exclusively based on vector control and personal protection practices to reduce transmission risk. In some instances, this requires the use of various insecticides applied as larvicides, outdoor space sprays, and indoor aerosol applications (Reiter and Gubler 1997, Grieco et al. 2007).

The intensive use of insecticides has led to high levels of chemical resistance in certain pests and disease vectors (Chareonviriyaphap et al. 1999, Thanispong et al. 2008) resulting in reduced effectiveness of more traditional chemical-based prevention and control methods. There have been numerous reports of dengue vector mosquitoes developing resistance to pyrethroids in Thailand (Jirakanjanakit et al. 2007, Thanispong et al. 2008, Chuaycharoensuk et al. 2012). An alternative measure of bite prevention is the use of topical (skin) insect repellents. One of the most common synthetic insect repellents is N, N-diethyl-meta-toluamide (DEET), an ingredient that has been used for >50 yr by tens of millions of people

[1] Department of Entomology, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
[2] Bureau of Vector-Borne Disease, Department of Disease Control, Ministry of Public Health, Nonthaburi 11000, Thailand.
[3] Institute of Research and Development, Rajamangala University of Technology Thanyaburi, Patumthani 12110, Thailand.
[4] Eck Institute for Global Health, Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556.
[5] Public Health & Malaria Control Department, International SOS, Kuala Kencana, Papua, Indonesia.
[6] Corresponding author, e-mail: faasthc@ku.ac.th.