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Ommer Dafalla,[1] Adel Alsheikh,[1] Waheed Mohammed,[1] Khalid Shrwani,[1] Feras Alsheikh,[2] Yahya Hobani
[1]
and Elsiddig Noureldin
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[1]Saudi Centre for Disease Control & Prevention, Ministry of Health, Jazan, Saudi Arabia (Correspondence to: Omer Dafalla: omerosa@yahoo.com).

[2]Faculty of Public Health & Tropical Medicine, Jazan University, Jazan, Saudi Arabia.

Introduction

The Aedes aegypti mosquito is by far the most competent vector of many arboviral diseases, including dengue, yellow fever, chikungunya, Zika and West Nile. Dengue fever and dengue haemorrhagic fever have consequently spread through more than 100 countries in tropical and subtropical zones, resulting in more than half of the world population being at risk (1). Using insecticides to control vector-borne diseases is still the main intervention although efforts to introduce licensed vaccines have progressed greatly.

Dengue is endemic in Saudi Arabia, especially in the Jeddah, Mecca, Asir and Jazan areas. Around 12 131 confirmed cases were reported from Jeddah and Mecca between 2013 and 2015 (2). Likewise, 1790 confirmed cases were reported from Jazan region between 2005 and 2016, with a severe outbreak in 2016 (555 cases). The number of confirmed cases from Jazan region in 2017 was 320 (3).

Knockdown resistance (kdr) is a mechanism that describes cases of resistance to pyrethroid as a result of target site insensitivity due to point mutations in the insect voltage-gated sodium

channel (VGSC) regulatory protein, which block pyrethroid and DDT action (genetic makeup) (4). Several kdr mutations have been reported in Ae. aegypti populations worldwide; these include G923V, L982W, I1011M/V,S989P, V1016G/I, F1534C and D1763Y (5).

The majority of resistance-associated mutations are found in segment 6 of domain II (IIS6) and domain III (IIIS6) of the sodium channel gene. For instance, valine to glycine in domain II (V1016G) is associated with resistance to type I and type II pyrethroids, such as permethrin and deltamethrin (6), while phenylalanine to cysteine substitution at position 1534 within domain III (F1534C) is associated with resistance to type I pyrethroids (7). On the other hand, serine to proline (S989P) in domain II in VGSC has also been associated with pyrethroid resistance (8) and valine to isoleucine transversion in domain II (V1016I) contributed to Ae. Aegypti pyrethroids resistance in Latin America (9). However, S989P has not been found alone (10).

The kdr mutations in Ae. aegypti have been reported from Singapore (11), China (12,13) and Greece (13), and 1534Leu and 1534Ser have been found in the United States of America (14).

Few studies have been reported on the resistance status of Ae. aegypti to insecticides in Saudi Arabia (15–17). Furthermore, studies on mechanisms of resistance to pyrethroids in Ae. aegypti populations from Saudi Arabia are lacking. Only one has been conducted in Jeddah and Mecca, in the western region of Saudi Arabia (2). This study reported 2 mutations (V1016G and S989P) in Ae. aegypti, which were shown to be responsible for the resistance of permethrin and deltamethrin.

To the best of our knowledge, no studies have been carried out to investigate the resistance mechanisms of Ae. aegypti to pyrethroid insecticides in Jazan region. The aim of this study is therefore to explore the resistance status of Ae. aegypti to pyrethroids and the underlying mechanisms.

Methodology

Study area

Jazan region is situated in the subtropical zone, south-western Saudi Arabia, lies between 16° 12′, and 18° 25′ north. It is surrounded by the Red Sea (260 km) from the west, by Yemen (120 km) from the south and east and by Asir region from the north, with a total area of about 22 000 km2 and a population of 1.3 million (18).

Adult bioassay

This study was carried out in 2017. Larvae of Ae. aegypti were collected from Gizan City and were left to develop until adult under laboratory conditions, 25 ± 2 °C and 75% relative humidity with a constant photoperiod; 12 h light, 12 h dark.

About 100 sugar-fed, 3–5-day-old Ae. aegypti female mosquitoes were used for each of permethrin, lambda-cyhalothrin and cyfluthrin for bioassay testing. A batch of 25 adults was introduced into a holding tube before being exposed to insecticide-impregnated papers. Equal numbers of control tests were also carried out by exposing mosquitoes to insecticides–free papers. The experiment was replicated 4 times. After a period of exposure of 60 min under laboratory conditions (25 ±2 °C and 75% relative humidity with a constant photoperiod; 12 h light, 12 h dark), all mosquitoes were transferred to new tubes, provided with 10% sugar solution and held for 24 hours recovery period (19). Mortality was recorded and resistance status was determined as per WHO criteria, i.e., a population is considered susceptible if the mortality rate is (98–100%), having a possibility of resistance 90–97% and resistant