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Susceptibility of anopheles arabiensis (Diptera: Culicidae) adults to some commonly used agricultural insecticides in El Rahad Agricultural Corporation, Central Sudan

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As with other insects, resistance to insecticides has become a limiting factor in the use of insecticides to control mosquitoes. The control of mosquito is dependent on the use of insecticides over a long period of time (initially organochlorines, followed by organophosphates, carbamates and pyrethroids). This study aimed to determine the susceptibility of Anopheles arabiensis adult to the public health and agricultural insecticides, namely, DDT 4%, fenitrothion 1%, malathion 5%, bendiocarb 0.1%, propoxur 0.1%, deltamethrin 0.05% and lambda-cyhalothrin 0.05% at El Rahad Agricultural Corporation (RAC) area, Central Sudan, to provide base-line data about the Anopheles susceptibility, by determining their KDT₅₀ and KDT₉₅. The WHO procedure was adopted. The number of knockdown (kd) mosquitoes was recorded after 10, 15, 20, 30, 40, 50 and 60 min of exposure. The percent mortalities after 24 h for each chemical were determined. The KDT₅₀ and KDT₉₅ were calculated with the 95% CI. These were as follows: for DDT 4% (34.84 and 74.41), fenitrothion 1% (58.96 and 112.44), malathion 5% (49.37 and 141.25), bendiocarb 0.1% (97.20 and 292.06), propoxur 0.1% (38.88 and 138.20), and deltamethrin 0.05% (58.30 and 147.82) and in lambda-cyhalothrin 0.05% (34.80 and 66.65) respectively. Some recommendations were listed namely: 1) The importance of annual monitoring and evaluation of insecticides commonly used in the area to evaluate the status of resistance, 2) conducting bioassays for insecticides recommended but not commonly used, 3) conducting bioassays for insecticides commonly used for other purposes and possibility for mosquitoes to come in contact with them and 4) screening for new molecules with new modes of action.

Key words: Anopheles arabiensis, DDT, fenitrothion, malathion, Bendiocarb, Propoxur, deltamethrin, lambdacyhalothrin, knockdown time, resistance, El Rahad Agricultural corporation Scheme, Central Sudan.

INTRODUCTION

Malaria is a major health problem in the tropical countries, especially in sub-Saharan Africa, where about 90% of the clinical cases occur. There are nearly 500 million clinical cases of malaria worldwide each year and 1.1 to 2.7 million people die annually (WHO, 2000). The Federal Ministry of Health (FMOH) in the year 2006 stated that malaria is a significant health problem in the Sudan, affecting 52% of outpatients and accounting for 9% of all hospitals deaths. Estimating the burden of malaria is highly needed for evidence-based planning of malaria control. In Sudan, malaria has been the subject of a large amount of epidemiological, entomological and biomedical research (Abdalla et al., 2007).

The use of insecticides is the main strategy for controlling malaria vectors in the Sudan through indoor residual house spraying and, more recently, the use of insecticide-treated bed nets (ITNs) (WHO, 2005).

Anopheles arabiensis is the major malaria vector

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reported from all parts of the country, coexisting with *Anopheles gambiae* s.s. (s. s.) and *Anopheles funestus* in Southern Sudan (Petrarca et al., 2000). These three African mosquitoes are as efficient as malaria vectors because of their marked preference for human environments and humans as hosts and because they adapt so rapidly to changes in the environment. The intensity of malaria transmission by these mosquitoes is determined largely by environmental conditions. *An. gambiae* is usually predominant in humid environments while *An. arabiensis* is found in drier areas, but they coexist widely over much of their range of distribution (Coetzee et al., 2000).

*An. Arabiensies* is adapted to change in the breeding sites according to the change in the environment (WHO, 1975). In Sudan, *An. arabiensis* utilizes different types of breeding sites, such as pools made by the flood (receding floodwater) along the bank of the Nile River, rain pools, and artificial water storage containers. The Anopheline tend to breed in sluggishly moving streams or in stagnant pools, especially where there is a luxuriant growth of weeds or grass and not apt to be found in rapidly flowing streams. Hence, the need for constant care of ditches to prevent them from being obstructed by vegetation (WHO, 2001).

In the absence of methods to control adult mosquitoes, the strategy was to reduce their breeding sites. Accordingly, a considerable effort was made to drain swamps and marshes and to somehow limit the populations of mosquitoes, whether vectors or not (Clive, 2002). What has been learned over the past several decades is that specific control strategies should be developed for specific country conditions (Gillies, 2001). The most important tools to control malaria consist of properly trained personnel with authority to coordinate and carry out their scientific work (Roberts et al., 2000).

Resistance is a potentially powerful, pervasive natural phenomenon. The development and severity of resistance to pesticides is controlled primarily by human action. Ignorance or a lack of concern in dealing with resistance can set the stage for explosions in pest populations leading to reversals in the effectiveness of public health protection programs. Insecticide resistance in *An. Arabiensis* has been reported in various African localities to commonly used insecticides in public health, like organochlorines (OCs) DDT, BHC, dieldrin, pyrethroids and other insecticides (Matambo et al., 2007). Heimingway (1983) in his study reported resistance to malathion (organophosphate, OP), DDT, dieldrin and permethrin (pyrethroids) insecticides in Sudan. Current surveys of *An. arabiensis* in the Sudan showed high levels of DDT, malathion and permethrin resistance in the Gezira and Central Sudan (Abdalla et al., 2007; El Gaddal et al., 1985).

Several reports, workshops and scientists accused agricultural insecticide spraying, whether for the summer or the winter crops, as one of the major reasons behind the fast development of resistance in mosquitoes in general. Agricultural pesticides belong to organochlorines (OCs), for example, endosulfan, Ops, namely, dimethoate, omethoate, malathion, chlorpyrifos, some carbamates, for example, carbayl, methophyl and aldicarb, and several pyrethroids, for example, permethrin, deltamethrin, cypermethrin, alphamethrin, cyhalothrin and fenvalerate etc.

Evidence of DDT resistance in *An. arabiensis* was clearly found in El Dwaime town, where DDT showed only 67.5% (+ 7) mortality rate. *An. arabiensis* was tolerated to DDT in Kosti, Kenana sugar cane and Assalaya sugar cane with mortality rates: 97% (+ 1), 93% (+ 1) and 95% (+ 2) respectively. The susceptibility of *An. arabensis* to the pyrethroid insecticide Lambda cyhalothrin was 74% (+ 8) in Kosti town, 90% (+ 2), Kenana, 94% (+ 2), Assalaya, 88.75% (+ 3), and El Dwaim 76% (+ 4) in Assalaya sugar cane area respectively (Ismail, 2009).

Current surveys of *An. arabiensis* in the Sudan showed high level of DDT and permethrin resistance in the central states of Sudan. The Ministry of Health and malaria vector control program relies mostly in the present studies and investigations. The importance of the (kdr) mutation and potential enzyme-related in DDT resistance strain of *An. arabiensis* from Sennar state to the center of Sudan were detected. Most colonies were exposed to insecticides from all four classes and were approved for use in malaria vector control program (Abdella, 2007).

Insecticide susceptibility bioassay was carried out by Abdella (2007) and the results showed 100% mortality on bendiocarb, 54 to 78% on permethrin, 55 to 66% on DDT and 76 to 78% on malathion. These findings have serious implication for malaria control program in Gezira state. Susceptibility of *An. arabiensis* in Eastern Sudan to insecticide DDT, malathion and fenithrothion were 97.8, 98.3 and 100% respectively. *An. arabiensis* is the sole malaria vector in the Eastern Sudan and is perennial rather than seasonal (Himeidan et al., 2004).

A colony of *An. arabiensis* from the Sennar region of Sudan was selected for resistance to DDT. Adults from the F16 generation of the resistant strain were exposed to all four classes of insecticides approved for use in malaria vector control and showed high levels of resistance to them all (24 h mortalities: malathion 16.7%, bendiocarb 33.3%, DDT 12.1%, dieldrin 0%, deltamethrin 24.0% and permethrin 0%). Comparisons between the unselected base colony and the DDT-resistant strain showed elevated glutathione-Stransferase (P < 0.05) in both sexes and elevated esterase’s (P < 0.05) in males only. The Leu-Phe mutation in the sodium channel gene was detected by polymerase chain reaction and sequencing, but showed no correlation with the resistant phenotype. These results do not provide any explanation as to why this colony exhibits such widespread resistance and further studies are needed to determine the precise mechanisms involved. The implications for malaria vector control in central Sudan...
are serious and resistance management through the rotational use of different classes of insecticides is recommended (Matambo et al., 2007).

Insecticide resistance has long been recorded in almost all West-African countries. Pyrethroid resistance due to Kdr mutation has recently been observed, other resistance mechanisms (resistant AChE, esterases, oxydases, GST) have also been recorded in West- and Central-African populations of An. gambiae (Weill et al., 2003). Although, pyrethroid insecticides are a promising means of controlling Anopheles malaria vectors as compared to DDT, there is a need to monitor for resistance, in order to provide the baseline information for development of an effective control measures for An. arabiensis mosquitoes in the Rahad Agricultural Corporation (RAC) area, the study aims at determining the DDT 4%, fenitrothion 1%, malathion 5%, bendiocarb 0.1%, propoxur 0.1%, deltamethrin 0.05% and lambda-cyhalothrin 0.05%. The present study investigates the susceptibility of An. arabiensis adults to the recommended public health insecticides and their counterparts (DDT 4%, fenitrothion 1%, malathion 5%, bendiocarb 0.1%, propoxur 0.1%, deltamethrin 0.05% and lambda-cyhalothrin 0.05%) that are used in the agricultural sector, namely, in the Rahad Agricultural Corporation (RAC). The study aims at determining the knockdown (KDT_{50} and KDT_{95}) to An. arabiensis and evaluates the level of resistance to these insecticides.

MATERIALS AND METHODS

Study area

EL Rahad agricultural areas, which are found at the East part of the Sudan, include a big agricultural scheme surrounded by many channels. It is covered by several vegetations which make a suitable habitat for mosquito's breeding sites. This study was carried out at (12.5 to 14.5° N and 32.9 to 35.4° E). The state is delimited from the North-east direction by the River Nile state, from the West by Khartoum and Gezira state, from the East by the Ethiopia boarders and from the South by the Blue Nile state.

The climate of the area is tropical continental with 600 mm of annual rainfall. There are three seasons per year; a dry winter from November to February with an average temperature of 27°C, a hot dry summer from March to May with an average temperature 32°C and a cooler rainy season from June to October with an average temperature 26°C. In general, the land is flat, but in many places, it is interrupted by the seasonal khors (Elnaiem et al., 1997).

An. arabiensis existed throughout the year with two peaks, a major one at the end of the rainy season (September) during the irrigated season of the scheme. The second peak is most likely due to the presence of breeding sites that were formed from the puddles of irrigation canals around the area. Thus, An. arabiensis has become perennial instead of seasonal because of irrigation and agricultural practices. Similar findings were reported from an irrigated area in the Gezira scheme in central Sudan (Elgaddal et al., 1985).

Sampling

The study was carried out by collection of mosquitoes' aquatic stages from village 10, 13, 18, 19 and 20. Mosquito larva collection was carried out weekly starting from March to April, 2010.

METHODOLOGY

Insecticide susceptibility/resistance tests

One-to three-day-old female mosquitoes were tested with different insecticides for their susceptibility, using the WHO standard protocol (WHO, 1998) under optimum conditions (temperature 26 to 29 °C and 70 to 80% relative humidity). The results were recorded for either dead or alive mosquitoes during 24 h post-exposure. The test kits and the impregnated papers were obtained from the WHO Eastern Mediterranean Regional Office (EMRO) in Cairo, Egypt. Each test had five replicates on papers impregnated with the aforementioned insecticides and a control tube with oil-treated paper, that is, without insecticide for public health insecticides, and for their counter part of agricultural insecticides, the impregnated papers were brought from University of Gezira, Department of Pesticides and Toxicology. A total of 25 mosquitoes were used per tube. Knockdown was recorded after 1 h and final mortality was recorded after 24 h post exposure, during which time a 10% sugar solution was made available to survivors. Dead and surviving mosquitoes were stored separately in clearly labeled 1.5 ml tubes containing silica gel.

Specimen's collection, identification and rearing

Anopheline larvae were collected from different breeding sites in the study area using standard larval collection kits including: dippers, screened netting, glass and plastic pipettes, plastic buckets, iron dishes and sorted out from other aquatic organisms. Larvae were kept in plastic bottles and bowls covered so as to protect them from the heat. After cleaning and isolating of predators in the field, they were transferred on the same day of collection to the insectary of BNNICD. In the insectary, larvae were reared and fed. When larvae became adults, they were kept in
Table 1: Chemicals used.

<table>
<thead>
<tr>
<th>Class</th>
<th>Insecticides</th>
<th>Concentration %</th>
<th>Expiry date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organochlorines</td>
<td>DDT</td>
<td>4</td>
<td>January, 2014</td>
</tr>
<tr>
<td>Organophosphates</td>
<td>Fenitrothion</td>
<td>1</td>
<td>December, 2010</td>
</tr>
<tr>
<td></td>
<td>Malathion</td>
<td>5</td>
<td>January, 2011</td>
</tr>
<tr>
<td>Carbamates</td>
<td>Bendiocarb</td>
<td>0.1</td>
<td>December, 2011</td>
</tr>
<tr>
<td></td>
<td>Propoxur</td>
<td>0.1</td>
<td>January, 2012</td>
</tr>
</tbody>
</table>

Table 2: Insecticides percentage of mortality rates after 24 h post exposure for the An. arabiensis 2010.

<table>
<thead>
<tr>
<th>No.</th>
<th>Insecticides</th>
<th>No. of tested replicates</th>
<th>No. killed (24 h)</th>
<th>% Mortality (± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DDT</td>
<td>150 (6)</td>
<td>110</td>
<td>88 (± 3)</td>
</tr>
<tr>
<td>2</td>
<td>Fenitrothion</td>
<td>150 (6)</td>
<td>121</td>
<td>96.8 (± 2)</td>
</tr>
<tr>
<td>3</td>
<td>Malathion</td>
<td>150 (6)</td>
<td>74</td>
<td>59.2 (± 9)</td>
</tr>
<tr>
<td>4</td>
<td>Bendiocarb</td>
<td>150 (6)</td>
<td>16</td>
<td>12.8 (± 2)</td>
</tr>
<tr>
<td>5</td>
<td>Propoxur</td>
<td>150 (6)</td>
<td>68</td>
<td>54.4 (± 10)</td>
</tr>
<tr>
<td>6</td>
<td>Deltamethrin</td>
<td>150 (6)</td>
<td>91</td>
<td>72.8 (± 7)</td>
</tr>
<tr>
<td>7</td>
<td>Lambda-cyhalothrin</td>
<td>150 (6)</td>
<td>124</td>
<td>99.2 (± 0.8)</td>
</tr>
</tbody>
</table>

cages with fine meshes (156 meshes/ inch) to rest. 125 adult Anopheles arabiensis mosquitoes per test as exposure and another 25 adult Anopheles arabiensis mosquitoes per test as control were used.

Chemicals used in the study

In this present study, we chose certain chemicals used in the public health sector recommended from WHO (Table 1). These same insecticide classes are widely used to control agricultural pests in Africa and this can pose additional selection pressure on mosquitoes when insecticides contaminated ground water permeates their larval habitats (Hilary et al., 2009). On the other hand, we also tested an agricultural insecticides recommended.

WHO tubes for testing susceptibility of adult mosquitoes

The WHO tube test kit consists of two plastic tubes (125 mm in length and 44 mm in diameter), with each tube fitted at one end with a 16-mesh screen. One tube (exposure tube) is marked with a red dot and the other (holding tube) with a green dot. The holding tube is screwed to a slide unit with a 20 mm hole into which an aspirator will fit for introducing mosquitoes into the holding tube. The exposure tube is then screwed to the other side of the slide unit. Sliding the partition in this unit opens an aperture between the tubes such that the mosquitoes can be gently blown into the exposure tube to start the treatment and then blown back to the holding tube after the timed exposure (generally one hour). The filter-papers are held in position against the walls of the tubes by four spring wire clips: two steel clips for attaching the plain paper to the walls of the holding tube and two copper clips for attaching the insecticidal paper inside the exposure tube (WHO, 2006).

Data analysis

Data was subjected to probit statistical analysis to determine KDT$_{50}$ and KDT$_{95}$.

RESULTS AND DISCUSSION

Susceptibility tests

An. arabiensis females were collected (ca. 1050) and tested. A total of 42 replicates were used, each one containing 25 An. arabiensis, for all the agricultural and public health insecticides tested. All the agricultural insecticides were procured from the Agricultural Research Corporation. The number of knocked down mosquitoes were counted during the exposure time (one hour), and the overall mortality rates were recorded for each insecticide after 24 h and analyzed using SPSS software program probit analysis.

The WHO criteria for determining resistance/susceptibility were applied: 98 to 100% mortality indicates susceptibility; < 80% mortality suggests resistance, and 80 to 97% mortality requires confirmation of resistance (WHO, 1998).

Assessment of resistance to seven insecticides to Anopheles arabiensis and detection of knockdown
resistance (kdr) was carried out in El Rahad area. The result observed from the study showed that Anopheles arabiensis is resistant to DDT 4% (88% ± 3), deltamethrin 0.05% (72.8% ± 7), malathion 5% (59.2% ± 2) and propoxur (54.4% ± 10), while it is highly resistant to bendiocarb (12.8% ± 2). It was found tolerant to fenitrothion 0.1% (96.8% ± 2) although, it was found susceptible to lambda-cyhalothrin 0.05% (99.2% ± 0.8) according to WHO criteria (Table 2 and Figure 1). During bioassay, control showed no mortality.

Knockdown bioassay

Knockdown susceptibility status of Anopheles arabiensis to insecticides and the adult mosquitoes were exposed to the insecticides recommended by WHO using adult susceptibility test according to the standard procedure. The number of mosquitoes knockdown after 10, 15, 20, 30, 40, 50 and 60 min were recorded. Knockdown effects of the tested insecticides to the An. arabiensis population collected from El Rahad are presented in Table 3. The

![Figure 1: An. Arabiensis percentage mortality, after 24 h exposure to the tested chemicals.](image-url)

<table>
<thead>
<tr>
<th>No</th>
<th>Insecticides</th>
<th>No tested (Rep.)</th>
<th>KD (1 h)% mortality</th>
<th>KDT50 min (95% CL)</th>
<th>KDT95 min (95% CL)</th>
<th>Test significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DDT</td>
<td>150 (6)</td>
<td>87.2</td>
<td>33.58 (27.48 - 41.09)</td>
<td>79.06 (61.76 - 101.07)</td>
<td>X² =9.7; df=4; P= 0.04</td>
</tr>
<tr>
<td>2</td>
<td>Fenitrothion</td>
<td>150 (6)</td>
<td>52.0</td>
<td>78.63 (50.45 - 62.89)</td>
<td>358.28 (75.41 - 299.1)</td>
<td>X² =13; df=4; P = 0.01</td>
</tr>
<tr>
<td>3</td>
<td>Malathion</td>
<td>150 (6)</td>
<td>53.2</td>
<td>49.91 (31.66 - 79.13)</td>
<td>157.82 (85.56 - 716.31)</td>
<td>X² =23.48; df=4; P= 0.00</td>
</tr>
<tr>
<td>4</td>
<td>Bendiocarb</td>
<td>150 (6)</td>
<td>21.6</td>
<td>106.08 (77.21 - 174.38)</td>
<td>423.03 (166.32 - 1327.79)</td>
<td>X² =6.47; df=4; P= 0.14</td>
</tr>
<tr>
<td>5</td>
<td>Propoxur</td>
<td>150 (6)</td>
<td>71.2</td>
<td>39.81 (33.97-43.15)</td>
<td>140.17(109.48-202.37)</td>
<td>X² =7.83; df=4; P= 0.001</td>
</tr>
<tr>
<td>6</td>
<td>Deltamethrin</td>
<td>150 (6)</td>
<td>51.2</td>
<td>64.62 (53.85 - 66.86)</td>
<td>191.25 (108.15 - 299.06)</td>
<td>X² =5.21; df=4; P= 0.36</td>
</tr>
<tr>
<td>7</td>
<td>Lambda-cyhalothrin</td>
<td>150 (6)</td>
<td>90.4</td>
<td>35.38 (32.78 - 36.67)</td>
<td>67.46 (61.55- 73.82)</td>
<td>X² =5.24; df=4; P= 0.00</td>
</tr>
</tbody>
</table>

Table 3: KDT₅₀ and KDT₉₅ for An. arabiensis collected from El Rahad area 2010 that were exposed to the tested insecticides.
Figure 2: Regression line of log time knockdown of DDT to *Anopheles arabiensis* collected from El Rahad area after 60 min of exposure.

\[ y = 4.409x - 1.727 \]

\[ \text{Slope} = 4.41 \]

Figure 3: Regression line of log time knockdown of fenitrothion to *Anopheles arabiensis* collected from El Rahad area after 60 min of exposure.

\[ y = 2.4864x + 0.2803 \]

\[ \text{Slope} = 2.49 \]
results indicated that the *An. arabiensis* was found to be resistant to all insecticides tested. The susceptibility bioassay results showed the knockdown times KDT$_{50}$ and KDT$_{95}$ for all the insecticides used; calculated using log-time and probit-mortality regression models.

During the exposed time of mosquitoes to insecticides, numbers of mosquitoes knocked down were recorded after 10, 15, 20, 30, 40, 50 and 60 min of exposure. The study observed that in DDT 4%, the percent mortalities after 24 h were 0, 0, 16, 42.4, 61.6, 78.4 and 87.2% respectively. In fenitrothion 1%, the percent mortalities after 24 h were 0.8, 4.8, 9.6, 8.8, 16, 42.4 and 52% respectively. In malathion 5%, the percent mortalities after 24 h were 0, 0, 5.6, 34.4, 43.2, 48 and 53.6% respectively. In bendiocarb 0.1%, the percent mortalities after 24 h were 0.04, 0.05, 0.02, 6.4, 12.8, 24 and 21.6% respectively. In propoxur 0.1%, the percent mortalities after 24 h were 5.6, 4.4, 26.4, 37.6, 50.4, 63.2 and 71.2% respectively. In deltamethrin 0.05%, the percent mortalities were 0, 1.6, 4, 7.2, 25.6, 35.2 and 51.2% respectively. In lambda-cyhalothrin 0.05%, the percent mortalities were 0, 1.6, 4, 43.2, 64.8, 80 and 90.4% respectively.

The quick knockdown time minutes were obtained by DDT (KDT$_{50}$ = 33.58) and lambda-cyhalothrin (KDT$_{50}$ = 35.38) to *An. arabiensis* followed by propoxur (KDT$_{50}$ = 39.81), malathion (KDT$_{50}$ = 49.91), deltamethrin (KDT$_{50}$ = 64.62), fenitrothion (KDT$_{50}$ = 78.63), while the latest knockdown was obtained by bendiocarb (KDT$_{50}$ = 106.08) (Table 3 and Figures 2, 3, 4, 5, 6, 7 and 8). With regard to the KDT$_{95}$, it was observed that the quick knockdown time minutes were obtained by lambda-cyhalothrin (KDT$_{95}$ = 67.49) and DDT (KDT$_{95}$ = 79.06) which indicate that the population were more homogenous to lambda-cyhalothrin and DDT than other insecticides (Table 3 and Figures 2, 3, 4, 5, 6, 7 and 8).

This entomological study was carried out in an agricultural area in eastern Sudan. *An. arabiensis* was the main vector (99.9%) found in the area; only 0.1% was *An. pharoensis* and no other species were detected. This agrees with a previous study from the nearby area (Gedaref) in the eastern Sudan, where *An. arabiensis* was the main vector, besides 2 other species, *An. pharoensis* and *An. funestus* (Hamad et al., 2002). *An. arabiensis* and *An. gambiae* are the only species of the *An. gambiae* complex reported in Sudan (Petrarca et al., 2000; Zahar, 1985). Previous studies carried out in central Sudan based on morphology and cytogenetics identified only *An. arabiensis* (El Gaddal et al., 1985; Petrarca et al., 2000).

In Africa, resistance to pyrethroid insecticide in malaria vector mosquitoes may become a major problem for malaria interventions because pyrethroids are the mainstay of vector control strategies (WHO, 2000). According to the WHO criteria for characterizing insecticide susceptibility; Anopheles species was found to
Figure 5: Regression line of log time knockdown of bendiocarb to *Anopheles arabiensis* collected from El Rahad area after 60 min of exposure.

y = 2.7262x - 0.5335
Slope = 2.73

Bendiocarb (KDT50 = 106.08, KDT95 = 423.03)
El Rahad area

Figure 6: Regression line of log time knockdown of propoxur to *Anopheles arabiensis* collected from El Rahad area after 60 min of exposure.

y = 3.0049x + 0.1999
Slope = 3.00

propoxur \{KDT50 = 39.81, KDT95 = 140.17\}
El Rahad area
be resistance to DDT 4% 88% (± 3) and evidence of DDT resistance in An. arabiensis was clearly found in other many semi areas like El Dwaim, where DDT showed only 67.5% (± 7) mortality rate. Current surveys of An. arabiensis in the Sudan showed high level of DDT and permethrin resistance in the central states of Sudan.
Also, the insecticide susceptibility bioassay result showed 55.4 to 99.1% mortality on DDT 4% in Gezira and Sennar states (Hiba et al., 2007). Resistance to the organochlorines DDT and the now obsolete dieldrin was first reported in African malaria vectors in the 1950s and 1960s (Hilary et al., 2009).

Anopheles species were found to be tolerant to fenitrothion 0.1% (96.8%) and at the same time, it found also tolerant in an irrigated area of eastern Sudan (96.3%) (Hamad et al., 2002). This result is in line with central Sennar (96.6%) march 2005 (Dukeen, 2006).

The use of malathion for IRS in central Sudan was stopped in 1978 as a result of physiological resistance (El Gaddal et al., 1985). Insecticides from the organophosphate group are still widely used for agricultural purposes in the Gezira Agricultural Scheme (GAS, unpublished data) and presumably play an important role in selecting for resistance to this group of insecticides, in this study, Anopheles species was found to be resistant to malathion 5 and 59.2% (± 9) and the semi result (56.3%) obtained from Khartoum state 2005 (Dukeen, 2006). On the other hand, the results obtained from Gezira and Sennar states (Hiba et al., 2007) showed that the insecticide susceptibility bioassay result showed 76 to 100% mortality on malathion 5%. An. arabiensis showed high resistant to bendiocarb (12.8%) and was found resistant in Sennar state (33.3%). An. arabiensis was found resistance to propoxur (54.4%) in the study area and also, it recorded low percentage of mortality in other areas like (47.5%) in Tabat and Wad Raiah in Gezira state, February, 2005 (Dukeen, 2006).

An. arabiensis was found resistance to deltamethrin 0.05% (72.8%), in Sennar, Anopheles arabiensis was found highly resistance (24.0%), while in El Maygooma, Khartoum state, it was found at the same range (52 to 96%) (Dukeen, 2006). An. arabiensis was found susceptible to lambda-cyhalothrin 0.05% (99.2%) at El Rahad area, while in other studies, it was found resistance in Kosti town (74% ± 8), in Kenana (90% ± 2), in Assalaya village (94% ± 2), in El Dwaim (88.75% ± 3) and in Assalaya sugar cane area (76% ± 4) (Ismail, 2009).

The KDT50 and KDT95 for An. Arabiensis were collected from El Rahad area 2010. The most effective insecticides among the tested were lambda-cyhalothrin and DDT, followed by propoxur; then medium fenitrothion, malathion and deltamethrin and the weakest is bendiocarb. The fastest in knockdown is DDT, followed by lambda-cyhalothrin and propoxur; the rest of the tested insecticides were taken from 64 to 106 min. This indicates that resistances may occur due to the lack of operational research in the area, proper application of the insecticides and the accurate usage of techniques related with dosages and procedures. The highest values of the slope were recorded by lambda-cyhalothrin followed by DDT and the rest are from 2.5 to 3.5. The high values refer to the more homogeneity of the population of An. Arabiensis to the tested insecticides.

Possible factors influencing the frequency of resistant individuals observed in the study area were discussed. The results of this study highlight the importance of standardized longitudinal insecticide resistance monitoring and the urgent need for studies to monitor the impact of this resistance on malaria vector control activities.

These results are in line with Gedaref State Ministry of Health reports which, indicate that this area is the highest endemic area with malaria victims as compared to other areas of the State, this reflects that the intensive use of different insecticides in agricultural and public health sectors in this area could be the reason of resurgence of the malaria vectors and selection malaria vector resistant.

**Conclusion**

In conclusion, the findings on insecticide resistance or susceptibility have serious implications for the vector and pest control programs. A resistance management strategy through the rotational use of insecticides should be applied, but issues of cost and residual life would have to be taken into consideration. As it stands, resistance data collected during this study indicate vector control program failure, and whether this is due to insecticide resistance in An. arabiensis, poor spray coverage, incorrect dosages applied to the walls or breakdown of the insecticide, this needs to be urgently addressed. The results of this study will enable informed selection of insecticides for vector control programs as well as provide baseline information essential in the monitoring of the development of insecticide resistance. It is important to note that the establishment of the El Rahad agricultural corporation in the area has resulted in a serious abundance of An. arabiensis throughout the year. More studies are needed in order to assess the role of malaria vector control and other pests.

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