NEW PARADIGMS FOR MALARIA VECTOR CONTROL AND ELIMINATION

PARASITE RATES OF INFANTS UP TO ONE YEAR OLD

Gerry Killeen

IFAKARA HEALTH INSTITUTE

LSTM

LIVERPOOL SCHOOL OF TROPICAL MEDICINE
FIG. 1. Numbers of *A. gambiae* and *A. funestus* in spray catches in huts.
\[ \beta = -0.0013, \text{ se } = 4.19 \times 10^{-5} \]

\[ p < 0.0001 \]
DISTINGUISHING VECTOR CONTROL LIMITATIONS FROM FAILURES

SUSTAINED IMPACT

IMPACT LIMITATION

MALARIA TRANSMISSION INTENSITY

YEARS SINCE INTRODUCTION OF AN INTERVENTION

VERSUS

UNSUSTAINED IMPACT

IMPACT LIMITATION

REBOUNDSING RESIDUAL TRANSMISSION

MALARIA TRANSMISSION INTENSITY

YEARS SINCE INTRODUCTION OF AN INTERVENTION

LIMITATION OF VECTOR CONTROL IMPACT DUE TO PRE-EXISTING BEHAVIOURAL RESILIENCE TO THE INTERVENTION WITHIN THE MOSQUITO POPULATION

FAILURE OF VECTOR CONTROL IMPACT DUE TO EITHER
1) WEAKENING OF CONTROL IMPLEMENTATION OR
2) EMERGENCE OF SELECTED BEHAVIOURAL OR PHYSIOLOGICAL RESISTANCE TO THE INTERVENTION WITHIN THE MOSQUITO POPULATION

Govella et al 2013 Malar J 12: 124
Best practice for holoendemic sub-Saharan Africa over the last half century

Adapted from Smith et al. 2007 PLoS Biol 5: e42

Killeen 2013 AJTMH 88:809
GLOBAL PLAN FOR INSECTICIDE RESISTANCE MANAGEMENT IN MALARIA VECTORS

Kabula et al 2013 Med Vet Entomol ePub ahead of print
Kabula et al 2012 Trop Med Int Health 17: 742
Fig. 5. Experimental hut study of mortality of *An. gambiae* and *An. funestus* when exposed to chlorpyrifos-methyl (C-M), carbosulfan (Carbo) or deltamethrin.

Figure 3. Experimental hut trial 3: mortality of free-flying wild *Anopheles arabiensis* and *Culex quinquefasciatus* over 2 months to dosages of chlorfenapyr and alpha-cypermethrin. The key indicates the number of mosquitoes entering the 250 mg/m² chlorfenapyr, 30 mg/m² alpha-cypermethrin and untreated huts for *A. arabiensis* and *C. quinquefasciatus*, respectively. Mortality in the same time period for each treatment sharing a letter does not differ significantly (P > 0.05). Error bars represent 95% CI.
THE FIRST COMBINATION NETS WITH TWO COMPLEMENTARY ACTIVE INGREDIENTS

Tungu et al 2010 Malar J 9: 21
JUVENILE HORMONE ANALOGUES FOR STERILIZING BLOOD FED MOSQUITOES

Lwetoijera et al 2014 AJTMH ePub ahead of print
NEW GENERATION COMBINATION NETS THAT SUPPLEMENT PYRETHROIDS WITH JUVENILE HORMONE ANALOGUES TO KILL MORE MOSQUITOES AND STERILIZE ALL SURVIVORS

Table 5. Fecundity and Fertility of blood-fed *An. gambiae* females alive after 24 h from experimental huts.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>PPF LN</th>
<th>Olyset Net</th>
<th>Olyset Duo</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of blood fed females observed</td>
<td>27</td>
<td>19</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>% of females that oviposited (95% CI)</td>
<td>37(17–57)^a</td>
<td>0^b</td>
<td>47(20–74)^a</td>
<td>0^b</td>
</tr>
<tr>
<td>Total number of eggs laid</td>
<td>1003</td>
<td>0</td>
<td>850</td>
<td>0</td>
</tr>
<tr>
<td>Eggs per female laying eggs (95% CI)</td>
<td>100</td>
<td>–</td>
<td>121</td>
<td>–</td>
</tr>
<tr>
<td>Fecundity: eggs per blood fed female observed (95% CI)</td>
<td>37(15–58)^a</td>
<td>0^b</td>
<td>57(30–74)^a</td>
<td>0^a</td>
</tr>
<tr>
<td>% reduction in fecundity per female observed</td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>100</td>
</tr>
<tr>
<td>Total number of larvae</td>
<td>981</td>
<td>0</td>
<td>782</td>
<td>0</td>
</tr>
<tr>
<td>Hatch rate %, (95% CI)</td>
<td>98 (97–99)^a</td>
<td>–</td>
<td>92 (90–94)^b</td>
<td>–</td>
</tr>
<tr>
<td>Larvae per female laying eggs (95% CI)</td>
<td>98</td>
<td>–</td>
<td>112</td>
<td>–</td>
</tr>
<tr>
<td>Larvae per female observed (95% CI)</td>
<td>36(14–57)^a</td>
<td>0^b</td>
<td>52(39–71)^a</td>
<td>0^a</td>
</tr>
<tr>
<td>% reduction in reproductive rate per blood fed female observed</td>
<td>–</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

^a,b^ Values along each row sharing the same letter superscript are not significantly different at the 5% level.
doi:10.1371/journal.pone.0093603.t005
Fig. 1. Numbers of *A. gambiae* and *A. funestus* in spray catches in huts.
CAUSES OF PERSISTING RESIDUAL TRANSMISSION

- Oviposit
- Emerge
- Feed on unprotected humans or animals outdoors
- Feed on unprotected humans indoors
- Avoid contact with insecticide-treated surfaces and exit house in search of unprotected hosts
- Nocturnal host-seeking
- Crepuscular host-seeking
- Sugar feeding
- Gestate

Dusk and dawn
Night time
Day time
EMERGE
GESTATE
FEED ON UNPROTECTED HUMANS OR ANIMALS OUTDOORS
FEED ON UNPROTECTED HUMANS INDOORS

NIGHT TIME
DUSK AND DAWN
DAY TIME

NOCTURNAL HOST-SEEKING
Crepuscular Host-Seeking

SUGAR FEEDING
FEED ON UNPROTECTED HUMANS OR ANIMALS OUTDOORS

AVOID CONTACT WITH INSECTICIDE-TREATED SURFACES AND EXIT HOUSE IN SEARCH OF UNPROTECTED HOSTS

REPELLENTS OR INSECTICIDAL CLOTHING/EMANATORS/DRUGS

OVIPosit
EMERGE
GESTATE
SUGAR FEEDING

Protecting humans outdoors with vapour phase repellents

Classical formats

Contemporary formats
Ogoma et al (In preparation)
EMERGE
GESTATE
FEED ON UNPROTECTED HUMANS OR ANIMALS OUTDOORS
FEED ON UNPROTECTED HUMANS INDOORS
NIGHT TIME
DUSK AND DAWN
DAY TIME
NOCTURNAL HOST-SEEKING
CREPUSCULAR HOST-SEEKING
SUGAR FEEDING
FEED ON UNPROTECTED HUMANS OR ANIMALS OUTDOORS
AVOID CONTACT WITH INSECTICIDE-TREATED SURFACES AND EXIT HOUSE IN SEARCH OF UNPROTECTED HOSTS
TOPICAL OR SYSTEMIC INSECTICIDE TREATMENTS OR LETHAL HOST-MIMICKING TRAPS
SUGAR FEEDING
EMERGE
GESTATE
LIVESTOCK AS A TARGET FOR VECTOR CONTROL

Figure 1: Picture of a rectangular net hut and its schematic representation. The sections of net hut are (A) left-hand side releasing chamber, (B) host or middle chamber, (C) right-hand side releasing chamber, and (D) open eaves with baffles to allow host-seeking mosquitoes to enter host chamber.

Figure 2: Mud hut at Lupiro village with fixed (A) cotton-cloth roof treated with fungal conidia, (B) baffles to reduce exit of mosquitoes, (C) mud walls either treated with fungal conidia or untreated for resting mosquitoes, and (D) open eave to allow host seeking mosquitoes to enter inside the hut.
Lwetoijera et al 2014 AJTMH ePub ahead of print

![Image](image-url)

**A**

![Chart showing data](chart-url)

**B**

![Chart showing data](chart-url)
EMERGE
GESTATE
FEED ON UNPROTECTED HUMANS OR ANIMALS OUTDOORS
FEED ON UNPROTECTED HUMANS INDOORS
NIGHT TIME—DUSK AND DAWN
NOCTURNAL HOST-SEEKING
CREPUSCULAR HOST-SEEKING
FEED ON UNPROTECTED HUMANS OR ANIMALS OUTDOORS
SUGAR FEEDING
AVOID CONTACT WITH INSECTICIDE-TREATED SURFACES AND EXIT HOUSE IN SEARCH OF UNPROTECTED HOSTS
SUGAR FEEDING
TOXIC SUGAR BAITS
GESTATE
OVIPOSIT
EMERGE

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TOXIC SUGAR BAITS

Muller et al. Malar J 9: 262
**Anopheles arabiensis** females

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Chlorfenapyr (0.5%)</th>
<th>Boric acid (2%)</th>
<th>Tolfenpyrad (1%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total caught</td>
<td>97</td>
<td>100</td>
<td>104</td>
<td>109</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>18 (11-26)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48 (38-58)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41 (32-51)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45 (36-54)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mosquitoes with visible dye (%)</td>
<td>25 (17-34)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17 (11-26)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15 (10-24)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17 (11-26)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mortality of visibly dyed mosquitoes (%)</td>
<td>13 (4-32)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94 (67-99)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>84 (61-95)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dead mosquitoes that were visibly dyed (%)</td>
<td>18 (6-43)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35 (23-50)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35 (22-50)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33 (21-47)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Figure 1. ATSB station positioning in experimental huts.*

Stewart et al 2014 PLoS One 8: e81468

Okumu et al 2013 Parasit vector 6: 46

<table>
<thead>
<tr>
<th>IRS/LLIN combinations</th>
<th>Mortality of <em>Anopheles arabiensis</em></th>
<th>Median (IQR)</th>
<th>Total dead(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated nets only**</td>
<td>10.4 (04.2 - 18.1)</td>
<td>968 (90)</td>
<td></td>
</tr>
<tr>
<td>Olyset® only</td>
<td>14.8 (09.3 - 23.9)</td>
<td>1742 (90)</td>
<td></td>
</tr>
<tr>
<td>PermaNet 2.0® only</td>
<td>19.7 (11.2 - 30.1)</td>
<td>1644 (90)</td>
<td></td>
</tr>
<tr>
<td>Icon Life® only</td>
<td>16.7 (07.2 - 26.4)</td>
<td>2121 (90)</td>
<td></td>
</tr>
<tr>
<td>Pirimiphos methyl and untreated nets</td>
<td>23.4 (12.9 - 36.7)</td>
<td>1599 (60)</td>
<td></td>
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<tr>
<td>Pirimiphos methyl and Olyset®</td>
<td>20.3 (12.4 - 31.2)</td>
<td>2171 (60)</td>
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<tr>
<td>Pirimiphos methyl and PermaNet 2.0®</td>
<td>25.0 (14.6 - 36.9)</td>
<td>2146 (60)</td>
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<tr>
<td>Pirimiphos methyl and Icon Life®</td>
<td>21.8 (11.9 - 34.2)</td>
<td>2305 (60)</td>
<td></td>
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<tr>
<td>DDT and untreated nets</td>
<td>17.1 (08.0 - 28.3)</td>
<td>943 (60)</td>
<td></td>
</tr>
<tr>
<td>DDT and Olyset®</td>
<td>19.2 (11.6 - 28.1)</td>
<td>1201 (60)</td>
<td></td>
</tr>
<tr>
<td>DDT and PermaNet 2.0®</td>
<td>19.4 (12.6 - 34.1)</td>
<td>1171 (60)</td>
<td></td>
</tr>
<tr>
<td>DDT and Icon Life®</td>
<td>14.7 (09.7 - 24.1)</td>
<td>1255 (60)</td>
<td></td>
</tr>
<tr>
<td>Lambda cyhalothrin and untreated nets</td>
<td>17.8 (10.4 - 28.6)</td>
<td>1431 (60)</td>
<td></td>
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<tr>
<td>Lambda cyhalothrin and Olyset®</td>
<td>14.2 (09.0 - 27.7)</td>
<td>1578 (60)</td>
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</tr>
<tr>
<td>Lambda cyhalothrin and PermaNet 2.0®</td>
<td>19.0 (10.8 - 33.4)</td>
<td>1768 (60)</td>
<td></td>
</tr>
<tr>
<td>Lambda cyhalothrin and Icon Life®</td>
<td>18.4 (09.3 - 26.2)</td>
<td>1893 (60)</td>
<td></td>
</tr>
</tbody>
</table>
EMERGE
GESTATE
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AVOID CONTACT WITH INSECTICIDE-TREATED SURFACES AND EXIT HOUSE IN SEARCH OF UNPROTECTED HOSTS
SUGAR FEEDING
IMPROVED METHODS FOR KILLING INSIDE HOUSES

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FORCING MOSQUITOES INTO FATAL CONTACT WITH CONTAMINATED EAVE BAFFLES WHEN THEY EXIT HOUSES
LOW COST MOSQUITO CONTAMINATION DEVICES

Eave tube

Eave brick

Eave screen

Smart patch
Female is attracted to the trap

Oviposition/resting device

Combination therapy of insecticides

Outdoor host seeking mosquito device
FEED ON UNPROTECTED HUMANS INDOORS

AVOID CONTACT WITH INSECTICIDE-
TREATED SURFACES AND EXIT HOUSE IN
SEARCH OF UNPROTECTED HOSTS

SUGAR 
FEEDING

IMPROVED IMPLEMENTATION MODELS
FOR LARVAL SOURCE MANAGEMENT

NOCTURNAL HOST-
SEEKING

CREPUSCULAR 
HOST-SEEKING

EMERGE

GESTATE

FEED ON UNPROTECTED HUMANS OR 
ANIMALS OUTDOORS

NIGHT TIMEDUSK AND DAWN

DAY TIME
Application of microbial larvicide granules (*Bacillus thuringiensis* var.*israelensis*) by UMCP field worker
Auto-dissemination of Pyriproxyfen (JHA) in breeding sites by adult mosquitoes (mothers killing their own babies!!!)

resting exposure to JHA dust

transfer of dust on body

contamination of sentinel site containing juvenile stages
JHA AUTODISSEMINATION BY ANOPHELES ARABIENSIS IN LARGE CAGES

Lwetoijera et al 2014 Malar J (In press)
Thanks very much
Asanteni sana