EFFICACY OF INSECT REPELLENTS CURRENTLY AVAILABLE IN NEW ZEALAND

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Diseases transmitted by arthropods (vector-borne) account for more than 17% of all infectious diseases, causing more than one million deaths annually. Vector-borne diseases such as malaria, Chagas disease, leishmaniasis and schistosomiasis affect hundreds of millions of people worldwide. Vector species include mosquitoes, sandflies, tsetse flies, black flies, fleas and ticks. In addition to disease transmission, arthropods bites or stings can constitute a considerable nuisance and have the potential to be entry sites for infections. Use of insect repellents has been identified as one measure for reducing the personal and societal burden associated with biting arthropods.

The current project reviewed information on the efficacy of chemical repellents of disease vector and human nuisance insects. It has not included review of material on repellents for the control of stored food pests or repellents that are not applied to human skin (eg. permethrin). It has also not included substances that are primarily for use on animals. Studies were selected for this report if they included comparative assessments of repellency, and comprised of at least one active ingredient contained within products currently available in New Zealand.

A number of general conclusions can be drawn:

- A high proportion of commercial insect repellents are based on a small number of active ingredients; *N,N*-diethyl-3-methylbenzamide (DEET), picaridin, IR3535 and oil of lemon eucalyptus or its active ingredient, *p*-methane-3,8-diol (PMD).[1]
- Most insect repellent products available in New Zealand are based on these active ingredients, although a number of companies are producing 'natural' (plant-oil based) alternatives.
- With all active ingredients the effectiveness, either expressed as the degree of protection or the duration of protection, increases with the concentration of active ingredient in the product.
- DEET remains the 'gold standard' against which other products are compared. While occasional comparisons may suggest that other products offer superior protection to DEET, such studies often use quite low concentrations of DEET (5-10%).
- While the protective performance of DEET is concentration-related, there is evidence to suggest that the marginal benefits of products containing greater than 25-30% DEET are minor and the performance of DEET-based repellents appears to plateau at concentrations above 50% DEET.
- The protective performance of the other main active ingredients is also concentration-related, however, these active ingredients are rarely present in commercial formulations at concentrations above 20-25%.
- While some plant oil-based product show excellent protection in the short-term, most of the available evidence suggests that protection due to such products is less long-lasting than with the synthetic active ingredients. The duration of protection of plant oil-based products can often be improved by addition of vanillin (5-10%). Although

[1] PMD may be added to insect repellent formulations as oil of lemon eucalyptus, containing approximately 65% PMD, or as synthetic PMD. Products currently available in New Zealand use oil of lemon eucalyptus.

the duration of protection of synthetic insect repellents can also be extended by addition of vanillin, the effect is particularly marked with plant oil-based products.

- While the majority of comparative studies have been carried out against mosquito species, the small number of studies available suggest that the common active ingredients are effective against a wide range of vector and nuisance-biting arthropod species. A single study also demonstrated repellency against a non-arthropod species (leeches). No studies were found on the efficacy of repellents against native New Zealand blackflies (*Austrosimulium spp.).*
- Different mosquito species show differing susceptibilities to the effects of insect repellents, with repellents often having shorter durations of complete protection against *Aedes* spp. than *Anopheles* or *Culex* spp.
- There is some evidence that different species of non-mosquito arthropods also vary in their susceptibility to the effects of insect repellents.

It is worth noting that, while a number of studies have included assessment of repellency against one of the major biting mosquito species in New Zealand, *Culex quinquefasciatus*, no information was found on the effectiveness of various insect repellents against other human-biting mosquito species present in New Zealand. Similarly, although studies have assessed repellency against black flies of the genus *Simulium*, none were found that assessed repellency against our native black flies (sand flies), which are of the genus *Austrosimulium.* While these genera are members of the same tribe, it is uncertain how applicable results on *Simulium* species are to *Austrosimulium* species. However, this observation will also be true of many human-biting arthropod species in many countries. The main active ingredients appear to be effective against all arthropod species tested so far and there is no reason to expect that New Zealand species would be resistant to these repellents.

The Ministry of Health's current advice on insect repellents is:

> "Wear a repellent cream or spray, preferably containing DEET (diethyltoluamide). (Repellents containing less than 35% DEET are recommended because higher concentrations are no more effective – they just work for longer – and in rare cases they can cause poisoning. Repellent should not be applied to wounds or irritated skin.)"

On the basis of the current review, this advice is still valid. Given the range of insect repellents available in New Zealand and the information in the current review, this advice could be expanded to include formulations based on picaridin and oil of lemon eucalyptus or PMD. The highest levels of protection will be associated with the highest concentrations of actives in commercial products. This is currently 20-25% for picaridin and 30% for oil of lemon eucalyptus, equating to about 20% PMD.

1. INTRODUCTION

Diseases transmitted by arthropods (vector-borne) account for more than 17% of all infectious diseases, causing more than one million deaths annually (WHO 2016). Vector-borne diseases such as malaria, Chagas disease, leishmaniasis and schistosomiasis affect hundreds of millions of people worldwide. Vector species include mosquitoes, sandflies (blackflies), tsetse flies, fleas and ticks (WHO 2016). In addition to disease transmission, arthropods bites or stings can constitute a considerable nuisance and have the potential to be entry sites for infections (MoH 2014).

Many of the disease and nuisance consequences of human interactions with arthropods are preventable through the application of suitable protective measures (WHO 2016). Virtually all prevention campaigns against vector-borne diseases recommend repellent use. In many cases, applying repellent to the skin may be the only feasible way to protect against arthropod bites (Antwi et al 2008; Fradin and Day 2002). While not all vectors are insects, for the remainder of the current document repellent compounds or formulations will be referred to as insect repellents.

1.1 TYPES OF INSECT REPELLENTS

It has been suggested that an ideal insect repellent would have the following properties (Diaz 2016):

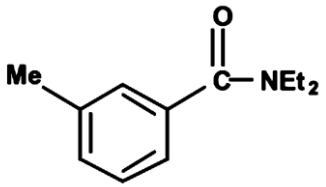
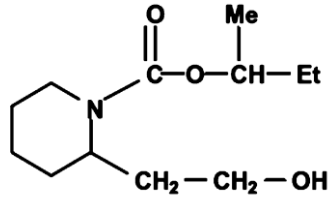
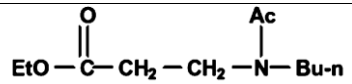
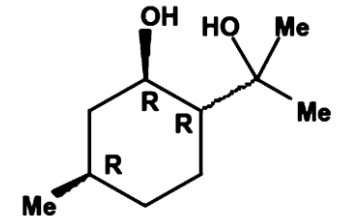
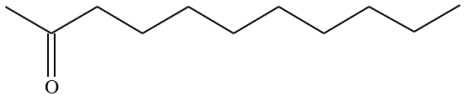
- Effective against a broad range of arthropods
- Can be applied to skin without adverse effects
- Does not cause damage to clothing (ie. staining, bleaching, thinning)
- Can be applied with sunscreen
- No odour or has pleasant odour
- No oily residues left on skin
- Difficult to remove by washing, wiping, or sweating
- No effect on plastics (ie. glasses, watches, upholstery)
- Chemically stable
- Reasonably priced for broad range of people
- Non-toxic
- Duration of efficacy is adequate.

Although the safety of insect repellents is extremely important, for the purpose of the current project, two of these characteristics are of primary interest; effectiveness against a broad range of arthropods and duration of efficacy.

Commercially available insect repellents contain active ingredients that can be divided into two categories; synthetic chemicals and plant-derived essential oils (Fradin and Day 2002). The best-known synthetic chemical insect repellent is *N,N*-diethyl-3-methylbenzamide (formerly known as *N,N*-diethyl-*m*-toluamide or DEET).

Table 1 lists the most common synthetic and plant-derived insect repellent active ingredients and some of their properties.

Table 1. Common synthetic and plant-derived insect repellent chemicals

Name	CAS Number	Chemical name	Chemical Structure	Plant source(s)
Synthetic				
DEET	134-62-3	*N,N*-diethyl-3-methylbenzamide (formerly known as *N,N*-diethyl-*m*-toluamide)		
Picaridin (KBR3023)	119515-38-7	2-[2-hydroxyethyl]-1-piperidinecarboxylic acid-1-methylpropyl ester		
IR-3535	52304-36-6	3-[*N*-butyl-*N*-acetyl]-aminopropionic acid, ethyl ester		
Plant-derived				
PMD (active component in lemon eucalyptus oil)	42822-86-6	*p*-methane-3,8-diol		*Corymbia citriodora*
Citronella oil	89998-15-2 (Ceylon type) 91771-61-8 (Java type)	Complex mixture, but the major repellent ingredients are considered to be geraniol and citronellal	Complex mixture	*Cymbopogon nardus, C. winterianus*
2-Undecanone	112-12-9	Undecan-2-one		Various, but originally isolated from the wild tomato (*Lycopersicon hirsutum*)

1.2 INSECT REPELLENT PRODUCTS CURRENTLY AVAILABLE IN NEW ZEALAND

Information of available product was largely drawn from internet sources, such as retailer and producer websites. Resources consulted included websites for major pharmacy chains and camping/outdoors retailers. Table 2 summarises information obtained on insect repellent products available in New Zealand.

Table 2. Insect repellent products available in New Zealand

Manufacturer	Product name	Product type	Active ingredient (%)
Aerogard	Heavy duty	Aerosol	DEET (40%)
	Odourless	Pump spray	Picaridin
	Odourless	Aerosol	Picaridin
	Tropical strength	Aerosol	DEET (17.1%)
	Tropical strength	Pump spray	DEET (17.1%)
	Tropical strength	Roll-on	DEET (17.1%)
Bushman	Plus	Aerosol	DEET (20%)
	Plus	Pump spray	DEET (20%)
	Plus	Gel	DEET (80%)
	Heavy duty	Aerosol	DEET (40%)
	Heavy duty	Gel	DEET (80%)
True Blue Organics	Goodbye Sandfly	Pump spray	Plant oils, including eucalyptus, lavender, pine, manuka, tea tree and lemongrass (2.2%)
S. C. Johnson and Son – Off!	Tropical strength	Spray pump	Picaridin (19.1%)
	Tropical strength	Aerosol	Picaridin (19.1%)
Select	Tropical strength	Aerosol	
Rid Australia	Medicated	Aerosol	DEET (16%)
	Tropical	Pump spray	DEET (19.1%)
Skin Shield Products – Repel	Junior	Roll-on	DEET (10%)
	Natural baby	Spray pump	Citronella, lemongrass, lavender
	Natural	Roll-on	Eucalyptus, citronella, lavender
	Natural	Stick	Eucalyptus, citronella, lavender, tea tree
	New Era	Roll-on	Picaridin (20%)
	New Era	Pump spray	Picaridin (25%)
	Olé	Pump spray	Lemon eucalyptus oil (30%)
	Tropical strength	Aerosol	DEET (30%)
	Tropical strength	Pump spray	DEET (30%)
	Tropical strength	Roll-on	DEET (30%)
	Tropical strength	Stick	DEET (30%)
	Tropical strength with sunscreen	Pump spray	DEET (30%), IR3535 (3.75%)
	Ultra	Pump spray	DEET (40%), IR3535 (3.75%)
	Xtreme	Gel/cream	DEET (80%), eucalyptus, lemongrass, tea tree
Wildflower	No bites	Pump spray	Citronella, geranium, lemon, tea tree, peppermint, cedarwood
	No bites balm	Cream	Geranium, lemon, tea tree, cedarwood
Kiwiherb	Herbal	Pump spray	Lemongrass, fennel, *Vitex agnus-castus* extract
Tui Balms	Extra strength	Pump spray	Lemon eucalyptus oil, lavender
	Bug balm	Cream	Neem, lemongrass, citronella, eucalyptus, lavender
Botanica	No insects	Various	Jojoba, canola, wheat germ, avocado, balm mint, geranium and other
	Total outdoor	Various	Jojoba, canola, wheat germ, avocado, balm mint, geranium and other
Badger	Anti-bug face and body	Cream	Castor (10%), citronella, lemongrass, cedar, rosemary, geranium
Dolphin Clinic	Bugs away	Pump spray	Peppermint, citronella, lavender, witch hazel
Ecoroa	Trip spray	Pump spray	Citronella, lavender, lemongrass
Home Essentials	Citronella oil	Oil	
Sky Bright	Ward Off	Pump spray	Almond, neem, lemongrass, tea tree castor

Manufacturer	Product name	Product type	Active ingredient (%)
Protect Skin Technology	Protect	Pump spray	Picaridin (20%)
2B	2B	Pump spray	Lemon eucalyptus oil, lemongrass, vanilla
Hebe Botanicals	Safe	Pump spray	Lemon eucalyptus oil
Red-Eyed	Gotcha	Pump spray	DEET (19.1%)
Bugband	Insect repellent	Pump spray	Geraniol (20%), soybean oil, mint, rosemary, geranium oil
Armed Forces	Insect repellent	Stick	DEET (40%), permethrin (1%)
Skin Technology	Insect repellent	Stick Pump spray Lotion	Picaridin (25%) Picaridin (25%) Picaridin (25%)
New Zealand Cancer Society	SPF30+ Insect Repel	Cream	DEET (4%)
Life Systems	Expedition 20 Expedition 50+ Expedition 100+	Pump spray Pump spray Pump spray	DEET (20%) DEET (50%), pyrethroids DEET (95%), pyrethroids

No national approval register for insect repellents is in place in New Zealand, although all active ingredients and/or products must be approved with respect to their safety by the New Zealand Environmental Protection Authority (NZEPA). Approval may either be for individual actives/products or by demonstrating that the product is eligible for inclusion under the Cosmetic Products Group Standard 2006 (HSR002552).[2] The New Zealand Inventory of Chemical (NZIoC) lists individual approvals for DEET (HSR003365), picaridin (HSR007997), IR3535 (HSR005698) and 2-undecanone (HSR003174), while PMD-containing products are covered under the Group Standard.[3] NZEPA approval does not include assessment of the efficacy of products.

1.3 CURRENTLY APPROVED PRODUCTS - USA

The US Environmental Protection Agency (USEPA) has a registration process for skin-applied insect repellents.[4] Registered products are assessed for both safety and efficacy. In addition there are repellent ingredients that do not require registration, as the ingredients have previously been assessed for safety. However, products containing these ingredients have not been assessed for effectiveness.

The USEPA database contains 629 products (as at 1 March 2017). A summary of these products is included in Table 3.

Table 3. Summary of insect repellent products registered by USEPA

Active ingredient	Range of active concentrations (%)	Number of products
DEET	5-98.1	505
Picaridin	5-20	54
IR3535	7.5-20.1	41
Oil of lemon eucalyptus	30-40	13
PMD (synthetic)	8-10	8
Catnip oil	7-15	4

[2] http://www.epa.govt.nz/Publications/gs-cosmetic-2006.pdf Accessed 3 May 2017
[3] http://www.epa.govt.nz/Publications/New-Zealand-Inventory-of-Chemicals.xlsx Accessed 3 May 2017
[4] https://www.epa.gov/insect-repellents/regulation-skin-applied-repellents Accessed 1 March 2017

Citronella	4.2-5	3
2-Undecanone	7.75	1

By far the majority of products are formulated with DEET, with concentrations of the active ingredient ranging from 5% to a near pure solution (98.1%).

1.4 RECOMMENDED INSECT REPELLENT – CDC

The US Centers for Disease Control and Prevention (CDC) recommend the use of products containing active ingredients registered by USEPA. CDC also notes that "Of the products registered with the EPA, those containing DEET, picaridin, IR3535, and some oil of lemon eucalyptus and para-methane-diol products provide longer-lasting protection".[5]

1.5 CURRENT PROJECT

The current project reviews information on the efficacy of chemical repellents of disease vector and human nuisance insects. It has not included review of material on repellents for the control of stored food pests or repellents that are not applied to human skin (eg. permethrin). It has also not included substances investigated primarily for use on animals.

Studies were selected for this report if they included comparative assessments of repellency, and comprised of at least one active ingredient contained within products currently available in New Zealand.

[5] https://www.cdc.gov/westnile/faq/repellent.html Accessed 27 March 2017

2. REPELLENT TESTING

There are two quite distinctive characteristics of chemicals used to protect against insect biting that can be tested under laboratory or field conditions. These tests may measure the insecticidal activity of the chemical (knock down and mortality) or spatial repellency (WHO 2013). The current report is primarily concerned with spatial repellency; the ability of a chemical to induce behaviours in a vector species, such as movement away from a chemical stimulus, interference with host detection (attraction inhibition) and feeding response (WHO 2013).

2.1 LABORATORY TESTING

It should be noted that descriptions of testing methods included below are not intended to be detailed, but are intended to give the reader context in the later discussions of relative efficacy of different products.

2.1.1 WHO Methods

The WHO methods for spatial repellency are worded in terms of mosquito repellency, but are presumably applicable to all biting arthropod species (WHO 2013). Standardised insect rearing conditions should be used and it is recommended that testing (for mosquitoes) be carried out with nulliparous female mosquitoes at age 6-8 days post-emergence.

Movement away from chemical stimulus

The apparatus for this test is shown in Figure 1. The apparatus has a clear central cylinder, with identical metal cylinders that can be attached to either end of the clear cylinder. The metal cylinders have an absorbant material impregnated with either control or active ingredient introduced into the base (furthest from the clear cylinder). The metal cylinders also have shutters or other means of isolating them from the clear cylinder.

Test insects are introduced into the clear cylinder and, after a set period of time (10 minutes), the shutters are closed and the number of insects in the control and treatment metal cylinders are counted. Initial and 24 hour knockdown is also recorded to determine if the test substance also needs to be separately tested for insecticidal activity. Test substances are tested at five dilutions, as a minimum.

Nine replicates of the test are performed at each dilution and a repellency index calculated from the difference in insect numbers between the control and test metal cylinders. The spatial activity index (SAI) is calculated as:

$$SAI = \left[\frac{N_c - N_t}{N_c + N_t}\right] \times \left(\frac{N_m}{N}\right)$$

Where:

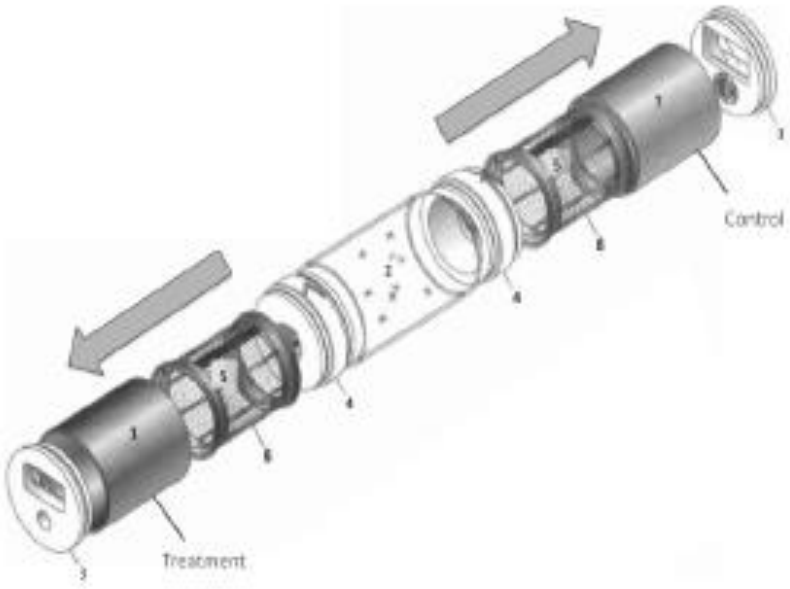
N_c is the number of insects in the control metal cylinder

N_t is the number of insects in the test metal cylinder

N_m is the total number of insects in the two metal cylinders

N is the total number of insects in the test apparatus

A SAI of zero means there has been little movement of insects or the movement has been totally random. A SAI of one means that all insects are present in the control cylinder (strong repellency).

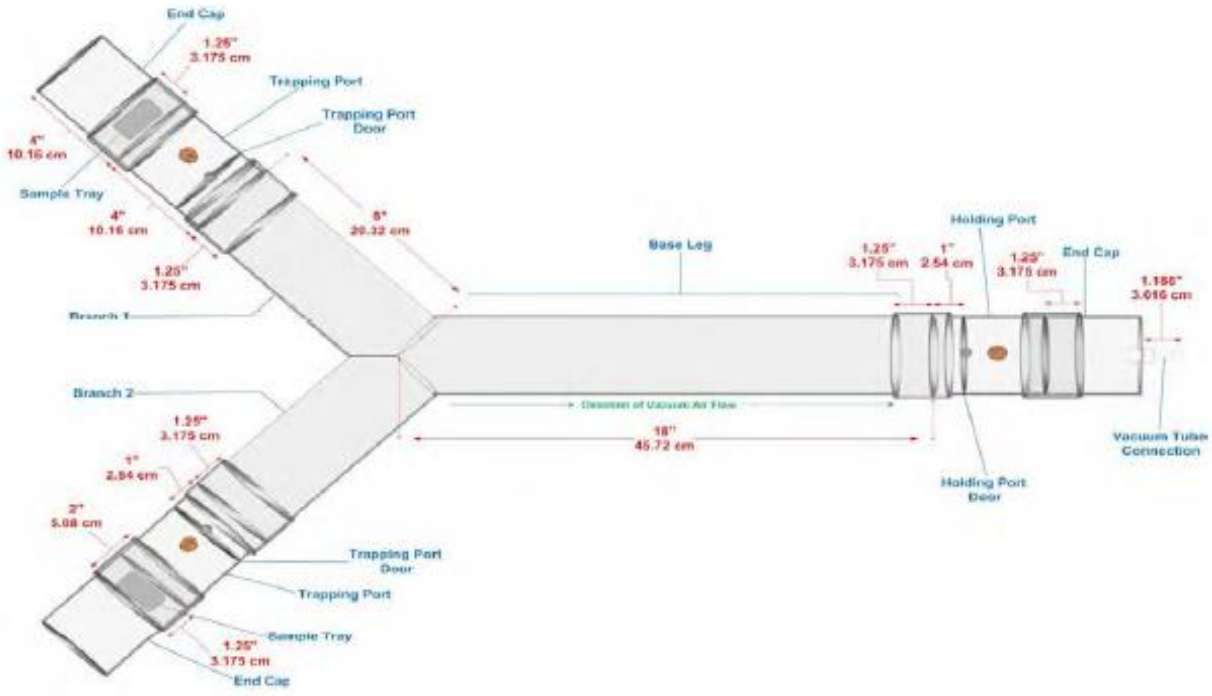


Reproduced from (WHO 2013)

Figure 1. Spatial repellency test apparatus

Host attraction-inhibition

The host attraction-inhibition test measures the ability of a test substance to inhibit mosquito attraction to a host. This is achieved by use of a Y-tube olfactometer to measure attraction to host odours in the absence and presence of the test substance. A schematic of the Y-tube olfactometer is shown in Figure 2.



Reproduced from (WHO 2013)

Figure 2. Attraction-inhibition test apparatus

Insects (mosquitoes) are introduced along the central arm of the apparatus. Host odours are circulated up both the control and test arms. The control arm contains diluent only, while the test arm contains serial dilutions of the test substance. Both of these arms contain trapping ports for collection of insects that move down the arm.

At the end of testing, the proportion of mosquitoes attracted to the test substance is determined. The percentage attracted to the test substance is calculated by dividing the number of insects trapped in the test substance port by the total number of insects in the test (minus damaged mosquitoes). Spatial repellency is indicated by a lower percentage attraction of insects to host odours plus test substance than to host odours with diluent only.

Protective efficacy of formulated products

In these tests insects are introduced into a room or a pair of inter-connected 'free flight' rooms. Insects are released into the room containing a human volunteer or an adjacent room if vector entry into a space is the objective of the evaluation. If human landing catch is being measured, insects are collected for one hour continuously. If feeding inhibition is being measured, the volunteer remains in the room for the period of interest, and blood-fed insects are collected by aspiration from the interior space at the end of the test. For duration of efficacy studies, test should be carried out at specified intervals throughout the expected efficacy period. Tests are carried out in the same space under conditions of repellent treatment (treatment space) or without repellent treatment (control space).

Results of the study are determined as:

$$\%\ Landing\ inhibition = 100\ \times \frac{(C_l - T_l)}{C_l}$$

Where:
C_l is the number of insects landing in the control space
T_l is the number of mosquitoes landing in the treatment space

$$\%\ Feeding\ inhibition = 100\ \times \frac{(C_f - T_f)}{C_f}$$

Where:

C_f is the number of blood fed insects in the control space
T_f is the number of blood fed insects in the treatment space

2.1.2 Other laboratory methods

Test cages

A huge number of variants of this method have been used. In its general format, test insects are introduced into a cage (usually about 30 x 30 x 30 cm), fitted with an access sleeve. The forearm or hand of a human volunteer is treated with repellent. The forearm or hand is introduced into the cage for a period of time (30 seconds to 5 minutes) at intervals (usually every 30 minute or 1 hour). Tests are usually continued until two bites were received in a single exposure period or one bite was received in each of two successive exposure periods. Protection time was defined as the time from repellent application to the exposure period immediately preceding the final exposure period or the first of the two final exposure periods. Individual studies varied in the size of cage, the number of insects in the cage, the duration and frequency of exposure, the application rate of repellent substance and the amount of skin exposed.

2.2 SEMI-FIELD STUDIES

Semi-field trials seek to extend the results of laboratory efficacy studies by testing formulated products against free-flying insect populations under simulated indoor or outdoor conditions. Semi-field trails are conducted in screened enclosures with controlled vector populations and population densities. Indoor trials can be carried out in experimental huts within the screened enclosures.

2.2.1 WHO Methods

Indoor effective dosage and duration of protective efficacy

It is preferable that several identical huts are available and that these huts are similar in design to dwellings in the region that the repellent is intended for. A human volunteer is positioned in the centre of the hut. A known number of well-characterised insects are introduced into the exposure. The WHO document does not provide exact details of study design, but notes that these experimental set-ups can be used for studies of landing inhibition or feeding inhibition.

Outdoor effective dosage and duration of protective efficacy

The study designs outlined in the WHO document relate to point repellents, such as mosquito coils, rather than topical repellents. A single human volunteer is placed in a netted space at a set distance from a repellent source or control source. A set number of insects (n = 100) are released into the enclosure, with the repellent source between the volunteer and the release point. This study design can be used to measure landing inhibition or feeding inhibition.

2.3 FIELD STUDIES

The aim of field studies is to measure the personal protection offered by a spatial repellent product in operational settings and against free-flying natural indoor and/or outdoor populations of a target species. The degree of personal protection is measured by comparing landing inhibition with treatment and with control.

2.3.1 WHO methods

Due to the wide range of requirements for such studies, WHO provide only general guidelines, including the need for replication and randomisation of treatment and control households and blinding with respect to insect collectors (i.e. insect collectors should not know whether they are assigned to a treatment or control household). In addition, the health status of volunteers should be monitored before, during and after the trial.

3. COMPARATIVE STUDIES OF INSECT REPELLENT EFFICACY

3.1 LABORATORY STUDIES

3.1.1 Afify et al (2014)

Three repellents (Methyl N,N-dimethyl anthranilate (MDA), ethyl anthranilate (EA) and butyl anthranilate (BA)) were compared to DEET in their ability to prevent blood feeding and oviposition by the mosquito species, *Aedes aegypti*. A y-tube olfactometer (see Figure 2) was used to test attraction/repellency of host-seeking mosquitoes toward the test substances. All test substances were diluted to 10% in acetone. The experimenter provided two fingers as a host attractant. Each experiment involved release of 20 non-blood fed female *A. aegypti* mosquitoes, aged 5-10 days.

The oviposition experiments tested the ability of the test substances to deter or stimulate egg-laying and are not of relevance to the current review.

Results were expressed in terms of a preference index (PI):

$$PI = \frac{Number\ of\ mosquitoes\ in\ test\ chamber - Number\ of\ mosquitoes\ in\ control\ chamber}{Number\ of\ mosquitoes\ in\ test\ chamber + Number\ of\ mosquitoes\ in\ control\ chamber}$$

The PI will have values between +1 and -1, with negative values indicating repellency. MDA, EA and DEET all showed significant repellency, while the PI for BA was not significantly different to zero. While the authors of the study did not comment on the matter, the PIs for MDA, EA and DEET do not appear to be significantly different at a concentration of 10% test substance.

3.1.2 Aguiar et al (2015)

Essential oil from the plant *Siparuna guianensis* was compared to DEET using 'forearm in cage' methodology. One hundred blood starved 4-5 day old female mosquitoes (*Aedes aegypti* or *Culex quinquefasciatus*) were introduced into a cage 24 x 24 x 24 cm. Ethanol-washed and air-dried dorsal forearm skin (25 cm^2) of volunteers was treated with ethanol (control), essential oil dissolved in ethanol or DEET (14.55%) and placed in the cage for two hours, with the number of bites counted every 10 minutes. Percent protection was defined as:

$$P = 100 \times \frac{N_c - N_t}{N_c}$$

Where N_c is the number of bites received by the control arm and N_t is the number of bites received by the treated arm.

S. guianensis essential oil at a concentration of 0.55 μg/cm^2 of skin maintained 100% protection against both species across the two hour study period, while 14.55% DEET protection was reduced to 60% and 80% after two hours for *A. aegypti* and *C. quinquefasciatus*, respectively. It should be noted that two hours is a reasonably short period for a repellency study. Due to their volatility, plant essential oils tend to perform at their best in the early stages of repellency studies.

3.1.3 Amer et al (2006)

Essential plant oils (*n* = 41) and combinations of essential oils were compared to 20% DEET and 20% picaridin using 'forearm in cage' methodology. *Aedes aegypti, A. stephensi* or

Culex quinquefasciatus (250 nulliparous females, 5-15 days old) were introduced into a cage (48.5 x 40 x 30 cm). Test material (0.1 mL) was applied to a marked area (30 cm^2) of the forearm of human volunteers. Forearms were introduced into the cage for 2 minutes every 30 minutes, for up to 8 hours. The proportion of mosquitoes landing on the treated area (L) or biting on the treated area (B) was recorded until two bites were received in one 2 minute period or one bite was received in each of two successive 2 minute periods. The time to receiving two bites was the protection period. The study was also carried out on untreated (control) arms, with percent repellency calculated as for Aguiar et al above.

Both synthetic repellents and 12 essential oils showed 8 hour protection periods and 100% repellency against *A. stephensi* and *C. quinquefasciatus.* Three essential oils had 8 hour protection period against *Aedes aegypti*, while 20% DEET had a 6 hour protection time against this species and 20% picaridin had a 4 hour protection time. The majority of the essential oils exhibited superior repellency to the synthetic products.

The best performing essential oils were combined in various formulations, with one formulation demonstrating 100% repellency and 8 hour protection against all three mosquito species. While the details of the formulations were not given, the plant sources used to make the formulations were litsea (*Litsea cubeba*), cajeput (*Melaleuca leucadendron*), niaouli (*M. quinquenervia*), violet (*Viola odorata*), and catnip (*Nepeta cataria*).

3.1.4 Badolo et al (2004)

This study assessed the impact of differing dose rates of DEET and picaridin on repellency against *Aedes aegypti* and *Anopheles gambiae*. Control (ethanol washed) and treated arms were exposed to mosquitoes for 30 seconds each (details of number, gender and age of mosquitoes not given). The treated arm was then ethanol washed and the next dose of repellent applied. The number of mosquitoes attempting to bite the arm during the 30 second interval was counted and a coefficient of protection defined:

$$q = 1 - \frac{T}{C}$$

Where T was the total number of mosquitoes trying to land on the treated arm and C was the number trying to land on the control arm. Doses equivalent to q = 0.5 and 0.9 were estimated (ED_{50} and ED_{90}). For *A. aegypti,* ED_{50} and ED_{90} for DEET were 0.05 and 20.8 $\mu g/cm^2$, respectively, while for picaridin the values are 0.002 and 63.8 $\mu g/cm^2$, respectively. Protective doses were higher for *An. gambiae* at 0.6 and 89.4 $\mu g/cm^2$ for DEET and 0.99 and 180 $\mu g/cm^2$ for picaridin. The study report does not provide sufficient data to back-calculate these doses to a product strength. However, if we assume an application rate the same as that outlined in Amer et al (2006) (0.1 mL to 30 cm^2) ED_{90}s would equate to product concentrations in the range 0.6-2.6% for DEET and 1.9-5.4% for picaridin.

3.1.5 Barnard and Xue (2004)

A range of commercial insect repellents were tested for their activity against three species of mosquitoes; *Aedes albopictus, Culex nigripalpus* and *Ochlerotatus triseriatus*. Tests were carried out using 'forearm in cage' methodology, with 200 5-7 day old female mosquitoes introduced into a cage 46 x 38 x 37 cm. Repellents were applied at a rate of 1 mL/650 cm^2, with the forearm exposed for 3 minutes every 30 minutes until two or more bites occurred in a single observation period or two bites occurred in successive observation periods. In the absence of confirmed bites, tests were terminated at 8.5 hours, with 8.5 hours being recorded as the protection time. A repellency index (R_i) was defined as the protection time for the product divided by the protection time for the product with the lowest DEET concentration (7%). R_i values across all three mosquito species ranged from 0.2 to 1.7. The lowest R_is were associated with plant oil-based products. Products with R_is greater than one were:

1.7 26% oil of lemon eucalyptus (65% PMD) = 16.9% PMD
1.5 10% KBR3023 (Picaridin)
1.5 15% DEET
1.5 glycerin, lecithin, vanillin, oils of coconut, geranium and soybean

The authors of the study were unsure why the latter product was so effective, considering the relative ineffectiveness of the other plant oil based products studied. It was assumed that the repellency of this product was due to soybean oil and the potentiating ability of vanillin.

3.1.6 Bissinger et al (2009)

While most studies of arthropod repellency have been carried out on mosquitoes, ticks are also disease vectors and the repellents used against mosquitoes are often also effective against ticks. This studied involved 'choice experiments' with groups of two tick species; *Amblyomma americanum* and *Dermacentor variabilis.* Six ticks were placed in a petri dish containing two circular pieces of cotton cheese cloth; one impregnated with repellent formulation and one untreated. The distribution of ticks was examined every 5 minutes for 30 minutes. The most effective repellents were then tested in 'head-to-head' choice tests; in which the two pieces of cheese cloth were impregnated with two different repellents.

A new plant-based USEPA-registered repellent (BioUD; 7.75% 2-undecanone), DEET (98.1%) and oil of lemon eucalyptus (approximately 19.5% PMD) exhibited average repellency of >90% across the two tick species. In the head-to-head choice trials, there was no significant difference between BioUD and DEET for either tick species. BioUD exhibited significantly greater repellency than oil of lemon eucalyptus and IR3535 for both tick species.

3.1.7 Bissinger et al (2014)

A new plant-based repellent (TT4302) was compared to 16 existing formulations for repellency against *Aedes aegypti* using 'forearm in cage' methodology. A smaller range of products were tested against *Anopheles quadrimaculatus.* For the test, 80 nulliparous female mosquitoes aged 5-10 days were introduced into a cage 45.7 x 45.7 x 45.7 cm. Testing began 30 minutes after test substance application and involved observation period of 1 minute every 30 minutes for 6 hours. The metric was the number of landings (insect landing on arm for ≥2 seconds). The volunteer's untreated arm was used as a control, with the same procedure applied to the control arm as the test arm. Repellency was expressed as:

$$\%R = 100 \times \frac{(C-T)}{C}$$

Where:

C is the total number of mosquitoes landing on the forearm of the control subject in a 1 minute observation period and T is the total number of mosquitoes landing and probing on the forearm of a repellent-treated subject in a 1 minute observation period.

Individual experiments were terminated when repellency dropped below 90%.

TT4302 exhibited the greatest duration of repellency, with %R still at 94.7% after 5 hours. The next most effective repellent contained 15% DEET, with %R dropping below 90% after 3.5 hours. The next most effective products were a mixture of plant oils (soybean, peppermint, geranium and geraniol) and 10% PMD, which dropped below 90% repellency after 2 hours.

TT4302 and 15% DEET were trialled against *Anopheles quadrimaculatus*, with TT4302 maintaining repellency above 90% after 6 hours, while 15% DEET repellency dropped below

90% after 4.5 hours. The only detail provided of the composition of TT4302 was that contained 5% geraniol.

3.1.8 Bissinger et al (2016)

Further 'arm in cage' studies were carried out comparing TT4302 to 15% DEET for repellency against *Aedes aegypti*. Protocols were the same as above, except a repellent was considered to have failed when repellency dropped below 95% in two consecutive exposures. Exposure was continued for 8 hours. TT4302 provided higher average protection times (time to first of two consecutive time periods with less than 95% repellency; 6.5 hours) than 15% DEET (4.7 hours).

3.1.9 Carroll et al (2004)

Laboratory repellency tests were carried out with two tick species; black-legged tick (*Ixodes scapularis*) and lone star tick (*Amblyomma americanum*) against DEET and AI3-37720. Two bioassays were used; concentric circles were drawn on filter papers, with the third circle treated with repellent or ethanol. Repellency was assessed as reluctance of the ticks to enter or cross the treated zone. The assay was performed in a horizontal and vertical mode; the vertical mode allowed ticks to 'drop off' as they would in their natural environment. Varying concentrations of the repellents were trialled to allow estimation of EC_{50} and EC_{95} values; concentrations repelling 50% and 95% of ticks. No apparent repellency of lone star ticks was seen in the horizontal assay, but black-legged ticks were repelled by both substances, with DEET having lower EC_{50} and EC_{95} than AI3-37720 against both young and old specimens. Both substances repelled lone star ticks in the vertical assay, with AI3-37720 showing lower EC_{50} and EC_{95} values.

3.1.10 Carroll and Loye (2006)

Two PMD formulations (10 and 20%) and two DEET formulations (10 and 30%) were compared in 'arm in cage' trials. Trials were conducted with 200 3-4 day old female *Aedes aegypti* per cage (45 x 45 x 45 cm). Formulations were applied to the forearm at a rate of 1.0 g/600 cm^2. Forearms were exposed to mosquitoes for 1 minute every 30 minutes for 8 hours. The subject's arm was retired after receiving four bites in one exposure period. The complete protection time (CPT) was the time to the first exposure when two bites were received or to the first exposure where one bite was received in each of two successive periods.

DEET (30%) achieved a CPT equal to the full 8 hour study time (480 minutes), while 10% DEET had a CPT of 120 minutes (2 hours). PMD (10%) had CPTs in the range 0-270 minutes, depending on the volunteer, while 20% PMD had volunteer-dependent CPTs in the range 120-480+ minutes.

3.1.11 Carroll (2008)

Repellency of IR3535 against black-legged ticks (*Ixodes scapularis*) was determined using a bioassay. A portion of volunteers' arms were treated with repellent and ticks were placed on the arm, away from the treated area, one at a time for a period of 3 minutes. It was assessed whether ticks changed their direction of locomotion to avoid the treated area. Ticks were considered to not be repelled if they moved 3 cm or more into the treated area. Exposure was terminated when a confirmed crossing occurred in two consecutive observations or two of three consecutive observations. Mean complete protection times (time to first confirmed crossing) for different IR3535 products ranged from 9.1 hours (lotion, 10% IR3535) to 12.2 hours (pump spray, 20% IR3535).

3.1.12 Carroll et al (2011)

Plant oils from *Juniperus communis, J. chinensis* and *Cupressus funebris* were compared to DEET for their ability to repel lone star (*Amblyomma americanum)* and black-legged (*Ixodes scapularis*) ticks in a vertical filter paper assay and mosquitoes (*Aedes aegypti*) in an 'arm in

cage' experiment. In the mosquito experiment, mosquito densities were high (500 mosquitoes in a 45 x 37.5 x 35 cm cage). A 32 cm^2 portion of the arm was covered with muslin treated with the test material, with the rest of the arm protected. Varying concentrations of repellents were assayed, with a repellent 'passing' if four or fewer bites were received on the treated cloth in a one minute exposure period. The essential oils all showed superior tick repellency to DEET (lower concentrations that repelled 50% and 95% of ticks) in the vertical filter paper assay. However, the duration of repellency was better for DEET, with 90% of lone star ticks repelled after six hours, while for *C. funebris* and *J. chinensis* oils repellency had dropped to 68% and 47%, respectively, after six hours. In the mosquito assay, only *J. communis* oil demonstrated any consistent capacity to repel female *A. aegypti* at any of the concentrations tested, but still had a higher minimum effective dose than DEET.

3.1.13 Champakaew et al (2016)

A plant extract from *Angelica sinensis* was compared to DEET at concentrations in the range 5-25% against *Aedes aegypti* (250 starved female 5-7 days old) in 'arm in cage' (30 x 30 x 30 cm) trials. Treated forearms (0.1 mL of formulation) of volunteers were exposed in the cage for 3 minutes every 30 minutes. The experiment was complete when two mosquitoes had bitten on the treated area in one observation period or one had bitten in each of two consecutive observation periods. Formulations were also trialled with and without addition of 5% vanillin. Without vanillin, DEET showed longer mean complete protection periods at all concentrations, except 10%. With added vanillin, differences between the repellents were minor, except at 15%, where the mean protection time for DEET was markedly longer (7.5 hours, compared to 5.5 hours). At 25%, with added vanillin, both repellents provided mean CPTs greater than eight hours.

3.1.14 Chio et al (2013)

Repellency of extracts of leaf and seed from a Taiwanese native plant, djulis (*Chenopodium formosaneum*) against *Aedes albopictus* was compared to 15% DEET in a caged mouse bioassay. Mesh screen was treated with repellent and then used to make a feeding cage containing a live mouse. The number of mosquitoes landing on the cage in a two minute exposure period was recorded. Repellency was calculated by comparison to the number of mosquitoes landing on a control cage (methanol only). At 5% all plant extracts achieved >95% repellency (15% DEET gave 100% repellency). It should be noted that the time course for this study was very short and the volatility of plant extracts often mitigates against their effectiveness over time (see Chio et al, under field studies).

3.1.15 Chou et al (1997)

Eight DEET formulations and four 'natural' repellent formulations were compared using an olfactometer. The olfactometer was made up of two compartments, with 10 female 3-14 day old yellow fever mosquitoes introduced into the top compartment and a female human hand (treated or untreated) placed at a protected port at the bottom of the bottom compartment. The number of mosquitoes descending into the lower compartment and landing and probing in 10 minutes was recorded. The first exposure was 30 minutes after treatment, followed by exposure every two hours up to 10-14 hours. DEET formulations were applied at rates that gave equivalent DEET concentrations on the skin of 1 mg/cm^2. While there were some differences between the different DEET formulations, all showed high levels of protection up to at least eight hours. By contrast, none of the 'natural' repellents achieved greater than 50% protection at any time point and none offered any protection past six hours. It should be noted that the worst performing products contained citronella, which is registered as a repellent by the USEPA.

3.1.16 Consumer Reports[6]

The organisation Consumer Reports assessed a range of commercially available insect repellents against *Culex* and *Aedes* mosquitoes (arm in cage) and deer tick (treated zone crossing) and derived species specific and composite scores for each product. The highest composite score (96) was achieved by a 20% picaridin spray pump product, followed by 30% DEET (aerosol), 20% PMD (spray pump), 15% DEET (aerosol) and 20% picaridin (aerosol). The lowest rated products (composite score <30) were mostly plant oil-based products (geraniol, citronella, lemongrass oil, etc.) and a dilute picaridin product (5%).

3.1.17 Deletre et al (2013)

A variation on the spatial repellency test device shown in Figure 1 was used to assess the repellency of 20 plant extracts, mainly oils. Mosquitoes (20 non-blood fed female *Anopheles gambiae*, 4-7 days old) were introduced into a treated container and after 30 seconds acclimatisation were given 10 minutes to either move to the untreated container or remain in the treated container. Extracts were tested at 0.01, 0.1 and 1% solutions. DEET was included as a control, however, DEET is not an effective repellent at these low concentrations. Extracts of lemongrass (*Cymbopogon citratus)* and coleus (*Plectranthus tenuicaulis*) showed significant repellency at all concentrations tested, while 10 other extracts showed repellency for at least one concentration. It should be noted that no test of the duration of repellency or comparison to DEET at normal working concentrations was carried out.

3.1.18 Fradin and Day (2002)

The repellency of 16 products was examined against *Aedes aegypti* using an 'arm in cage' methodology. The cage measured 30 x 22 x 22 cm and was populated with 10 disease-free female mosquitoes, aged 7 to 24 days. Repellency was measured in terms of the time to the first bite. The longest mean complete protection times were for DEET formulations, with the protection time correlated with the DEET content of the formulation, that is, formulations containing 4.75, 6.65, 20 and 23.8% DEET had mean complete protection times of 88, 112, 234 and 302 minutes, respectively. Of the non-DEET-based products, a soybean oil-based product had a mean complete-protection time of 95 minutes, a 7.5% IR3535 product had a mean complete protection time of 23 minutes, while a range of citronella-based products (0.05 to 12%) gave a maximum complete protection time of 20 minutes.

3.1.19 Gkinis et al (2014)

Dichloromethane extracts of plant material of *Nepeta parnassica* were compared to DEET (20%) and a commercial plant oil based product (myrtle oil, andiroba oil and neem tree extract). Repellency was tested using 'arm in cage' (33 x 33 x 33 cm) methodology. Mosquitoes were 400-500 starved 5-10 day old *Culex pipiens* or *Aedes cretinus* (equal mix of genders). Test materials were applied to a 30 cm^2 area of forearm at a rate of about 1 mg/cm^2. The arm was inserted into the cage for 2 minutes every hour, up to 6 hours. The test was terminated when two mosquitoes landed on the treated area in a single observation period or a single mosquito landed in each of two successive periods. Against *A. cretinus* DEET provided 100% protection up to five hours and >95% protection at six hours. The commercial oil mix provided >95% protection for one hour, while the best of the *N. parnassica* preparations provided 100% protection up to two hours and >95% protection up to five hours. DEET provided similar protection against *C. pipiens*, but the *N. parnassica* preparations provided >95% protection up to two hours, at best.

[6] http://www.consumerreports.org/cro/insect-repellent.htm Accessed 14 March 2017

3.1.20 González et al (2014)

The efficacy of 23 synthetic or plant-based substances in repelling biting midges (*Culicoides obsoletus*) was assessed using a Y-tube olfactometer. Each compound was evaluated at concentrations of 1.0, 0.1 and 0.01 μg/μL in hexane using 10-12 midges per experiment. Behavioural responses were assessed after 4 minutes. At 1.0 μg/μL, DEET was the most effective repellent (97.8%), while at the lowest concentration (0.01 μg/μL) plant-based substance (jasmine, geranyl acetone) tended to be more effective. The 10 best performing compounds in the olfactometer assay were then tested in a filter paper landing assay.

The landing assay determined the number of midges landing on filter papers impregnated with repellent (100 μL at 1μg/μL). Six filter papers were mounted in conical plastic tubes, with three papers being controls and three papers treated. The number of midges on each filter paper was measured 2 seconds and 5 minutes after release (20-30 midges per release). Lemon eucalyptus oil (PMD) was the most effective substance in this assay (100% repellency at 2 seconds and 5 minutes) followed by lavender oil (96.1% repellency). DEET performed relatively poorly in this assay (76.1% repellency).

The most promising substances from this assay were then assessed in a semi-field assay, using light traps situated near a stable housing sheep. Mesh was treated with the test substances at concentrations of 10 or 25%, with the mesh placed at the front of the light trap. Traps were operated for five hours. In the first set of experiments, 'mix 3', an equal mixture of octanoic, nonanoic and decanoic fatty acid, exhibited the greatest repellency at 10 and 25% (least average number of midges in light trap), followed by DEET. In the second set of experiments, DEET showed the greatest repellency, followed by lemon eucalyptus oil.

3.1.21 Govere et al (2000)

DEET (15%), PMD and a mixture of plant oils (jojoba, rapeseed, coconut and vitamin E), were compared using 'arm in cage' (40 x 40 x 40 cm) against the malaria vector *Aedes arabiensis* (200 female 4-6 day old mosquitoes, starved for 24 hours). Repellency was assessed in terms of the number of mosquitoes attempting to bite during 1 minute exposures each hour for 6 hours. DEET and PMD exhibited 100% protection at 5 hours, with protection dropping to about 90% at 6 hours. The plant oil-based product maintained 100% protection to 4 hours, but protection had fallen to about 50% by 6 hours.

3.1.22 Kayedi et al (2014)

Essential oils from myrtle (*Myrtus communis*), lavender (*Lavendula officinalis*) and *Salvia sclarea* were compared to DEET (33 or 50%) using 'arm in cage' (50 x 50 x 50 cm) against *Anopheles stephensi* (50 starved females, 2-3 days old). Treated forearms were exposed for 45 seconds every hour, up to 5 hours. No significant difference in biting was seen between forearms treated with 33 and 50% DEET and these treatments outperformed the plant oils at all time points. Lavender oil appeared to be the least effective repellent and by 5 hours its effect was indistinguishable from the control.

3.1.23 Keziah et al (2015)

Extracts of plant material from *Ocimum gratissimum* and *Lantana camara* were formulated into creams and compared to a cream formulation of DEET (12%). Products were tested using a 'hand in cage' (30 x 30 x 30 cm), rather than the more usual 'forearm in cage'. Cages were stocked with *Aedes aegypti* (60 female, 7-10 days old). An initial dose-response study was conducted and in the final study all products were applied at a rate of 8 mg/cm^2. Hands were exposed for 3 minutes every 30 minutes and exposure was discontinued after 3 hours. Repellency was defined relative to a non-treated control. DEET provided complete protection at all application doses in the range 2-8 mg/cm^2, while the plant extracts only achieved complete protection at the highest application rate. In the protection time study, DEET provided 100% protection to the end of the study period (3 hours), while only one of

nine plant-based products provided better than 90% protection by the end of the study period.

3.1.24 Klun et al (2004)

DEET and AI3-37220 were compared as to their ability to repel *Aedes aegypti* and *Anopheles albimanus*. Tests were carried out using a Klun and Debboun (K&D) module. The module allows multiple 3 x 4 cm areas of volunteers' legs to be exposed to groups of mosquitoes (5 female, 5-15 days old) via sliding doors in the module. The different areas can receive different treatments. Each area was exposed for 2 minutes and the number of mosquitoes biting during that time were recorded. Both products were tested against both mosquito types at application rates in the range 0.0-19.2 x 10^{-2} μmol/cm^2. The minimum application dose providing 95% protection was estimated. Both products were effective against *A. aegypti* with DEET achieving 95% protection at a slightly lower dose (2.3 x 10^{-2} μmol/cm^2) than AI3-37220 (3.5 x 10^{-2} μmol/cm^2). *An. Albimanus* showed greater resistance to the repellent effects of both substances, with DEET achieving 95% protection at an application dose of 12.0 x 10^{-2} μmol/cm^2, while AI3-37220 failed to achieve 95% protection at any of the studied doses.

3.1.25 Klun et al (2006b)

The same experimental protocol, using the K&D module, was used to assess the repellency of DEET, SS220, an analogue of DEET (DM159) and two analogues of *N*,*N*-diethylphenylacetamide (DEPA) (DM156 and DM34). These analogues had shown promising results in an earlier *in vitro* study. All substances were compared at application rates of 24 nmol/cm^2. It should be noted that this was approximately the threshold dose for 95% protection by DEET against *Aedes aegypti* in the study summarised above. All substances were assessed for their repellency against two species of mosquito (*A. aegypti* and *Anopheles stephensi*) and one species of sandfly (*Phlebotomus papatasi*).[7] A complex pattern of substance and species repellency was seen in this study. Against *P. papatasi*, DEET, SS220 and DM156 were not significantly different, but were superior to the other two analogues. Against *An. Stephensi*, SS220 was significantly superior to the other substances, while against *A. aegypti* DEET and SS220 were equally effective and more effective than the analogues.

3.1.26 Klun et al (2006a)

This study again used the K&D module and the three insect species used in the previous study by the same group to assess the repellency of DEET, picaridin and SS220. In this study each 'cell' was divided into equal area treated and untreated zones. A further set of experiments was conducted, covering the skin with cloth, to determine if the repellent effect depended on physical contact between the insect and the repellent or whether the odour was the main repellency factor. Repellents were applied at a rate of 48 nmol/cm^2. All three products gave complete protection against *P. papatasi* and *An. Stephensi* and greater than 95% protection against *A. aegypti.* After covering treated and untreated areas with cloth the insect still bit predominantly through the cloth covering the untreated skin.

3.1.27 Mittal et al (2011)

Cream formulations of DEET and the structurally related *N,N*-diethyl-benzamide (Odomos) were compared for their ability to repel *Aedes aegypti* and *Anopheles stephensi.* 'Forearm in cage' (cage dimensions not given) methodology was used, with forearms exposed for 5 minutes each hour up to 4 hours in a cage containing 100 mosquitoes (3 days old).

[7] These sandflies are different to the New Zealand sandflies, which are species of the genus *Austrosimulium*

Increasing application rates of active ingredient were trialled until 100% protection at 4 hours was achieved. Both substances achieved 100% protection at 4 hours against *An. Stephensi* at an application rate of 10 mg/cm^2, while both gave complete protection against *A. aegypti* at 12 mg/cm^2.

3.1.28 Naucke et al (2006)

This study tested the repellency of two substances (IR3535 and DEET) against insects other than mosquitoes, in this case the sandfly species *Phlebotomus mascittii* and *P. duboscqi.* IR3535 and DEET were applied at a concentration of 10% active ingredient to the forearms of volunteers, with the forearm exposed to caged sandflies (30 females aged 2-15 days, cage size 20 x 20 x 20 cm) for 10 minutes every hour. The protection time was taken to be the time to the first attempted bite.

Both substances were equally effective against *P. duboscqi*, with protection times of 5.9 hours. Both substances were more effective against *P. mascittii*, with protection times of 10.4 and 8.8 hours, respectively for IR3535 and DEET.

3.1.29 Reegan et al (2014)

Mixtures of plant oil were formulated into cream preparations and compared to DEET (12%). Formulations were compared at application rates of 1, 2.5 and 5 mg/cm^2 using a 'hand in cage' (45 x 45 x 40 cm) methodology. Cages were populated with 100 female *Aedes aegypti* mosquitoes, 4-6 days old. Treated hands were exposed for 2 minutes every 15 minutes until two bites occurred in the same 2 minute period. Mean protection times for 12% DEET at the three application rates were 71, 172 and 364 minutes. None of the oil formulations provided equivalent protection, with the best (a mixture of ocimum, lemongrass, citronella, camphor and orange) providing 211 minutes of protection at the highest application rate. Similar results were found when the study was repeated with *Culex quinquefasciatus* mosquitoes, with DEET providing 425 minutes of protection at the highest dose rate, compared to 258 minutes for the best oil formulation.

3.1.30 Rodriguez et al (2015)

Eight commercial products, two fragrances and a vitamin B patch were compared using a human hand as the attractant in a Y-tube olfactometer, with two mosquito species (*Aedes aegypti* and *A. albopictus*). Products containing DEET (98, 25 and 7%) showed results significantly different to control at all time points (up to 240 minutes) for *A. aegypti*, with effectiveness correlated to the DEET concentration. A product containing approximately 20% PMD produced results similar to the highest concentration of DEET. The two fragrances gave significant protection against *A. aegypti* up to 120 minutes. Only 98% DEET, 20% PMD and a product containing a mixture of geraniol, cinnamon, rosemary and lemongrass oils gave significant protection against *A. albopictus* at all time points up to 240 minutes.

3.1.31 Sanghong et al (2015)

The repellency of a hexane extract of plant material from *Ligusticum sinense* was compared to DEET (25%) using 'forearm in cage' (30 x 30 x 30 cm) methodology. Cages were populated with 250 female *Aedes aegypti* or *Anopheles minimus* mosquitoes (age not stated). Approximately 0.1 mL of product was applied to a 30 cm^2 area of the ventral forearm, with arms exposed in the cage for 3 minutes every 30 minutes. Complete protection time was defined as the time to the exposure period with two confirmed bites or the time to the second of two successive periods with one confirmed bite in each. Both DEET and the plant extract gave 11.5 hours of complete protection against *An. Minimis*. Addition of 5% vanillin increased the complete protection times to 12.5 and 14.25 hours for the plant extract and DEET, respectively. A similar pattern, but shorter complete protection times, were seen with *A. aegypti*. However, addition of 5% vanillin resulted in a greater complete protection time for the plant extract (11.0 hours) than DEET (8.75 hours).

3.1.32 Scott et al (2014)

Commercial formulations of DEET (15%), picaridin (5%) and citronella (10%) were compared as to their ability to repel the large floodwater mosquito species; *Psorophora ciliata* and *Psorophora howardii.* 'Forearm in cage' (45 x 45 x 37 cm) methodology was used, with cages containing 100 female wild-caught mosquitoes (70 *P. howardii* and 30 *P. ciliate*). Forearms were treated with 1.0 mL of repellent formulation and exposed for 3 minutes every 30 minutes. Failure of repellency was defined as two mosquitoes landing on the treated area and probing for more than three seconds. DEET demonstrated the longest mean protection time of 5 hours and 41 minutes, followed by picaridin (3 hours and 46 minutes) and citronella (2 hours and 26 minutes).

3.1.33 Trigg and Hill (1996)

DEET (20%, stick), citronella oil (50%) and PMD (50%, liquid, stick and gel) were compared for repellency against *Anopheles gambiae* mosquitoes using 'forearm in cage' (45 x 45 x 45 cm) methodology. Cages contained 20 female mosquitoes. Arms were placed into the cage for 30 seconds and the number of mosquitoes landing and probing was recorded. The application rate of repellent was increased until 100% repellency was achieved. Repellency was then tested for 30 seconds each hour. The DEET formulation had the lowest ED_{90} (application rate that resulted in 90% repellency) of 0.48 $\mu g/cm^2$, with the PMD formulations in the range 0.65-0.72 $\mu g/cm^2$ or $\mu L/cm^2$ and the citronella oil formulation having an ED_{90} of 1.37 $\mu L/cm^2$. The DEET formulation also retained its repellency for longer, with approximately 50% of mosquitoes repelled after five hours. This proportion was lower for the PMD formulations (30-40% after five hours), while the repellency of the citronella oil formulation had virtually disappeared by three hours).

3.1.34 Trongtokit et al (2005)

Nine commercial insect repellents were applied to the forearms or lower legs (1 g/600 cm^2) of volunteers. Three products (20% PMD, 10% PMD and a mixture of 10% clove oil and 10% makaen oil) were compared by placing treated arms in a cage (30 x 30 x 30 cm), containing 30 female *Anopheles stephensi* mosquitoes, for 1 minute every 30 minutes. Complete protection time was the time to the first two bites. The formulation containing 20% PMD provided the longest protection (5-7 hours), followed by the oil mixture (4-5 hours). However, protection from the oil mixture decreased rapidly after 5 hours. PMD at 10% only maintained complete protection for 30 minutes, but was still providing >70% protection at 5 hours.

The full range of products were compared for biting on the lower legs in a room 3 x 2 x 2.5 m in size. Exposure was for 10 minutes each hour, with 30 female *A. stephensi* mosquitoes in the room. PMD (20%) gave complete repellency for 6-7 hours, while 10% PMD only gave complete protection for 1-2 hours. DEET (50%) gave complete protection for 30 hours, while 30% PMD gave complete protection for 11-12 hours. A formulation containing 40% citronella oil and the mixed oil product described above gave complete protection for 7-8 hours, while a formulation with 5% citronella oil only achieved 2-3 hours of complete protection.

3.1.35 Uc-Puc et al (2016)

Commercial insect repellents available in the Yucatan region of Mexico were compared for complete protection times using a 'forearm in cage' (30 x 30 x 30 cm) for repellency against *Aedes aegypti* (100 female). Repellency was assessed for 3 minutes every 30 minutes. The longest complete protection period were achieved by DEET-based products and were concentration-dependent, with complete protection periods of 63, 93, 153 and 363 minutes for DEET formulations containing 5, 7.5, 15 and 25% DEET, respectively. A formulation containing 16% picaridin gave a complete protection period of 84 minutes. A range of other mainly plant oil-based products did not achieve complete protection times greater than 2.5 minutes.

3.1.36 Uniyal et al (2016)

A Y-tube olfactometer was used to test the repellency of 23 plant oils, DEET and *N,N*-diethyl phenyl acetamide (DEPA) against *Aedes aegypti* (female, 5-6 days old). All materials were tested at three concentrations (1, 10 and 100 ppm). Litsea oil performed the best of the all the plant oils investigated, exhibiting greater repellency than recognised repellent plant oils, such as citronella, lemon scented eucalyptus and catnip. However, repellency of all oils was less than DEET and DEPA at the same concentration.

3.1.37 Wang et al (2013)

A range of commercial and non-commercial repellent products were tested for their ability to repel the common bed bug, *Cimex lectularius* in a series of bioassays. The bioassays were specific to this study and details have not been included here in the interests of concision. In a petri-dish assay, 5% DEET achieved complete repellency after two and 24 hours (bugs would not enter a treated zone, even to seek out harbourage), while 2.5% DEET, 7% picaridin and 0.5% permethrin all achieved <40% repellency at two hours and <20% repellency at 24 hours. DEET (25%) was also the most effective repellent in an 'arena' assay, in comparison to two candidate repellents; isolongifolanone and isolongifolenone. In concentration comparisons, 10% DEET was significantly more effective at repelling than 5% DEET, but not significantly different to 25% DEET. The repellency of 25% DEET decreased after 21 days and was largely exhausted by 35 days. It is uncertain whether this study was advocating DEET as a personal repellent for bed bugs or as a surface treatment.

3.1.38 Witting-Bissinger et al (2008)

A 2-undecanone-based repellent (BioUD, 7.75% 2-undecanone) was compared to DEET (7-15%) for repellency against mosquitoes and ticks. 'Arm in cage' (27,000 cm^3) methodology was used, with cages stocked with 50 nulliparous 6-18 day old female mosquitoes (either *Aedes aegypti* or *A. albopictus*). BioUD, 7% or 15% DEET were applied at a rate of 1 mL/600 cm^2. Landing counts were assessed in 1 minute exposure periods each hour, up to 6 hours. DEET (15%) maintained >95% protection against both mosquito species for 5 hours, while BioUD and 7% DEET only maintained this level of protection for 1 hour *(A. Aegypti)* or 3 hours *(A. albopictus).*

Tick repellency studies were conducted using the American dog tick (*Dermacentor variabilis*). A comparative repellency assay was conducted in which two semi-circles of filter paper were placed in a petri dish; one treated with BioUD and the other treated with DEET (15%). Six ticks were placed on the dividing line between the two treated semi-circles and their distribution reported after 30 minutes. Ticks were predominantly found on the DEET-treated filter paper, indicating a greater repellency for BioUD.

3.1.39 Zermoglio et al (2015)

The triatomine insect *Rhodnius prolixus* is a major vector for Chagas disease. Repellency of various concentrations of DEET and piperidine and of various commercial or candidate repellents was examined using a custom bioassay. Single *R. prolixus* were confined in a polystyrene tube. The tube was open at one end, but with a mesh screen. Filter paper impregnated with repellent or control (70% ethanol) was placed outside the screen, with host attractant (experimenter's arm) beyond that. Repellency was assessed in terms of the amount of time the insects spent in the 'host zone', adjacent to the screen and how many proboscis extension responses (PER; a feeding response behaviour) occurred.

Both DEET and piperidine reduced the amount of time insects spent in the host zone and the mean number of PER, in a dose-dependent manner. However, piperidine was more effective and concentrations of piperidine of 10% or more virtually eliminated time spent in the host zone.

In a comparison of commercial and candidate substances; picaridin (25%) and DEET (50%) were significantly more effective in inhibiting PER in proximity to host than methyl-, ethyl- or butyl-anthranilate.

3.2 FIELD STUDIES

3.2.1 Barnard et al (2002)

Tests of four substances (DEET, picaridin, IR3535 and PMD; all 25%, except PMD, which was at 40%) were carried out in the Everglades National Park, Florida, USA. Five male volunteers were randomly treated with one of the products or a control (25% deionised water in ethanol). One forearm was treated at a rate of 1 mL/650 cm^2. Protective clothing was worn on the remainder of the body. Repellency was assessed in 3 minute observation periods, starting 15 minutes after application and then at 1 hour intervals up to 6 hours. Counts were made of mosquitoes that landed and probed the forearm skin. Control subjects observed landing in the same manner, but the observation period was restricted to 1 minute. Repellency was expressed as:

$$\%R = 100 \times \frac{(C-T)}{C}$$

Where:

C is the total number of mosquitoes landing and probing on the forearm of the control subject in a 1 minute observation period, multiplied by 3 and T is the total number of mosquitoes landing and probing on the forearm of a repellent-treated subject in a 3 minute observation period.

DEET maintained a %R of 100% for the longest period (complete protection time; mean = 5.6 hours), but had the second highest average %R at the end of 6 hours (94.8%), slightly lower than picaridin (97.5). PMD and IR3535 had average %R values of just under 90% across the whole experimental period. For both DEET and PMD, %R decreased quite quickly towards the end of the study period.

3.2.2 Bissinger et al (2014)

In addition to laboratory studies, TT4302 (5% geraniol) and 15% DEET were compared in field trials. For each volunteer, one lower leg was treated, while the other leg acted as a control. Landings on each leg were counted for 5 minutes every 30 minutes, with the first observation period 30 minutes after initial application. All mosquitoes collected in this open field study were *Aedes albopictus*. TT4302 maintained 100% repellency to the end of the 5 hour study period, while repellency with 15% DEET had dropped to 78% after 5 hours. Repellency was measured relative to the control leg.

3.2.3 Bissinger et al (2016)

A field comparison of TT4302 and 25% DEET with respect to ticks was carried out. Volunteers wore shorts and knee-high socks; one untreated and one treated with either of the repellents, at an application rate of 1 mL/600 cm^2. Volunteers walked in the test area for 15 minutes. Any ticks crossing the upper edge of the socks were removed and retained. At the end of 15 minutes the socks were carefully removed and bagged and sent for tick counting and identification. All specimens were lone star ticks (*Amblyomma americanum*). Significantly fewer ticks were collected from treated than untreated socks at 2.5 and 3.5 hours post-treatment, but no significant difference was seen between TT4302 and 25% DEET.

3.2.4 Carroll and Loye (2006)

Two PMD formulations (20 and 26%) and one DEET formulation (20%) were compared in a field study. Formulations were applied to forearms and lower legs at a rate of 1.0 g/600 cm^2. For the PMD formulations applications were also made at 1.5 g/600 cm^2. Subjects counted and recorded bites in each of 72 periods of 5 minutes (total of 6 hours). Untreated controls collected all biting mosquitoes by aspiration and retained for later identification. Mosquitoes collected were about two-thirds *Ochlerotatus melanimon* and about one-third *Aedes vexans*. All formulations tested and both application rates of PMD gave virtually complete protection throughout the study period.

3.2.5 Carroll (2008)

Repellency of three IR3535 formulations (lotion, aerosol, pump spray) against mosquitoes was assess in a field study. Volunteers treated one lower leg and one lower arm and exposed these for 1 minute every 15 minutes. Mosquitoes landing with intent to bite were aspirated into a storage container for subsequent counting and species identification. Mean complete protection times (time to first confirmed landing with intent to bite) ranged from 7.1 to 10.3 hours. More the 90% of mosquitoes were *Aedes melanimoni.*

3.2.6 Carroll et al (2008)

Cream formulations of three repellents (33% DEET, 10 and 20% SS220, and 10 and 20% picaridin) were tested in a semi-field study for repellency against the lone star tick (*Amblyomma americanum*). A 5 cm wide band of the lower leg was treated at a rate of 1.92 mg cream/cm^2 of skin. Bare-footed volunteers stood in a tray containing leaf litter seeded with 100 ticks. After 3 minutes, the number of ticks below, in and above the treatment zone were counted. After 5 minutes, the volunteer stepped out of the tray and ticks were counted again. This was repeated at 2 hour intervals, up to 12 hours. All repellents were effective through the complete 12 hour study time, with overall protection of 97.4%. Two treatments (20% picaridin, 20% SS220) provided 100% protection across the 12 hour period (no ticks crossed the 5 cm treated band of leg). DEET was assessed to be the least effective of the formulations tested, but still maintained >85% protection across the exposure period.

3.2.7 Champakaew et al (2016)

A plant extract from *Angelica sinensis* was compared to DEET at a concentration of 25% (with 5% added vanillin) in a field trial in the north of Thailand. Volunteers were covered except for the lower legs. Repellent (2 mL) was evenly applied to both lower legs. Controls applied 5% vanillin in ethanol. Mosquito collection occurred for 180 minutes, with nine 20 minute collection periods being defined. Subjects were moved to a new location for each of these 20 minute periods. Landing mosquitoes were collected by aspiration. Repellency was defined as for Barnard et al. (2002) above. Both repellents provided 100% protection across the duration of the study.

3.2.8 Chio et al (2013)

Repellency of extracts of leaf and seed from a Taiwanese native plant, djulis (*Chenopodium formosaneum*) against biting midges (*Forcipomyia taiwana*) was compared to 5.85% DEET in a field study. A 50 cm^2 area of one leg of volunteers was treated with 0.2 mL of varying concentrations of plant extract or DEET, while the other leg served as a control (methanol treated). Legs were exposed for 3 minutes every 30 minutes for 180 minutes, with the number of bites in the treated area recorded. Methanol extracts of leaf and seed at 1% concentration and DEET gave 100% protection at the first 3 minute observation period. However, after 180 minutes, repellency due to 5.85% DEET had reduced to 86%, while repellency due to 1% seed extract had reduced to about 60%. No residual repellency due to leaf extract remained after 180 minutes.

3.2.9 Costantini et al (2004)

DEET, picaridin and IR3535 were compared in a field trial in Burkina Faso, during a period of peak biting pressure from the malaria vector *Anopheles gambiae*. Repellents were applied to the lower leg at application rates in the range 0.1-0.8 mg/cm^2. Mosquitoes that landed on the treated area were removed by aspiration and kept for counting and identification. Collection occurred during two 4 hour periods – one outside and one indoors, with a 2 hour 'rest period' between, giving a total exposure period of 10 hours. Of the mosquitoes caught, 98.5% were anophelines, with 95% belonging to the *Anopheles gambiae* complex. Across the 10 hour study period, picaridin showed the best protection against anophelines, followed by DEET and IR3535. The same order was seen for the duration of protection, with picaridin showing the highest level of protection at 10 hours for all applied doses. The dose series results were also used to calculate ED_{50} and ED_{95} values (effective doses repelling 50 and 95% of mosquitoes). DEET had the lowest ED_{50}, while picaridin had the lowest ED_{95}.

3.2.10 Dadzie et al (2013)

A field trial of a low-cost insect repellent (No Mas, containing PMD and lemongrass oil) was carried out in two farming communities in northern Ghana. Lower legs of technicians were treated with repellent or control (20% mineral oil in ethanol) at 5 mL/1000 cm^2. Exposure was for a period of 9 hours, except for a 10 minute break every hour. Mosquitoes were removed by aspiration after landing, but before biting occurred. Anopheline mosquitoes accounted for 99.4% of collections. During the 9 hours of exposure, No Mas provided 90% protection, compared to controls, with protection dropping from 100% after 4 hours to approximately 80% after 9 hours.

3.2.11 Frances et al (2004)

In a field study carried out in the Northern Territory of Australia, volunteers (n = 4) were covered except for the lower legs, which were treated with picaridin (19.2%), DEET (20 or 35%) or ethanol (control). Mosquitoes were collected from the area and mosquitoes biting volunteers were collected. Repellency was determined in terms of the number of bites on treated legs relative to control legs.

The predominant mosquito species were *Culex annulirostris* (57.8%), *Anopheles meraukensis* (15.4%), and *Anopheles bancroftii* (13.2%). Picaridin and 35% DEET provided >95% protection against *Anopheles* species for only 1 hour, while 20% DEET provided <95% protection in the first hour after application. Repellency against *Culex* species was much better, with picaridin providing >95% protection for 5 hours, while both DEET formulations provided >95% protection for 7 hours.

3.2.12 Frances et al (2005)

Picaridin (9.2%) and DEET (10 or 80%) were compared in field trials in the Northern Territory of Australia. Volunteers treated their lower legs and feet 2-3 hours before the study began. Mosquitoes were collected by aspiration for 20 minutes each hour, up to 6 hours. The picaridin formulation gave >95% protection (compared to untreated control) against all mosquitoes for 2 hours, while the 10% DEET formulation gave this level of protection for 7 hours and the higher DEET concentration gave protection for more than 8 hours. The picaridin formulation performed better against the dominant mosquito species, *Culex annulirostris*, with >95% protection for 5 hours. The DEET formulations performed the same against this species as they did against all species combined.

3.2.13 Frances et al (2014)

DEET (40%) and lemon eucalyptus oil (32%, PMD content not stated) were compared in a field trial after showing similar complete protection times in laboratory tests. Volunteers applied repellent to the lower legs 3 hours before exposure. Biting mosquitoes were collected by aspiration for 10 minutes every hour up to 6 hours. Percent protection was determined by comparison to the bites in the same period for an untreated control. The main

mosquito species collected were *Aedes vigilax, Culex annulirostris* and *Culex sitiens*. The DEET-based formulation provided 100% protection for 7 hours, while the PMD-based formulation provided >95% protection for 3 hours. It should be noted that 3 hours after application was the first actual measurement point and after this point protection from the PMD-based product dropped to <80%.

3.2.14 Mittal et al (2011)

Following laboratory bioassay, cream formulations of DEET and the structurally related *N,N*-diethyl-benzamide (Odomos) were compared in a field study. Volunteers were treated on their faces and lower legs at a rate of 10 mg/cm^2 of active ingredient. Volunteers lay on a cot for 11-hour collection periods, while an attendant collected, by aspiration, all mosquitoes landing and attempting to bite. Complete protection times were defined as the time to the second successive landing on the volunteer. Both substances gave 100% protection (11 hour complete protection time) for four mosquito species (*Anopheles culicifacies, An. stephensi, An. annularis* and *An. subpictus*). DEET gave complete protection against *Culex quinquefasciatus*, while Odomos had a 9 hour complete protection period. Against *Aedes aegypti*, both products had complete protection periods of less than 7 hours, with DEET offering slightly longer protection (6.75 hours) than Odomos (6.2 hours).

3.2.15 Naucke et al (2007)

Seven commercial insect repellents containing either IR3535 or picaridin (10-20%) were compared in a field study. Volunteers had products applied to one forearm (1.5 g/600 cm^2 for lotion and 1.0 g/600 cm^2 for spray), with the rest of the body protected, except for the other (untreated) forearm, which was periodically exposed as a control. Female mosquitoes landing and biting were collected, with the time to the first, second and third bites recorded. Exposure was continued for 10 hours on each trial day. For treated arms, first bites occurred on average after 322-410 minutes, with third bites occurring on average after 463-518 minutes. No particular association was apparent between repellent composition and protection time. Differences between mean protection times were not significant.

3.2.16 Qualls et al (2011)

Four commercial insect repellents (15% DEET, 30% lemon eucalyptus oil, 7.75% 2-undecanone and a mix of soybean, geranium and castor oil) were compared in a field trial in a region with high populations of the floodwater mosquito, *Psorophora columbiae*. Only the lower arms were exposed and were treated with 1 mL of repellent formulation. The other arm was either treated with a different formulation or used as an untreated control. Protection times were defined as the time to a second mosquito landing on the treated area and probing for more than 3 seconds. All three plant oil products resulted in longer mean protection times than DEET, with lemon eucalyptus oil providing 330 minutes of protection on average. The DEET formulation achieved a mean protection time of <180 minutes. *Psorophora columbiae* accounted for more than 90% of the mosquitoes collected in the test area.

3.2.17 Reegan et al (2014)

Following laboratory trials, a mixture of plant oil (ocimum, lemongrass, citronella, camphor and orange) was formulated into a cream preparation and compared to DEET (12%). Exposed skin areas of volunteers (lower legs and lower arms) were treated at an application rate of 5 mg/cm^2 and exposed for 3 hours, with all landing mosquitoes collected by aspiration. Both products gave >98% protection against all mosquito species encountered for the 3 hour period, with the plant oil preparation providing complete protection. The predominant mosquito species was *Culex quinquefasciatus*.

3.2.18 Solberg et al (1995)

DEET and AI3-37220 (25% in ethanol) were compared for repellency against the lone star tick (*Amblyomma americium*) under field conditions. Repellents were applied to one lower

leg at a rate of 0.5 mg/cm^2, while the other leg was treated with ethanol and served as a control. At 0, 2, 4, 5 and 6 hours post-application, volunteers walked slowly through the test site for 30 minutes. Any ticks on the legs were classified as repelled (climbed on and dropped off in <5 minutes) or not repelled (climb on and attached in <5 minutes or successfully traversed the leg to the shorts). AI3-37220 showed superior repellency to DEET against the lone star tick, with a significantly lower proportion of ticks on the treated leg at 4, 5 and 6 hours. For AI3-37220 the proportion of ticks on the treated leg never exceeded 7%, while by 6 hours more the 30% of the ticks were on the DEET-treated legs. The proportion was the number of ticks on the treated leg compared to the sum of the number of ticks on the treated and non-treated legs.

3.2.19 Tawatsin et al (2006)

DEET (10%), a commercial plant-based product (5% turmeric oil, 4.5% lemon eucalyptus oil, 10% vanillin) and three plant oil preparations (finger root rhizomes, guava leaves and turmeric rhizomes; 10%) were prepared as creams. Lower legs of volunteers were treated with 2.0 mL of preparation, with the other leg left untreated as a control. Exposure was carried out for 10 minutes every 30 minutes for 9 hours (night) or 8 hours (day), with all mosquitoes landing and attempting to bite during the exposure period collected. Repellency was defined as the difference in the number of mosquitoes landing on the control and treated legs, divided by the number landing on the control leg. At another site, the same procedure was used to assess repellency against black flies, with a test duration of 11 hours. At a further site, the same procedure was used to test repellency against land leeches, with exposure being defined as walking along trails for 10 minutes each hour.

The main night-biting mosquito species were *Culex vishnui* (77%) and *C. quinquefasciatus* (14%). All preparations provided 100% repellency for the 9 hour duration of the study. The day-biting mosquitoes were almost exclusively *Aedes albopictus* (99.9%). All products, except turmeric oil, provided complete protection up to 5 hours and finger root oil provided complete protection up to 6 hours. However, none of the products provided >95% protection beyond 6 hours and at 8 hours protection rates were in the range 76-94%.

Only two black fly species were collected; *Simulium nigrogilvum* (99%) and *S. chumpornense* (1%). All repellents provided complete protection against black flies for 9 hours. DEET and guava oil maintained >95% protection at 10 hours, but no product had >95% protection at 11 hours.

Only one species of the land leech genus *Haemadipsa* was collected. All products provided complete protection across the 8 hour study period.

3.2.20 Uzzan et al (2009)

Four products (20% picaridin, 20% and 50% PMD, 50% DEET) were applied to 100 volunteers, skilled in mosquito capture in a double-blind placebo-controlled field study carried out in Senegal. One leg was exposed and treated with product or placebo for 9 hours. All mosquitoes attempting to bite were captured. All products provided similar and significant protection, with protection lasting 8 hours. Mosquitoes captured were mainly *Anopheles* (32%), *Culex* (31%) and *Mansonia* (27.5%). DEET 50% appeared to give greater protection than 20% PMD, however, the difference was not statistically significant. Exactly the same number of mosquitoes were captured by subjects using 50% DEET and 50% PMD.

3.2.21 Van Roey et al (2014)

In a study carried out in Cambodia, three repellent formulations (20% DEET, 10 and 20% picaridin) and a control (ethanol) were compared in a landing capture study. The lower limbs of volunteers were treated with formulation or control and collection of landing mosquitoes was carried out for 5 hours.

Mosquitoes collected on negative controls were mainly *Culex* (42%), *Mansonia* (23%), *Anopheles* (21%) and *Aedes* (13%). Repellency relative to control was uniformly high (>95%) across the 5 hour study period for all three repellent formulations. Protection was slightly greater with 20% DEET (98.6%) and 20% picaridin (98.4%) than 10% picaridin (95.4%). Repellents were more effective against *Mansonia* and *Culex* species (98%), than against *Anopheles* and *Aedes* species (96 and 97%).

3.2.22 Wilson et al (2013)

Six DEET-based formulations (9.5-100% DEET) and a product containing 16% PMD and 2% lemongrass oil were compared in their ability to repel blackflies (*Simulium damnosum*). Lower legs of volunteers were treated with a repellent product (approximately 0.5 mL per leg). Volunteers were seated on a river bank for 11 hours, with all blackflies landing on the lower legs collected. For the PMD-based product, the minimum complete protection period was 5 hours, while overall protection across the duration of the study was 81%. For a formulation containing 98-100% DEET, the minimum complete protection period was 3 hours, with overall protection of 61%, while with 50% DEET first bites were recorded after periods as short as 1 hour, with overall protection of 60%. More dilute DEET formulation had minimum complete protection periods of 2 hours and overall protection of <50%. Comparison of the DEET-based products demonstrated little additional protection with products containing >25% DEET.

3.2.23 Witting-Bissinger et al (2008)

A 2-undecanone-based repellent (BioUD, 7.75% 2-undecanone) was compared to DEET (25 or 30%) and a plant oil-based product for repellency against mosquitoes. Volunteers were covered except for one lower arm, which was treated or left untreated as a control. Mosquitoes landing and probing were counted for 5 minutes each hour at 3-6 hours after application. At a second site, both lower arms were treated and eight 3.5 minute counts were taken over a 30 minute period. The 30 minute period started either 3.5 or 5.5 hours after repellent application.

At the first site, 25% DEET provided >95% protection through the 6 hour study period, while BioUD provided >95% protection at 3 hours. Protection from BioUD had dropped to 79% by 6 hours. The dominant mosquito species were *Psorophora ferox* and *Aedes atlanticus/tormentor.* At the second study site, BioUD provided >95% protection up to 6 hours, while 30% DEET provided >95% protection at 4 hours, but only 72% at 6 hours. The plant oil-based repellent gave 94% protection at 4 hours, dropping to 54% at 6 hours.

3.2.24 Yap et al (2000)

Four insect repellent formulations; picaridin (5 and 12%) and DEET (7.5 and 15%) were compared in a field study against day-biting and night-biting mosquitoes in peninsular Malaysia. Arms and legs of volunteers were treated with repellent, with a different repellent applied to the left and right side of each volunteer. For the daytime study, field monitoring was carried out for 8 hours post-application. For the night-time study, volunteers were treated 4 hours before field monitoring began, with field monitoring continuing for a further 4 hours. All mosquitoes landing or landing and biting were counted and collected.

In a night-time study in a rural residential area the predominant species were *Anopheles* spp. (62%), *Culex quinquefasciatus* (23%) and *Mansonia uniformis* (15%). Although the study report only gave counts of mosquitoes landing or landing and biting, these can be used to calculate the %repellency/protection. The higher concentration of picaridin (12%) gave >95% repellency/protection to the end of the 8 hour study period, while 15% DEET was not significantly lower (94%). Protection provided by the lower concentration repellents was significantly lower than for the high concentration repellents.

In a night-time study in an urban squatter community, the predominant mosquito species was *Culex quinquefasciatus* (>90%). There was no significant difference between the performance of the four products after 8 hours, with protection rates in the range 92-95%.

In a daytime study, the predominant species were *Aedes albopictus* (77%) and *Armigeres subalbatus*. All products, except 7.5% DEET gave levels of protection at 8 hours that were not significantly different (>80%).

3.3 REVIEWS AND META-ANALYSES

3.3.1 Lupi et al (2013)

This review consolidated information from a large number of studies of repellent efficacy. Results were summarised in terms of four main arthropod genera:

Aedes spp. DEET, at high concentrations, showed the best performance against mosquitoes of this genus, with 100% repellency for up to 10 hours achieved. Repellency of IR3535 and picaridin against *Aedes* species was generally good, but inferior to DEET. PMD repellency against this genus was lower than for the other major repellent, with frequent reapplications required.

Anopheles spp. All four products exhibited similar repellency profiles against *Anopheles* species, with complete protection periods up to 8-12 hours, depending on the repellent.

Culex spp. All four products exhibited a high level of repellency against *Culex* spp. Complete protection periods were generally greater than 8 hours.

Ixodes spp. Few well-controlled experiments have been conducted to test repellency against these tick species. IR3535 appears to be a superior repellent against *Ixodes scapularis*, while it is inferior to the other three products in repelling *Ixodes ricinus*.

3.3.2 Webb and Hess (2016)

Information on repellent products available in Australia was reviewed and it was concluded that:

- There is a considerable body of evidence that DEET “effectively protects against a range of nuisance-biting and vector mosquito species in Australia”
- Picaridin has been shown to be effective and more cosmetically pleasant than DEET. In Australia, picaridin is more common amongst lower concentration products (9 to 20%), whereas DEET is usually marketed at higher concentrations
- PMD-containing formulations are becoming more widely available and a 30% PMD formulation appears to provide a similar duration of protection to lower concentrations (5-10%) of DEET or picaridin
- While there is evidence that some botanical extracts are effective for short periods, they need to be reapplied much more frequently than DEET, picaridin or PMD-based products.

4. CONCLUSIONS

The wide range of experimental variables, including application rates, biting pressure (number of insects), study duration and efficacy measures prevent meta-analysis of the wide range of information presented in section 3 of this report. However, a number of general conclusions can be drawn:

- A high proportion of commercial insect repellents are based on a small number of active ingredients; DEET, picaridin, IR3535 and oil of lemon eucalyptus or its active ingredient PMD.
- Most insect repellent products available in New Zealand are based on these active ingredients, although a number of companies are producing 'natural' (plant-oil based) alternatives.
- With all active ingredients the effectiveness, either expressed as the degree of protection or the duration of protection, increases with the concentration of active ingredient in the product.
- DEET remains the 'gold standard' against which other products are compared. While occasional comparisons may suggest that other products offer superior protection to DEET, such studies often use quite low concentrations of DEET (5-10%) or are based on short test duration periods.
- While the protective performance of DEET is concentration-related, there is evidence to suggest that the marginal benefits of products containing greater than 25-30% DEET are minor.
- The protective performance of the other main active ingredients is also concentration-related, however, these active ingredients are rarely present in commercial formulations at concentrations above 20-25%.
- While some plant oil-based product show excellent protection in the short-term, most of the available evidence suggests that protection due to such products is less long-lasting than with the synthetic active ingredients. The duration of protection of plant oil-based products can often be improved by addition of vanillin (5-10%). Although the duration of protection of synthetic insect repellents can also be extended by addition of vanillin, the effect is particularly marked with plant oil-based products.
- While the majority of comparative studies have been carried out against mosquito species, the small number of studies available suggest that the common active ingredients are effective against a wide range of vector and nuisance-biting arthropod species. A single study also demonstrated repellency against a non-arthropod species (leeches).
- Different mosquito species show differing susceptibilities to the effects of insect repellents, with repellents often having shorter durations of complete protection against *Aedes* spp. than *Anopheles* or *Culex* spp.
- There is some evidence that different species of non-mosquito arthropods also vary in their susceptibility to the effects of insect repellents.

It is worth noting that, while a number of studies have included assessment of repellency against one of the major biting mosquito species in New Zealand, *Culex quinquefasciatus*, no information was found on the effectiveness of various insect repellents against other mosquito species present in New Zealand. Similarly, although studies have assessed

repellency against blackflies of the genus *Simulium*, none were found that assessed repellency against our native blackflies (genus *Austrosimulium*), despite their obvious nuisance to locals and tourists. While these genera are members of the same tribe, it is uncertain how applicable results on *Simulium* species are to *Austrosimulium* species However, this observation will also be true of many human-biting arthropod species in many countries. The main active ingredients appear to be effective against all arthropod species tested so far and there is no reason to expect that New Zealand species would be resistant to these repellents.

The Ministry of Health's current advice on insect repellents is (MoH 2016):

> "Wear a repellent cream or spray, preferably containing DEET (diethyltoluamide). (Repellents containing less than 35% DEET are recommended because higher concentrations are no more effective – they just work for longer – and in rare cases they can cause poisoning. Repellent should not be applied to wounds or irritated skin.)"

On the basis of the current review, this advice is still valid. Given the range of insect repellents available in New Zealand and the information in the current review, this advice could be expanded to include formulations based on picaridin and oil of lemon eucalyptus or PMD. The highest levels of protection will be associated with the highest concentrations of actives in commercial products. This is currently 20-25% for picaridin and 30% for oil of lemon eucalyptus, equating to about 20% PMD.

REFERENCES

Afify A, Horlacher B, Roller J et al. 2014. Different repellents for *Aedes aegypti* against blood-feeding and oviposition. *Plos One* 9 (7): e103765

Aguiar RWS, dos Santos SF, Morgado FD et al. 2015. Insecticidal and repellent activity of *Siparuna guianensis* Aubl. (Negramina) against *Aedes aegypti* and *Culex quinquefasciatus*. *Plos One* 10 (2): e0116765

Amer A, Mehlhorn H. 2006. Repellency effect of forty-one essential oils against *Aedes*, *Anopheles*, and *Culex* mosquitoes. *Parasitology Research* 99 (4): 478-490

Antwi FB, Shama LM, Peterson RKD. 2008. Risk assessments for the insect repellents DEET and picaridin. *Regulatory Toxicology and Pharmacology* 51 (1): 31-36

Badolo A, Ilboudo-Sanogo E, Ouedraogo AP et al. 2004. Evaluation of the sensitivity of *Aedes aegypti* and *Anopheles gambiae* complex mosquitoes to two insect repellents: DEET and KBR 3023. *Tropical Medicine and International Health* 9 (3): 330-334

Barnard DR, Bernier UR, Posey KH et al. 2002. Repellency of IR3535, KBR3023, para-menthane-3,8-diol, and Deet to Black Salt Marsh Mosquitoes (Diptera: Culicidae) in the Everglades National Park. *Journal of Medical Entomology* 39 (6): 895-899

Barnard DR, Xue RD. 2004. Laboratory evaluation of mosquito repellents against *Aedes albopictus, Culex nigripalpus*, and *Ochlerotatus triseriatus* (Diptera: Culicidae). *Journal of Medical Entomology* 41 (4): 726-730

Bissinger BW, Zhu J, Apperson CS et al. 2009. Comparative efficacy of BioUD to other commercially available arthropod repellents against the ticks *Amblyomma americanum* and *Dermacentor variabilis* on cotton cloth. *American Journal of Tropical Medicine and Hygiene* 81 (4): 685-690

Bissinger BW, Schmidt JP, Owens JJ et al. 2014. Performance of the plant-based repellent TT-4302 against mosquitoes in the laboratory and field and comparative efficacy to 16 mosquito repellents against *Aedes aegypti* (Diptera: Culicidae). *Journal of Medical Entomology* 51 (2): 392-399

Bissinger BW, Kennedy MK, Carroll SP. 2016. Sustained efficacy of the novel topical repellent TT-4302 against mosquitoes and ticks. *Medical and Veterinary Entomology* 30 (1): 107-111

Carroll JF, Solberg VB, Klun JA et al. 2004. Comparative activity of deet and AI3-37220 repellents against the ticks *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) in laboratory bioassays. *Journal of Medical Entomology* 41 (2): 249-254

Carroll JF, Benante JP, Klun JA et al. 2008. Twelve-hour duration testing of cream formulations of three repellents against *Amblyomma americanum*. *Medical and Veterinary Entomology* 22 (2): 144-151

Carroll JF, Tabanca N, Kramer M et al. 2011. Essential oils of *Cupressus funebris, Juniperus communis*, and *J. chinensis* (Cupressaceae) as repellents against ticks (Acari: Ixodidae) and mosquitoes (Diptera: Culicidae) and as toxicants against mosquitoes. *Journal of Vector Ecology* 36 (2): 258-68

Carroll SP, Loye J. 2006. PMD, a registered botanical mosquito repellent with deet-like efficacy. *Journal of the American Mosquito Control Association* 22 (3): 507-514

Carroll SP. 2008. Prolonged efficacy of IR3535 repellents against mosquitoes and blacklegged ticks in North America. *Journal of Medical Entomology* 45 (4): 706-14

Champakaew D, Junkum A, Chaithong U et al. 2016. Assessment of *Angelica sinensis* (Oliv.) Diels as a repellent for personal protection against mosquitoes under laboratory and field conditions in northern Thailand. *Parasites & Vectors* 9: 373

Chio EH, Yang EC, Huang HT et al. 2013. Toxicity and repellence of Taiwanese indigenous djulis, *Chenopodium formosaneum*, against *Aedes albopictus* (Diptera: Culicidae) and *Forcipomyia taiwana* (Diptera: Ceratopogonidae). *Journal of Pest Science* 86 (4): 705-712

Chou JT, Rossignol PA, Ayres JW. 1997. Evaluation of commercial insect repellents on human skin against *Aedes aegypti* (Diptera: Culicidae). *Journal of Medical Entomology* 34 (6): 624-630

Costantini C, Badolo A, Ilboudo-Sanogo E. 2004. Field evaluation of the efficacy and persistence of insect repellents DEET, IR3535, and KBR 3023 against *Anopheles gambiae* complex and other Afrotropical vector mosquitoes. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 98 (11): 644-652

Dadzie S, Boakye D, Asoala V et al. 2013. A community-wide study of malaria reduction: evaluating efficacy and user-acceptance of a low-cost repellent in northern Ghana. *American Journal of Tropical Medicine and Hygiene* 88 (2): 309-314

Deletre E, Martin T, Campagne P et al. 2013. Repellent, irritant and toxic effects of 20 plant extracts on adults of the malaria vector *Anopheles gambiae* mosquito. *Plos One* 8 (12):
Diaz JH. 2016. Chemical and plant-based insect repellents: Efficacy, safety, and toxicity. *Wilderness & Environmental Medicine* 27 (1): 153-163

Fradin MS, Day JF. 2002. Comparative efficacy of insect repellents against mosquito bites. *New England Journal of Medicine* 347 (1): 13-18

Frances SP, Waterson DGE, Beebe NW et al. 2004. Field evaluation of repellent formulations containing DEET and picaridin against mosquitoes in Northern Territory, Australia. *Journal of Medical Entomology* 41 (3): 414-417

Frances SP, Waterson DG, Beebe NW et al. 2005. Field evaluation of commercial repellent formulations against mosquitoes (Diptera: Culicidae) in Northern Territory, Australia. *Journal of the American Mosquito Control Association* 21 (4): 480-482

Frances SP, Rigby LM, Chow WK. 2014. Comparative laboratory and field evaluation of repellent formulations containing deet and lemon eucalyptus oil against mosquitoes in Queensland, Australia. *Journal of the American Mosquito Control Association* 30 (1): 65-67

Gkinis G, Michaelakis A, Koliopoulos G et al. 2014. Evaluation of the repellent effects of *Nepeta parnassica* extract, essential oil, and its major nepetalactone metabolite against mosquitoes. *Parasitology Research* 113 (3): 1127-1134

González M, Venter GJ, López S et al. 2014. Laboratory and field evaluations of chemical and plant-derived potential repellents against Culicoides biting midges in northern Spain. *Medical and Veterinary Entomology* 28 (4): 421-431

Govere J, Durrheim DN, Baker L et al. 2000. Efficacy of three insect repellents against the malaria vector *Anopheles arabiensis*. *Medical and Veterinary Entomology* 14 (4): 441-444

Kayedi MH, Haghdoost AA, Salehnia A et al. 2014. Evaluation of repellency effect of essential oils of *Satureja khuzestanica* (Carvacrol), *Myrtus communis* (Myrtle), *Lavendula officinalis* and *Salvia sclarea* using Standard WHO Repellency Tests. *Journal of Arthropod-Borne Diseases* 8 (1): 60-68

Keziah EA, Nukenine EN, Danga SPY et al. 2015. Creams formulated with *Ocimum gratissimum* L. and *Lantana camara* L. Crude extracts and fractions as mosquito repellents against *Aedes aegypti* L. (Diptera: Culicidae). *Journal of Insect Science* 15 (1): 45-45

Klun JA, Strickman D, Rowton E et al. 2004. Comparative Resistance of Anopheles albimanus and Aedes aegypti to N,N-Diethyl-3-methylbenzamide (Deet) and 2-Methylpiperidinyl-3-cyclohexen-1-carboxamide (AI3-37220) in Laboratory Human-Volunteer Repellent Assays. *Journal of Medical Entomology* 41 (3): 418-422

Klun JA, Khrimian A, Debboun M. 2006a. Repellent and deterrent effects of SS220, Picaridin, and Deet suppress human blood feeding by *Aedes aegypti, Anopheles stephensi,* and *Phlebotomus papatasi*. *Journal of Medical Entomology* 43 (1): 34-9

Klun JA, Khrimian A, Rowton E et al. 2006b. Biting deterrent activity of a deet analog, two DEPA analogs, and SS220 applied topically to human volunteers compared with deet against three species of blood-feeding flies. *Journal of Medical Entomology* 43 (6): 1248-51

Lupi E, Hatz C, Schlagenhauf P. 2013. The efficacy of repellents against *Aedes, Anopheles, Culex* and *Ixodes* spp. - A literature review. *Travel Medicine and Infectious Disease* 11 (6): 374-411

Mittal PK, Sreehari U, Razdan RK et al. 2011. Efficacy of Advanced Odomos repellent cream (N, N-diethyl-benzamide) against mosquito vectors. *Indian Journal of Medical Research* 133 (4): 426-430

MoH. 2014. *Insect bites*. 23 September 2016. https://www.health.govt.nz/your-health/conditions-and-treatments/accidents-and-injuries/bites-and-stings/insect-bites

MoH. 2016. *Avoiding bug bites while travelling*. 19 April 2017. https://www.health.govt.nz/your-health/healthy-living/travelling/avoiding-bug-bites-while-travelling

Naucke TJ, Lorentz S, Grünewald H-W. 2006. Laboratory testing of the insect repellents IR3535® and DEET against *Phlebotomus mascittii* and *P. duboscqi* (Diptera: Psychodidae). *International Journal of Medical Microbiology* 296, Supplement 1: 230-232

Naucke TJ, Kropke R, Benner G et al. 2007. Field evaluation of the efficacy of proprietary repellent formulations with IR3535 and picaridin against *Aedes aegypti*. *Parasitology Research* 101 (1): 169-177

Qualls WA, Xue RD, Holt JA et al. 2011. Field evaluation of commercial repellents against the floodwater mosquito *Psorophora columbiae* (Diptera: Culicidae) in St. Johns County, Florida. *Journal of Medical Entomology* 48 (6): 1247-1249

Reegan AD, Kannan RV, Paulraj MG et al. 2014. Synergistic effects of essential oil-based cream formulations against *Culex quinquefasciatus* Say and *Aedes aegypti* L. (Diptera: Culicidae). *Journal of Asia-Pacific Entomology* 17 (3): 327-331

Rodriguez SD, Drake LL, Price DP et al. 2015. The efficacy of some commercially available insect repellents for *Aedes aegypti* (Diptera: Culicidae) and *Aedes albopictus* (Diptera: Culicidae). *Journal of Insect Science* 15 (1): 140

Sanghong R, Junkum A, Chaithong U et al. 2015. Remarkable repellency of *Ligusticum sinense* (Umbelliferae), a herbal alternative against laboratory populations of *Anopheles minimus* and *Aedes aegypti* (Diptera: Culicidae). *Malaria Journal* 14: 307

Scott JM, Hossain T, Davidson C et al. 2014. Laboratory evaluation of citronella, picaridin, and DEET repellents against *Psorophora ciliata* and *Psorophora howardii*. *Journal of the American Mosquito Control Association* 30 (2): 136-137

Solberg VB, Klein TA, McPherson KR et al. 1995. Field evaluation of deet and a piperidine repellent (AI3-37220) against *Amblyomma americanum* (Acari: Ixodidae). *Journal of Medical Entomology* 32 (6): 870-875

Tawatsin A, Thavara U, Chansang U et al. 2006. Field evaluation of deet, Repel Care, and three plant based essential oil repellents against mosquitoes, black flies (Diptera: Simuliidae) and land leeches (Arhynchobdellida: Haemadipsidae) in Thailand. *Journal of the American Mosquito Control Association* 22 (2): 306-313

Trigg JK, Hill N. 1996. Laboratory evaluation of a eucalyptus-based repellent against four biting arthropods. *Phytotherapy Research* 10 (4): 313-316

Trongtokit Y, Curtis CF, Rongsriyam Y. 2005. Efficacy of repellent products against caged and free flying *Anopheles stephensi* mosquitoes. *Southeast Asian Journal of Tropical Medicine and Public Health* 36 (6): 1423-1431

Uc-Puc V, Herrera-Bojorquez J, Carmona-Carballo C et al. 2016. Effectiveness of commercial repellents against *Aedes aegypti* (L.) in Yucatan, Mexico. *Salud Publica De Mexico* 58 (4): 472-475

Uniyal A, Tikar SN, Mendki MJ et al. 2016. Behavioral response of *Aedes aegypti* mosquito towards essential oils using olfactometer. *Journal of Arthropod-Borne Diseases* 10 (3): 372-382

Uzzan B, Konate L, Diop A et al. 2009. Efficacy of four insect repellents against mosquito bites: a double-blind randomized placebo-controlled field study in Senegal. *Fundamental & Clinical Pharmacology* 23 (5): 589-594

Van Roey K, Sokny M, Denis L et al. 2014. Field evaluation of picaridin repellents reveals differences in repellent sensitivity between Southeast Asian vectors of malaria and arboviruses. *Plos Neglected Tropical Diseases* 8 (12): e3326

Wang CL, Lu LH, Zhang AJ et al. 2013. Repellency of selected chemicals against the bed bug (Hemiptera: Cimicidae). *Journal of Economic Entomology* 106 (6): 2522-2529

Webb CE, Hess IMR. 2016. A review of recommendations on the safe and effective use of topical mosquito repellents. *Public Health Research & Practice* 26 (5): e2651657

WHO. 2013. *Guidelines for efficacy testing of spatial repellents*. Geneva: Organization WH

WHO. 2016. *Vector-borne diseases*. World Health Organization 23 September 2016. http://www.who.int/mediacentre/factsheets/fs387/en/

Wilson MD, Osei-Atweneboana M, Boakye DA et al. 2013. Efficacy of DEET and non-DEET-based insect repellents against bites of *Simulium damnosum* vectors of onchocerciasis. *Medical and Veterinary Entomology* 27 (2): 226-231

Witting-Bissinger BE, Stumpf CF, Donohue KV et al. 2008. Novel arthropod repellent, BioUD, is an efficacious alternative to deet. *Journal of Medical Entomology* 45 (5): 891-898

Yap HH, Jahangir K, Zairi J. 2000. Field efficacy of four insect repellent products against vector mosquitoes in a tropical environment. *Journal of the American Mosquito Control Association* 16 (3): 241-244

Zermoglio PF, Martin-Herrou H, Bignon Y et al. 2015. *Rhodnius prolixus* smells repellents: Behavioural evidence and test of present and potential compounds inducing repellency in Chagas disease vectors. *Journal of Insect Physiology* 81: 137-144

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