

Comparing Mosquito Repellency Efficacy on Textiles Sprayed with DEET and Permethrin

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ABSTRACT

N,N-Diethyl-*meta*-toluamide (DEET) and Permethrin are the most common active ingredients in mosquito repellents. They are commonly sprayed on textiles and clothing to repel insects, specifically, mosquitos, in order to avoid the vector-borne diseases spreading through communities. In this article, we first discuss the characteristic of DEET and Permethrin based on their composition and chemical structure. We then conducted experiments to evaluate the functionality of each ingredient. We also compared the anti-mosquito efficacy of the textiles and clothing sprayed with DEET and Permethrin; the government restriction of the application of these pesticides to textiles and clothing due to their toxicity level and impact on the human body, and any damages to textile and clothing materials.

Keywords

DEET, Permethrin, Mosquitos, Insects, Vector-borne disease.

Introduction

People working or staying outdoors such as in the countryside, parks, forests, etc. may like to wear insecticide-treated clothing to protect themselves from blood feeding arthropods, i.e. mosquitoes. There are many products and technologies designed to prevent bites from arthropods and to reduce the risk for transmission of vector-borne pathogens. *N,N*-Diethyl-*meta*-toluamide (DEET) and Permethrin are the most common active ingredients in mosquito repellents. They are typically sprayed on clothing to repel insects, like mosquitoes that may spread vector-borne diseases through community [1].

DEET was developed by the U.S. Army in 1946 for the protection of military personnel in insect-infested areas. It was registered in the United States for use by the general public in 1957, and has been commercially marketed as a personal insect repellent since 1965 [2,3]. DEET is a colorless liquid with a distinct and faint odor [2]. Since it is a plasticizer, it causes damage to certain rubber, plastic, vinyl, or elastic materials including certain synthetic or treated fabrics. However, DEET does not cause damage to natural fibers including cotton and wool. DEET works great as a mosquito repellent by inducing a intensive smell which is highly disliked by

mosquitoes as it activates a type of olfactory receptor neuron in special antennae of mosquitoes [4].

It has been previously estimated that approximately 30% of the U.S. population uses DEET annually as a personal insect repellent [3].

Permethrin is an insecticide in the pyrethroid chemical family. It was originally registered for use by the United States Environmental Protection Agency (U.S. EPA) in 1979, and it was re-registered in 2006 [5]. Commercially available Permethrin is a blend of two stereoisomers [6]. It ranges from a colorless crystal to a yellow or brown viscous liquid.

Other than general usage as mosquito's repellent, it is also used on a variety for crops that are given to livestock, as well as in structures and buildings, including livestock housing and food-handling establishments. It is also used in numerous residential sites, both indoor and outdoor, and on pets and clothing. Permethrin acts on the nervous system of insects. It interferes with sodium channels to disrupt the function of neurons, and causes muscles to spasm, culminating in paralysis and death [6]. It is a broad-spectrum insecticide, a chemical used to kill a variety of insects.

Comparing the regulations of both of these common repellent agents in developed countries (Table 1), Permethrin is relatively

less restricted among USA, Canada and developed countries in Europe for treated textiles and clothing as compared to DEET. Especially when US adopted permethrin-treated clothing in their military in 1979 and allowed consumer-oriented, permethrin factory-treated clothing products to be sold in their local market in 2003. In this study, we conducted the mosquito repellent efficacy test on textile sprayed with DEET and Permethrin respectively in order to evaluate their applicability on textiles.

(a)

USA	Canada	EU
<ul style="list-style-type: none">> Except for a few veterinary uses, DEET is registered for use by consumers, and it is not used on food.> Formulations is registered for direct application to human skin contain from 5 to 99% DEET.> Products containing DEET currently are available to the public in a variety of liquids, lotions, sprays, and impregnated materials (e.g., towlettes, roll on).> DEET is a plasticizer and can damage certain rubber, plastic, vinyl, or elastic materials such as contact lenses, eyeglass frames and lenses, watch crystals, combs, painted and varnished surfaces, and certain synthetic or treated fabrics.> DEET does not damage natural fibers including cotton and wool.	<ul style="list-style-type: none">> Pesticides are carefully regulated in Canada through a program of pre-market scientific assessment, enforcement, education, and information dissemination.> Insect repellents containing DEET can be used safely when applied as directed and in the right concentration, depending on age > 12 years old up to 30% 2 - 12 years up to 10% and 3 times daily 6 months - 2 years old up to 10% and NO more than once a day> For children younger than 12 years old, do not use a DEET product on a daily basis for more than a month.> For infants younger than 6 months old, do not use an insect repellent containing DEET. Instead, use a mosquito net when babies are outdoors in a crib or stroller.	<ul style="list-style-type: none">> As a biocide, DEET is now regulated under the EU Biocidal Products Regulations 528/2012 to ensure consistent product safety across EU.> DEET received EU approval in 2012 for use as an active ingredient in insect repellents.> The European Centre for Disease Prevention and Control does not recommend the use of repellents containing DEET in concentrations of 20% or more for protection.

(b)

USA	Canada	EU
<ul style="list-style-type: none">> Permethrin is registered by the EPA as an insecticide for use in a variety of settings. When used to pre-treat clothing, it is an insect repellent.> All pesticides sold or distributed in the USA must be registered by the EPA.> Permethrin has been registered since 1979, and was first registered in 1990 for use as a repellent on clothing by the military.> At about the same time, EPA also approved permethrin as a spray for use on clothing and gear by consumers, as well as for commercial factory treatment of clothing and various types of gear.> In 2003, EPA first registered consumer-oriented, permethrin factory-treated clothing products. More products have been approved since then	<ul style="list-style-type: none">> In Canada, Pesticides, including Permethrin, are regulated under the Pest Control Acts, administered by Health Canada's Pest Management Regulatory Agency (PMRA).> All pesticides are registered (that is, approved) if a rigorous scientific assessment indicates that the health and environmental risks are acceptable and the products have value.> Factory-produced clothing containing permethrin cannot be manufactured in Canada or shipped into the country, though Canadians can bring these items back with other purchases from the U.S. or abroad.> Permethrin spray designed for use on clothing (0.5% strength) is not available in Canada, but it can be purchased online and shipped into the country (at considerable expense).	<ul style="list-style-type: none">> Permethrin is an active substance evaluated in product-type (PT) 8, wood preservatives and PT 18, insecticides, acaricides and products to control other arthropods.> Other than as a wood preservative, permethrin is also used as an insecticide, for indoor use by spot treatment in cracks and crevices by professionals or non-professionals and for the treatment of textile fibres to be used for example in the manufacture of carpets.> Permethrin (CAS No. 52645-53-1) is not authorized for use in plant protection products in the EU where its agricultural use has been banned under Directive 91/414/EEC since 2003.> However, certain non-agricultural uses of permethrin are allowed under the Biocidal Products Regulation (Regulation (EU) No. 528/2012.

Table 1: Governmental restrictions and regulation in USA [7], Canada [8] and Europe [9] on the usage of (a) DEET and (b) Permethrin.

Experimental
Comparison of the Mosquito Repellent Efficacy between DEET and Permethrin

We tested two commercial mosquito repellent textile sprays respectively with DEET and Permethrin as the main ingredients. We carried out the Arm-in-Cage (AIC) testing under the commercial standards for conducting mosquito repellents efficacy tests in order to conduct the tests in a proper manner. To avoid any commercial conflict of interest from the testing results of two selected textile sprays available in the marketplace, we will not disclose the commercial brands of these products in this article.

Testing on 100% cotton knitted fabric sprayed with commercial mosquito repellent

Since cotton fibre has good absorbency, we chose 150 gm/m² as the testing amount of repellent to be sprayed on 100% cotton knitted fabric [10]. We prepared 6 pieces of 100% cotton knitted

fabrics per repellent, i.e. 3 pieces of treated fabrics and 3 pieces of untreated fabrics (control fabrics) for each of the commercial mosquito repellent to conduct the Arm in Cage (AIC) Test.

Since the two selected repellents have different lifetimes in regard to mosquito repellency efficacy, i.e. Repellent A has a 12-hour lifetime whereas Repellent B has 7 day (168 hours), we choose an appropriate testing duration schedule to test the repellency rate of the two repellents. The testing results are summarized in Table 2 below.

Testing Duration	Number of mosquito Landing on Repellent A Sprayed Fabric (N _R)			Number of mosquito landing on control fabric (without sprayed with Repellent A) (N _C)			Average repellency rate (%) ^a of Repellent A
	Human subject 1 (HT1)	Human subject 2 (HT2)	Human subject 3 (HT3)	Human subject 1 (HT1)	Human subject 3 (HT3)	Human subject 3 (HT3)	
							$A_{RB} = \frac{\sum (P_{HT1}), (P_{HT2}), (P_{HT3})}{3}$
12 hours	9	8	11	34	33	34	72.31
24 hours (1 day)	30	28	29	36	34	36	17.92
48 hours (2 days)	35	34	30	37	36	34	7.56
96 hours (4 days)	36	35	38	37	36	40	3.49
168 hours (7 days)	36	34	37	37	35	38	2.73
240 hours (10 days)	35	34	35	36	36	37	4.58
						T _{ARB} ^b	18.10

Testing Duration	Number of mosquito Landing on Repellent B Sprayed Fabric (N _R)			Number of mosquito landing on control fabric (without sprayed with Repellent B) (N _C)			Average repellency rate (%) ^a of Repellent B
	Human subject 1 (HT1)	Human subject 2 (HT2)	Human subject 3 (HT3)	Human subject 1 (HT1)	Human subject 3 (HT3)	Human subject 3 (HT3)	
							$A_{RB} = \frac{\sum (P_{HT1}), (P_{HT2}), (P_{HT3})}{3}$
12 hours	5	4	6	34	33	34	85.19
24 hours (1 day)	6	5	6	36	35	35	83.97
48 hours (2 days)	6	4	7	37	34	36	84.19
96 hours (4 days)	7	6	8	38	36	39	81.47
168 hours (7 days)	8	7	9	36	35	36	77.60
240 hours (10 days)	25	23	26	39	35	39	34.51
						T _{ARB}	74.48

^aRepellency Rate(%) P(HT) = (N_C - N_R) / N_C * 100%
^bT_{ARB}

Table 2: Mosquito Repellency Rate of Repellent A Sprayed Fabric Samples (a) results of repellent A, (b) Results of repellent B.

Referring to Figure 1a, the number of mosquito landing/biting on human subjects wrapped with fabric sprayed with Repellent A increased in proportion to the test duration. For a duration longer than 12 hours, the difference in mosquito repellency efficacy between the treated arm and the control arm became insignificant, implying the loss in mosquito repelling action of the repellent.

Referring to Figure 1b, although the mosquito repellency rate of Repellent B sprayed fabric also dropped in proportion to test duration. The mosquito repellency efficacy remained moderate and still had significant repellency effect compared to the control after 240 hours.

In comparison to Repellent A and Repellent B shown in Table 1, Figures 1 and 2, we concluded that the mosquito repellency efficacy of Repellent B (with Permethrin as main) is higher, with repellency rate up to 84% and a longer repellency period (more

than 168 hours). Meanwhile, Repellent A (with DEET content) lost its repellency efficacy shortly after 12 hours and had a much lower average repellency rate (18.1%) than that in repellent B (74.48%) in the whole 240 hours testing duration.

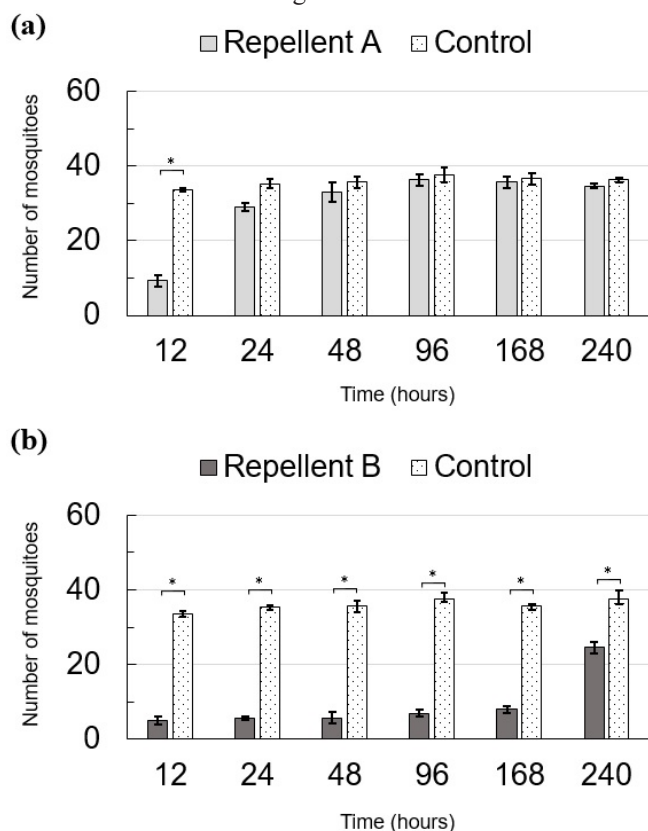


Figure 1: Results of AIC test Number of mosquitoes landed on the arm wrapped by 100% cotton knitted fabric sprayed with (a) Repellent A with DEET as the main ingredient, and (b) Repellent B with Permethrin as the main ingredient. Error bar represent standard deviation of number of mosquitoes landed in 3 experiments with identical experimental condition but with 3 different human subjects *P < 0.05 indicated a significant difference.

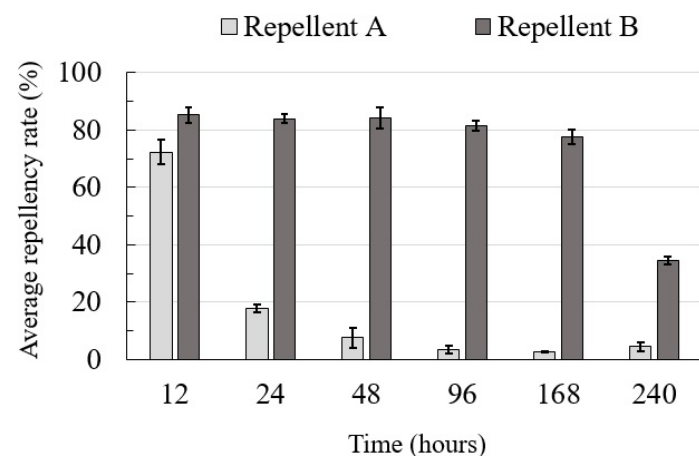


Figure 2: Comparison of repellency rate of Repellent A and Repellent B at different testing duration. Repellent A has DEET as the main active ingredient while Repellent B has Permethrin as the main active ingredient. Error bar represent standard deviation of testing results in 3 human subjects.

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Conclusion

Based on the chemical characteristic of DEET and Permethrin and our experimental results, we had the following conclusions on the application of the two pesticides-based mosquito repellents:

First, commercially available Repellent A containing DEET has a lifetime lasting for 12 hours, while another commercially available Repellent B containing Permethrin has lifetime lasting for 7 days. Under the same testing standard and procedure, the Repellent B had a longer standing duration than Repellent A when applied to cotton-based textile.

Second, in terms of fabric absorption based on the study of 100% cotton knitted fabric, due to the absorbency and capillary action, when 150 gm/m² of either Repellent A or Repellent B acted on the fabric, we saw that the material absorption is not the determining factor to influence the mosquito repellency efficacy.

DEET serves as a true repellent in that mosquitoes intensely dislike the smell of the chemical [4]. A type of olfactory receptor neuron in the special antennal of mosquitoes is activated by DEET to disenable a mosquito to smell human odor. The disability of olfactory receptor of a mosquito would be active again once the smell of DEET is diminished due to higher vapor pressure mentioned in the paragraph above. Permethrin is emulsified and absorbed by cotton fiber and vaporized. Permethrin acts on the nervous system of insects. It interferes with sodium channels to disrupt the function of neurons, and causes muscles to spasm, culminating in paralysis and death [6]. The lower vapor pressure of Permethrin enables it to have longer repellency duration and capability to repel mosquitos.

Considering the above, it is also concluded that DEET, as compared with Permethrin, is not an ideal pesticide-based repellent used for textiles and clothing as follows:

First, DEET is a plasticizer and can damage certain rubber, plastic, vinyl, or elastic materials such as contact lenses, eyeglass frames and lenses, watch crystals, combs, painted and varnished surfaces, and certain synthetic or treated fabrics. DEET does not damage natural fibers including cotton and wool [3]. That means DEET does damage synthetic fibres, i.e. nylon, polyester, etc. which are commonly utilized as materials for textiles, clothing, camping;

Second, DEET has vapor pressure⁽¹¹⁾: 5.6×10^{-3} mmHg at 20°C whereas Permethrin has vapor pressure⁽¹¹⁾: 2.15×10^{-8} mmHg at 20°C. DEET is a volatile pesticide which does not have a long

lasting repellency effect and Permethrin is not volatile and has longer repellency effect [12]. The shortened, hourly repellency effect of DEET on clothing does not make it a good pesticide-based repellent for clothing.

Third, Comparing with DEET having solubility (water) [2]: >1.0 g/L (>1000 mg/L), Permethrin has lower Solubility (water) [6]: 5.5×10^{-3} mg/L, 6×10^{-3} mg/L. In this case, Permethrin could have good washing fastness and be more durable than DEET for several washings without affecting the mosquito repellency efficacy. In fact, literature reviews show that Permethrin spray can be applied to clothing, hats, shoes, and other travel gear and its repellency efficacy can last through several washings [13].

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