EFFECTS OF WEATHERING ON FABRICS TREATED WITH PERMETHRIN FOR PROTECTION AGAINST MOSQUITOES[1,2]

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ABSTRACT. Permethrin-impregnated and untreated fabrics were evaluated for their toxic and repellent effects against *Anopheles stephensi* and *Aedes aegypti* after both types of fabrics were subjected to accelerated weathering for 9 weeks, under a simulated wet/tropical environment. The toxic (knockdown) effect of permethrin-impregnated fabrics against both species of mosquitoes diminished rapidly after 1 week compared to the repellent effect. After 6 weeks of weathering, the remaining low amounts of permethrin provided fair protection from mosquito bites; however, no knockdown was observed at those levels. Permethrin-treated fabric was effective in providing protection from mosquito bites and appears to be a means of attenuating both the nuisance effects and, possibly, disease transmission by mosquitoes.

INTRODUCTION

Recent studies of topical controlled-release personal-use arthropod repellent formulations and the impregnation of fabrics with permethrin (Schreck and Self 1985, Gupta et al. 1987) are an attempt to exploit modern materials and technology to effectively reduce or eliminate nuisance and disease due to arthropods. Incorporation of other materials, such as color dyes and chemicals, can greatly influence the effects of weathering on fabrics. Some fabric impregnants do not extend the useful life of a fabric, but add important qualities. One objective in impregnating clothing with permethrin is to add long-lasting protection against insects.

This study was designed to evaluate the toxic and repellent effects on mosquitoes after permethrin-impregnated fabrics were exposed to weathering in an accelerated weathering device. The current state-of-the-art accelerated weathering tests in the laboratory can provide results in the least possible time from which one can predict, within reasonable limits, the service or life expectancy of the material. Program cycles for this experiment were designed to predict the longevity of protection under environmental conditions that incorporated light, humidity and wetting effects similar to prevailing conditions found in heavily forested tropical areas of the world. These alternate wetting and drying conditions promote severe deterioration in material.

[1] Opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the U.S. Department of the Army. Use of trade names does not constitute an official approval of the products mentioned.

[2] Human subjects participating in this study gave free and informed voluntary consent.

MATERIALS AND METHODS

Mosquito species: The insects used in this study were a yellow fever vector, *Aedes aegypti* (Linn.), obtained from the University of California at San Francisco, and a malaria vector, *Anopheles stephensi* Liston, obtained from the Walter Reed Army Institute of Research, Washington, D.C. Mosquitoes were reared and maintained at 27 ± 3° C, 80 ± 10% RH and under a 12:12 L:D photoperiod. Larvae were fed a diet of floating catfish food (Continental Grain, Chicago, IL), and adults were maintained on 10% sucrose solution. The mosquitoes used were nulliparous females between 5 and 15 days of age.

Fabrics: Two fabrics, tropical (100% cotton, 7 oz poplin cloth) and temperate (50% cotton/50% nylon, 7 oz twill cloth), that had been impregnated with permethrin by a dynamic absorption method at Natick Research, Development and Engineering Center (NRDEC), Natick, MA, were evaluated. A known quantity of Permanone®/water emulsion was applied in sufficient volume to be totally absorbed by the fabric without dripping or running. Analysis by the NRDEC indicated that the permethrin had migrated to a near uniform level of 0.147 ± 0.02 mg/cm^2 (100% cotton) and 0.115 ± 0.01 mg/cm^2 (50% cotton/50% nylon) throughout the fabric. Then the fabric was air dried and cut into specimens (20.4 × 4.5 cm) for weathering in the Atlas Ci35 Weather-Ometer (Atlas Electric Devices Co., Chicago, IL), an accelerated weathering instrument, under alternate light and dark periods with intermittent sprays of water to simulate a forested tropical condition.

The Weather-Ometer is programmable, equipped with a light source (xenon arc lamp), specimen exposure rack and controls to automatically maintain preset temperature and humidity conditions during "light on" (day) and "light off" (night) cycles. The filtered spectral output and the moisture control systems provide close simulation of daylight and moisture conditions that exist in nature. The irradiance level, temperature and relative humidity recorded during the light (day) cycle were 0.45 W/m^2 at 340 nm, 70° C, and 40%, respectively. A temperature of 31° C and 96% RH were recorded during the dark (night) cycle. An intermittent spray of water (pH 6.9) sprayed the front of the fabric samples for 18 min during the dark cycle. Fabric specimens were removed from the Weather-Ometer at weekly intervals and tested against mosquitoes on test volunteer's forearm. After testing, the fabric specimens were assayed for permethrin by gas chromatography.

Mosquito test procedure: The test method used was a modification of American Society for Testing and Materials (ASTM) standard E951-83 (Anonymous 1983). A fabric specimen was placed on the flexor region of the forearm; then, a test cage (4 × 5 × 18 cm) containing 15 mosquitoes was bound to the forearm on top of the fabric with Velcro® tape, and a slide was withdrawn exposing the weathered fabric to the mosquitoes. The total number of mosquitoes biting and knocked down were recorded first at the end of 90 seconds and then at the end of 15 minutes. The slide was then closed, and the test was repeated with the second species in another cage. The numbers of mosquitoes knocked down after 1 and 24 hours was also recorded. This procedure was repeated four times with each species on bare skin and untreated and permethrin-treated fabrics before and after weathering every week for 9 weeks.

Permethrin analysis: Fabric specimens were uniformly cut into square 2.5-cm subsamples and transferred to a Soxhlet extraction apparatus. The subsamples were extracted for 6 hours with 100 ml of acetone, a time in excess of that required for complete removal of permethrin from the fabric. The extract was reduced to the sample volume of 10 ml and a portion transferred to an injector vial for gas chromatographic analysis.

A Hewlett Packard model 5880A gas chromatograph equipped with a flame ionization detector and an automatic injector was used to perform the analysis. The glass column (2 m × 2 mm, ID) was packed with 3% Supelco Sp-2100 on 100/120 Supelcoport. The carrier gas was nitrogen (25 ml/min); and the injector, detector and column temperatures were 250, 260 and 250° C, respectively.

Percent protection: The percent protection was calculated using the mean values of the 4 replications from total number of bites on the bare skin (control) and on untreated and permethrin-treated fabrics by Abbott's formula (Abbott 1925).

RESULTS AND DISCUSSION

In this study we observed a mean biting rate of 9.33 bites/min for *Ae. aegypti* and 9.06 bites/min for *An. stephensi* on bare skin. Since the area of skin exposed in the test was 33 cm^2, this is equivalent to a biting rate of 141 bites/min/forearm (500 cm^2 skin) for *Ae. aegypti* and 137 bites/min/forearm for *An. stephensi.*

Effectiveness of permethrin residues in weathered fabric specimens against *Ae. aegypti* is shown in Figures 1 and 2. The permethrin-treated 50% cotton/50% nylon fabric provided 95% or better protection for 6 weeks (except 93.3% before accelerated weathering), whereas the permethrin-impregnated 100% cotton fabric provided 95% or greater protection for 5 weeks (except 91.7% after 3 weeks) of weathering. The toxic (knockdown) effect of permethrin in both types of fabric samples against *Ae. aegypti* diminished rapidly as compared to the repellent effect. Unweathered permethrin-treated fabrics had 95% at 90 sec, 100% at 1-hr and 24-hr knockdown; and no bites were observed. After one week of weathering, less than 2% knock-

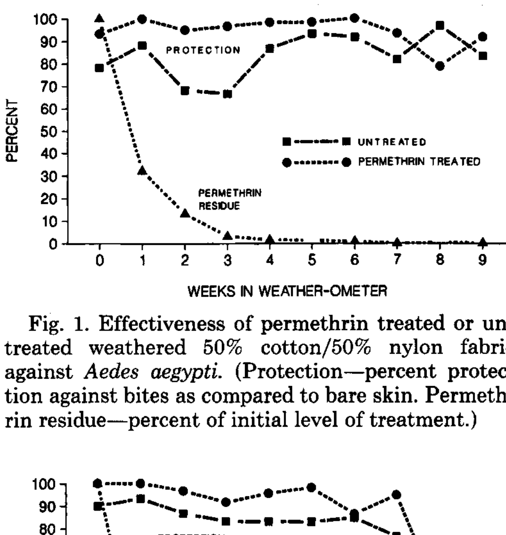

Fig. 1. Effectiveness of permethrin treated or untreated weathered 50% cotton/50% nylon fabric against *Aedes aegypti.* (Protection—percent protection against bites as compared to bare skin. Permethrin residue—percent of initial level of treatment.)

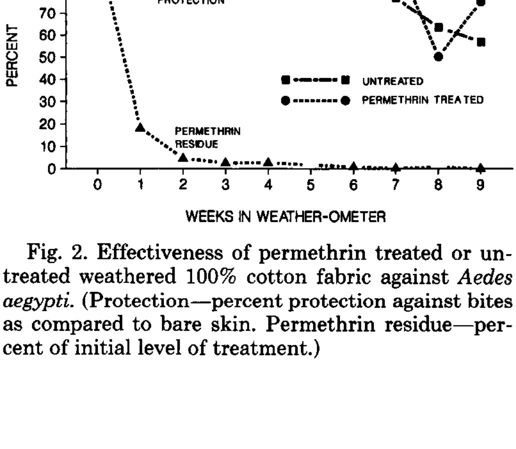

Fig. 2. Effectiveness of permethrin treated or untreated weathered 100% cotton fabric against *Aedes aegypti.* (Protection—percent protection against bites as compared to bare skin. Permethrin residue—percent of initial level of treatment.)

down was observed in mosquitoes exposed to permethrin-treated 50% cotton/50% nylon fabric as compared to 17% knockdown in those exposed to permethrin-treated 100% cotton fabric. After 2 weeks of weathering, there was less than 2% knockdown in mosquitoes exposed to permethrin-treated 50% cotton/50% nylon and no knockdown in mosquitoes exposed to permethrin-treated 100% cotton fabric.

Against *An. stephensi*, both types of permethrin-treated fabrics provided 95% or better protection for 9 weeks, except for 93% protection after 8 weeks of weathering against 100% cotton fabric (Figs. 3 and 4). No knockdown was observed at 90 sec, but 95% and 98% knockdown occurred at 15 min before weathering and 17% and 55% after one week of weathering against 50% cotton/50% nylon and 100% cotton, respectively. The 1-hr and 24-hr knockdown was 100% for both fabrics before weathering and only 7% (against 50% cotton/50% nylon) and 10% (against 100% cotton) after 1 week of weathering. Permethrin-treated 100% cotton

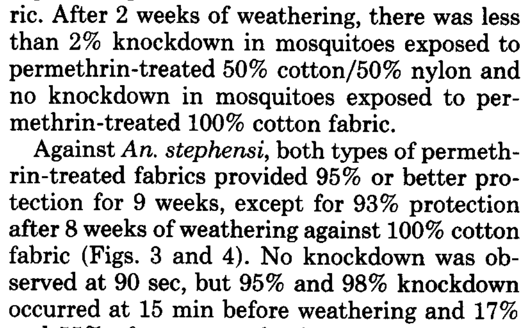

Fig. 3. Effectiveness of permethrin treated or untreated weathered 50% cotton/50% nylon fabric against *Anopheles stephensi.* (Protection—percent protection against bites as compared to bare skin. Permethrin residue—percent of initial level of treatment.)

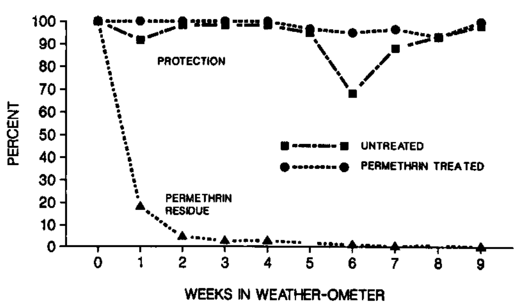

Fig. 4. Effectiveness of permethrin treated or untreated weathered 100% cotton fabric against *Anopheles stephensi.* (Protection—percent protection against bites as compared to bare skin. Permethrin residue—percent of initial level of treatment.)

had 10, 11 and 13% knockdown after 2, 3 and 5 weeks of weathering. These results indicate that *An. stephensi* was more susceptible than *Ae. aegypti* to permethrin-treated fabrics.

The results of gas chromatographic analysis for permethrin loss from the fabric are shown in Figures 1–4 as percent of the initial level of treatment. Acetone extraction of permethrin-treated fabric resulted in visible coextraction of dyes. However, the dyes or other coextracted substances did not interfere with the resolution of the permethrin peak because the peaks associated with dyes occur at different portions of the chromatogram. Although the loss of permethrin from the fabric occurred over 6 weeks, most of it was lost in the first week of weathering. Low residual amounts of permethrin in subsequent weeks (2–5) provided 93.8% protection from biting, but very little knockdown was observed at these levels. Nearly all the knockdown observed in the study occurred within the first 15 minutes of exposure.

The data indicate that knockdown was not necessary to achieve protection from mosquito bites. Permethrin is known to act both as an insecticide (Lillie et al. 1988, Schreck and Self 1985) and as a repellent (Shemanchuk 1981, Lane and Anderson 1984). Although there was very low knockdown after the second week of weathering, the permethrin-treated fabrics provided good protection from bites for up to 6 weeks as shown in Figures 1, 3 and 4. This suggests that permethrin in fabric functions as a contact repellent because when mosquitoes are observed to land on the treated fabric, they appear to acquire enough of a toxic dose to cause them to fly off, thus exhibiting what could be defined as repellent behavior. According to Buescher et al. (1987) this dual effect has also been documented for other classes of insecticides.

Although relatively good protection was provided by the untreated fabric as is evident in Figures 1–4, it was more variable than that provided by the permethrin-treated fabric. As shown in Figures 2 and 4, untreated 100% cotton fabric provided an average of 85 and 92% protection up to 6 weeks of weathering against *Ae. aegypti* and *An. stephensi.* This degree of protection probably was due to the fibrous content of the material and type of weave used in making the fabric, which provided a denser and tougher surface for mosquitoes to effectively bite through than the 50% cotton/50% nylon fabric. The 50% cotton/50% nylon fabric provided only 80% protection against *Ae. aegypti.* This could be attributed to the smooth nylon thread used with cotton in making the fabric which is comparatively thin and an easier material to bite through.

In conclusion, permethrin-impregnated fabric can provide protection from mosquito bites for long periods even after exposure to extreme weathering and thus could be an excellent means of reducing work loss or casualties in field operations caused by mosquito bites or mosquito-borne diseases.

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