Insect Resistant Textiles for Disease Vector Protection

WP19-1096

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To develop wash durable insect bite resistant textile treatments using known mechanical insecticides/repellents
- Validate insect resistance to mosquitoes (A. Aegypti) by in vitro and in vivo assays
- Evaluate textile properties to ensure mechanical and physical properties are maintained

Objective 1: Formulate durable insect resistant textile treatment employing mechanical insecticides
Objective 2: Demonstrate the mosquito resistance with bioassay testing
Objective 3: Evaluate textile and mechanical properties

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Luna at a glance

Headquarters in
Roanoke, VA

412 employees across locations in
VA, MI, CA and GA

$81M revenue projected for 2020
18.5 % Year-over-Year Growth since 2013

Founded in 1990
NASDAQ: LUNA

Lightwave · Products and Licensing

$44.5 M revenue in 2019

- Fiber optic sensing
- Fiber optic test & measurement
- Terahertz precision measurement

Luna Labs · Applied R&D

$26.0M revenue in 2019

- Protective materials
- Health sciences
- Systems & analytics
- Corrosion sensing
- Asset monitoring and reporting
- Energy & sustainability

Commercial Success: Evershield® Chemical Resistant Textiles

Development

Durable water and oil repellent textiles

2009

Field Demonstrations

2011 AFRL Tech Warrior

2013 CCAT Blacksburg Rescue Squad

2014 Army Chem/Bio Uniform

2017 DHS First Responder Uniforms

2014

Product Launch

UltraTech launches Evershield® product for commercial sale

EVERSHIELD™

Scale Up

Identified manufacturing and military partners

Scaled up formulation and textile treatment

2011

2013

Licensing Agreement

License of technology to UltraTech International for manufacturing, marketing, sales

Currently selling textile treatment product worldwide

ULTRATECH INTERNATIONAL, INC

Prototype Uniform Demonstrations

2011 AFRL Technology Warrior Ft. Hood, NY

Presented the “Outstanding Warfighter Transition Award” by Tech Warrior Staff

2013 Army Chem/Bio Suits Ft. Riley, KS

Validation of JC3 Chem/Bio protective uniform with simulated chemical exposure

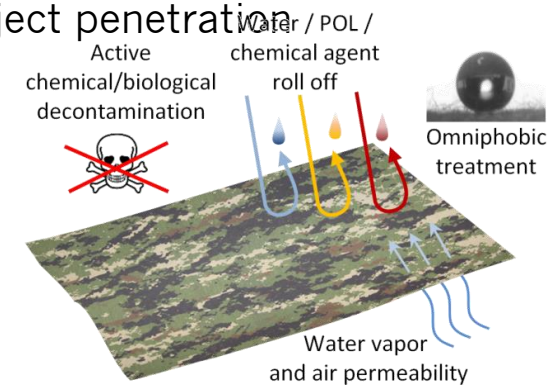
2018 DHS First Responder EMT Uniforms

Demonstration of multifunctional Uniforms:

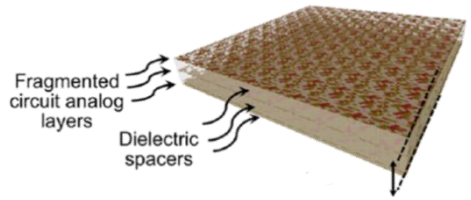
- Chemical protective
- Antimicrobial
- Puncture resistant
- Flame retardant
- Maintain comfort of current uniforms

Luna Textiles Technologies

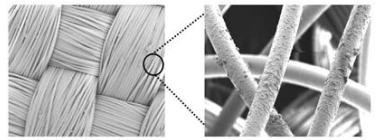
- **Omniphobic Textiles for Chemical Agent Repellency** Army Phase II SBIR (W911QY-10-C-0071)
  - Wash durable fluid resistant treatment for textiles
- **Multifunctional Textiles for Personal Protective Equipment** DHS Phase III (2014-ST-108-FRG002)
  - Multifunctional textiles for first responder uniforms to protect from chemicals, fire, sharp object penetration
- **Self-Decontaminating Textiles** CBD Phase II (FA8051-17-C-0004)
  - Breathable chemical and biological decontaminating textiles
- **Chemical Protective Gloves** CBD Phase I (contract in negotiation)
  - Chemical agent resistant stretchable fabrics
- **Fire Resistant Nylon Yarns** Army Phase II SBIR (W911QY-17-P-0264)
  - Inherently flame resistant Nylon 6,6 in Army NYCO based textiles



- **Wash Durable Non-Woven Textiles** Army Phase II STTR with NCSU (W911QY-18-C-0003)
  - Assessment of non-wovens to replace traditional woven uniforms for cost saving
- **Radar Absorbent Materials for Uniforms** Army Phase I
  - Thin, printable, lightweight frequency selective surface (FSS) patterns on textiles

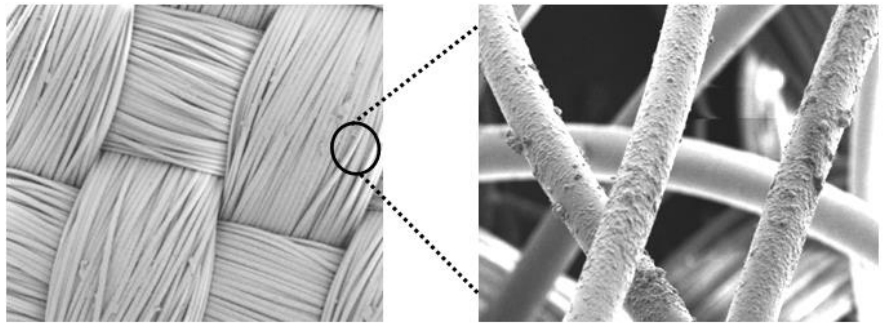


- **Insect Resistant Textiles** SERDP Seed with NCSU (W912HQ-19-P-0014)
  - Mosquito resistant treatment



Insect Bite Resistant Textiles

- Program Office: SERDP
  - Multifunctional Fibers and Textiles for Warfighter Integrated Protection
- Problem:
  - Reduce application of permethrin and other toxic insect repellents with negative health concerns
  - Desire for new sustainable insect repellents embedded in fibers or fabrics will reduce the potential for vector-borne illness
- Objective:
  - To develop wash durable insect bite resistant textile treatments using known mechanical insecticides / repellents
  - Validate insect resistance to mosquitoes (*A. Aegypti*) by *in vitro* and *in vivo* assays
  - Evaluate textile properties to ensure mechanical and physical properties are maintained



Nylon-Cotton fabric with wash durable treatment

Non-toxic mechanical insecticides bound to fiber

Background: Need for durable, non-toxic insect resistant clothing

- Current strategy:
  - Permethrin-treated uniforms
  - DEET repellent on exposed skin
  - Proper wear of uniform (tuck trousers into boots, sleeves worn in down position)
  - Malaria pills before, during, and after deployment

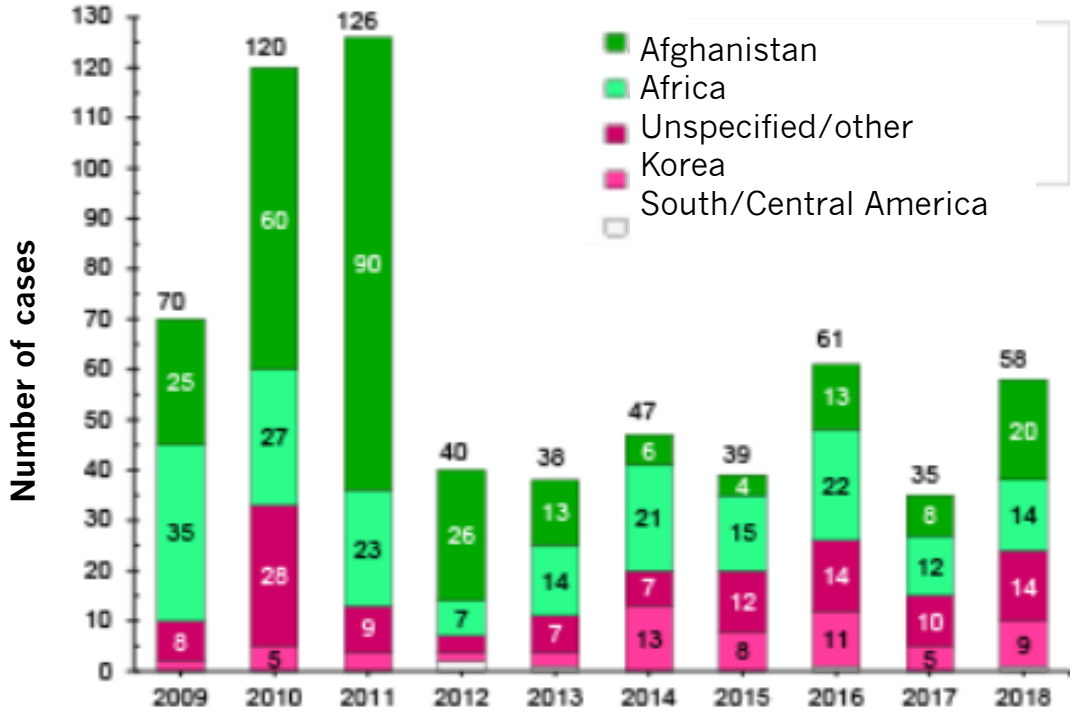
https://www.army.mil/article/129210/permethrin_treated_uniforms_protect_against_lethal_diseases

- Issues with current strategy
  - Improper compliance with current strategy leads to ineffective protection
  - Vector species are developing a resistance to permethrin and other pyrethroid-based repellents
  - Permethrin wears off with repeated use and laundering
  - Permethrin has significant toxicity concerns for personnel and environment

Motivation

- Malaria still represents a significant health threat to the combat effectiveness of U.S. Armed Forces
- Personnel from malaria-free areas are more vulnerable to the disease due to lack of immunity
- Mosquitos can spread diseases with serious short and long term effects on soldiers' health
  - Permanent scarring
  - Miscarriage
  - Possible death
- Antimalarial drug discovery & vaccine design:
  - Costly
  - Requires extensive R&D
  - FDA approval
  - Arduous and timely

- Number of malaria cases by U.S. Armed Forces, 2009 - 2018



https://health.mil/News/Articles/2019/02/01/Malaria

Program Objectives

Objective 1: Formulate durable insect resistant textile treatment employing mechanical insecticides

- Validate mechanical insecticides as viable, environmentally-friendly alternative to harmful pesticides
- Incorporate mechanical insecticides into Luna coating
- Apply coatings textiles with coating to produce wash durable treatment

Objective 2: Demonstrate the mosquito resistance with bioassay testing

- Perform laboratory testing at NCSU Entomology Department for insect resistance
- Down select best performing formulations
- Validate performance with arm-in-cage human use testing (IRB approval obtained)

Objective 3: Evaluate textile and mechanical properties

- Scale up formulation for physical testing
- Evaluate tear strength, wash durability, air permeation to meet textile specifications

Program Goals and Results

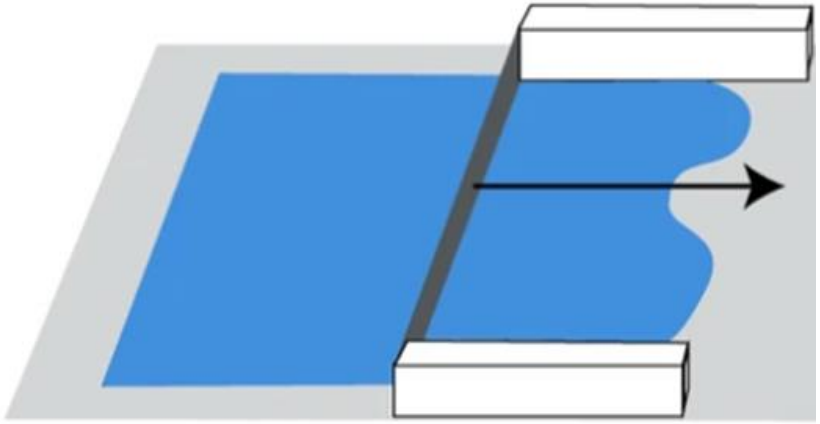
Goal	Result
Bite Resistance	
▪ >80% insect bite resistance after laundering (10x); NCSU BioAssay Tiers 1 · 4	▪ >90% bite resistance for in vitro and in vivo arm in cage testing
Durability and comfort	
▪ Wash durability – AATCC 135 (10 laundry cycles) ▪ Water vapor transport – ASTM E96 (≥700 g/day/m^2) ▪ Breaking strength – D5034 (200 warp x 125 fill lbf) ▪ Air permeability – ASTM D737 (25ft^3/min/ft^2) ▪ Drape – In house (Qualitative)	▪ Maintains bite resistance after 10 laundry cycles ▪ Water vapor transport – no change ▪ Breaking strength increased by up to 20% ▪ Air permeability – decreased, but still higher than permeability of Army Combat Uniform fabric ▪ Drape – no noticeable change
Scalable process	
▪ Materials readily available and cost effective ▪ Laboratory process that can be transitioned to US based textile mill	▪ Inexpensive, non-toxic, water-based coatings ▪ Application processes developed that match industrially relevant manufacturing ▪ Made partnerships with toll producers, textile mills and uniform producers

Textile Treatments

- Numerous selected textile chemistries were utilized to bind the mosquito treatment to textiles
- Three different industrially scalable processes were evaluated in Luna's labs

a) Dip-Pad

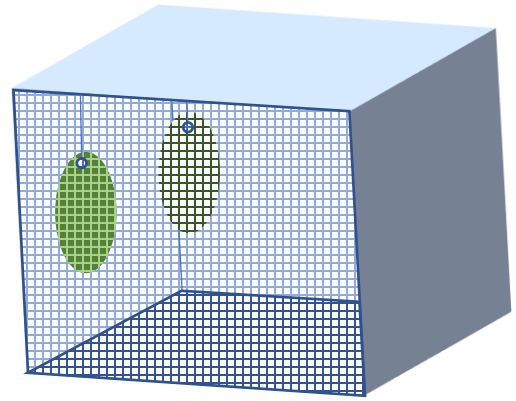
b) Spray



c) Doctor Blade

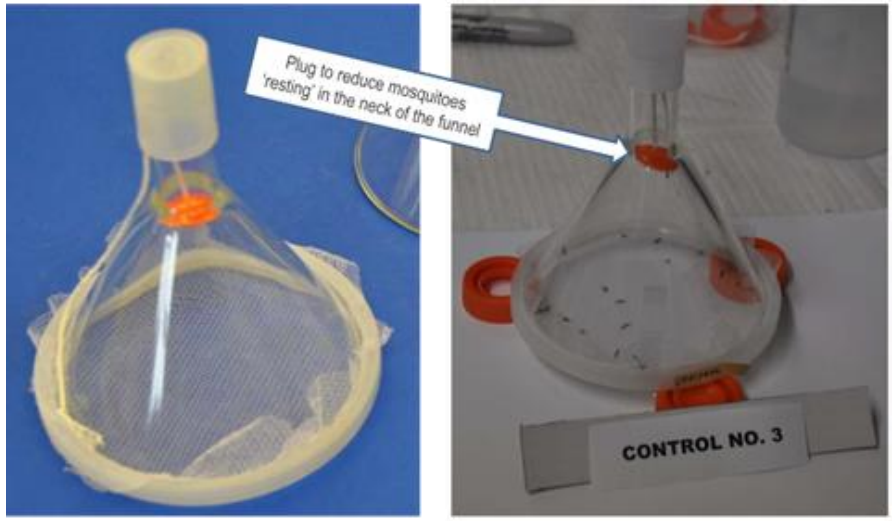
Tier 1 Bioassay: Repellency and mortality in absence of host cues

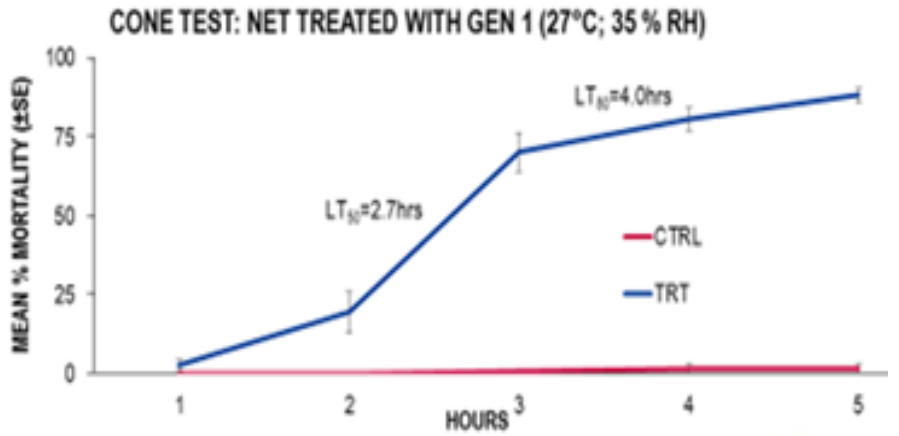
- Assessment of repellency without attractants
- 12” x 12” x 12” Plexiglas cage with air permeable sleeve on one end
- Two 3.5” diameter fabric swatches suspended on one end – one treated and one untreated control
- 25 female mosquitoes introduced
- Measure # of landings on each fabric
- Insecticidal performance will be evaluated by mortality compared with controls after 24 hours



Tier 2 Bioassay: Mortality in cone test

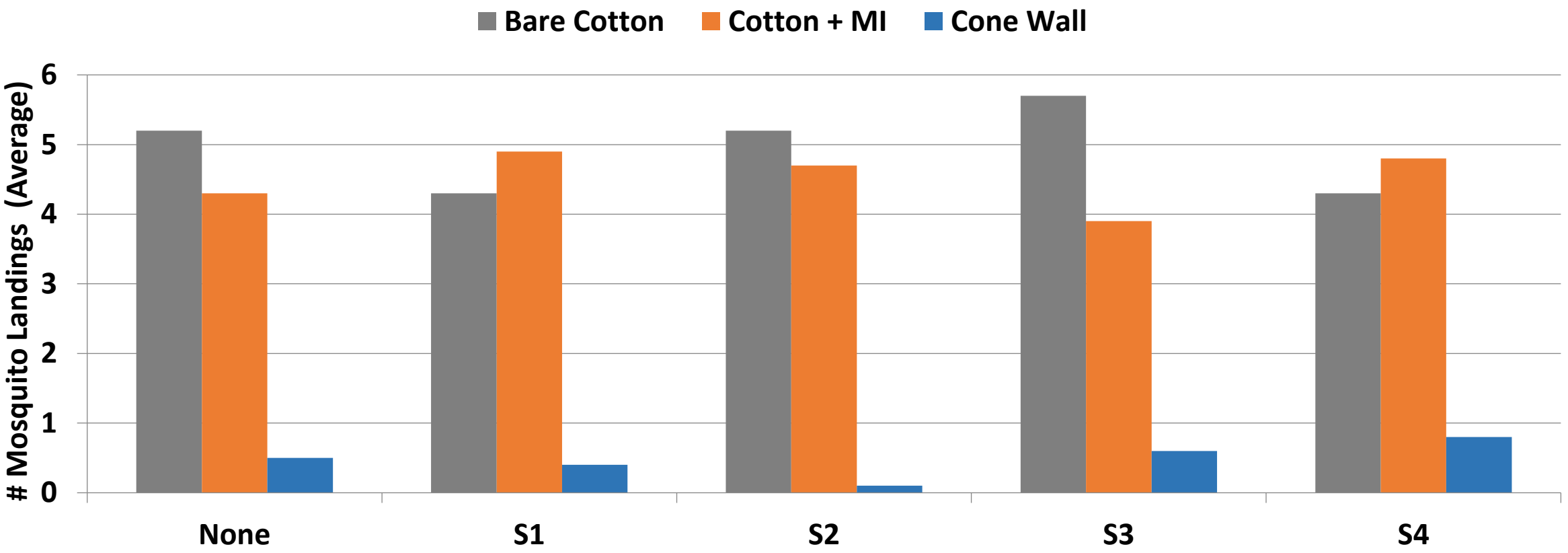
- Standard WHO funnel test for insect mortality
- Static cone bioassay test, no host cues
- 25 adult female *Aedes aegypti* tested in each bioassay (6x)
- Compare with uncoated fabric control
- LT_{50}: time taken to achieve 50% mortality per probit model
- End point physiological death (no movement when mosquito is touched or probed)





Representative Chart

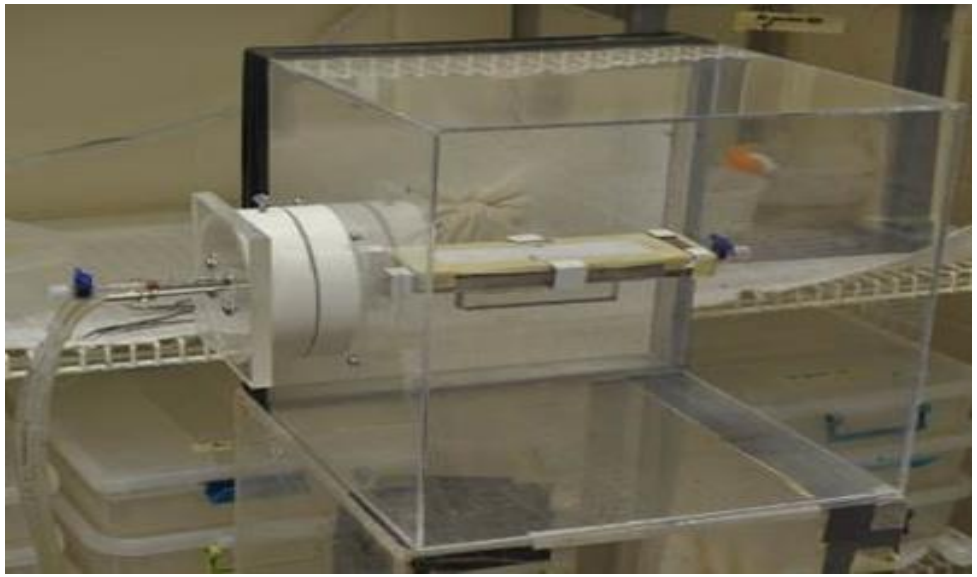
Tier 2 - Cone Test Results

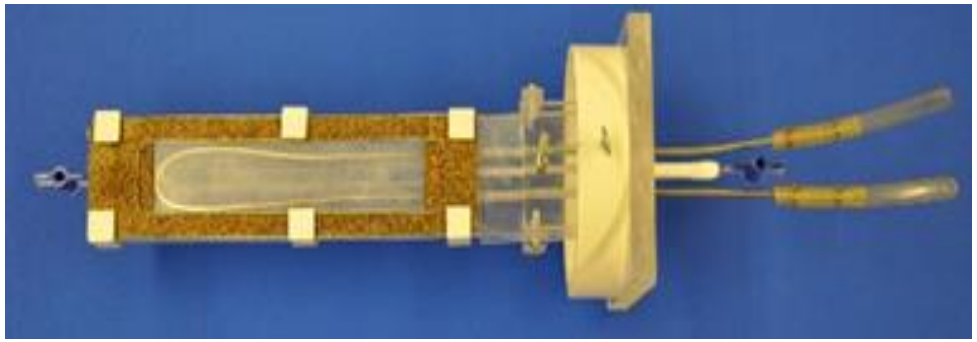


- Funnel test shows that textile is not resistant to mosquito landings as a traditional repellent
- Mortality testing shows small increase in insecticidal behavior over untreated cotton

Tier 3 Bioassay: Repellency and mortality; in vitro assay with host cues

- Plexiglas cabinet
- Warmed porcine blood circulated through device with test fabric over collagen membrane (see photo)
- ATP added to blood as phagostimulant
- 25 female mosquitoes 4-10 day age transferred to cage
  - *Aedes aegypti* starved overnight
- Record # of landing/probing events
- Crush insect post test to evaluate blood feeding





Tier 3 – Repellency with host cues (porcine blood)

- Four different mechanical insecticides (MI) tested against untreated cotton and coated cotton (no MI)

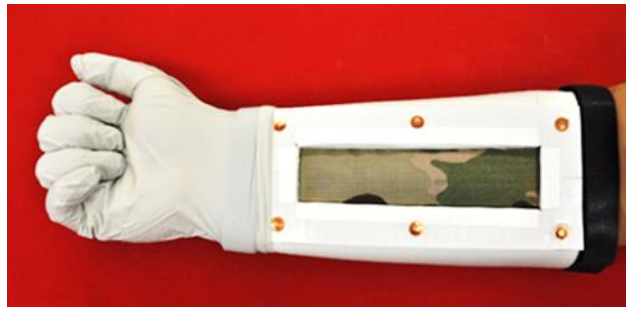
Fabric Treatment + MI	MI Loading (wt. %)	Number Mosquitoes	Number Landings	Bite Resistance (%)
None	None	100	167	2
Control	0	100	190	74
S1	40	100	117	98
S2	**40**	**100**	**150**	**100**
S3	40	100	90	99
S4	**40**	**100**	**36**	**100**

- Host cue test demonstrated close to 100% resistance for all MI treated samples tested
- Note that textile is not necessarily repellent to landings
- Control coating without MI showed some physical resistance to mosquito bites

Tier 4 Bioassay: Repellency and mortality; arm in cage

- Down selected fabrics with high bite resistance were validated by arm in cage testing
- Use of human subjects approved NCSU (IRB#2925)
- Bite proof glove with 16.5 cm x 3.5 cm opening in sleeve for test fabric

- Measure # of mosquitoes landing/probing in 10 min
- Mosquitoes examined for blood feeding as previous



Tier 4 – Arm in cage testing

- Four different mechanical insecticides (MI) tested against untreated cotton and coated cotton (no MI)

Fabric Treatment + MI	MI Loading (wt. %)	Number Landings	Tier 3 Bite Resistance (%)	Tier 4 Bite Resistance (%)
None	None	167	2	2
Control	0	28	74	78
S1	40	16	98	95
S2	**40**	**21**	**100**	**92**
S3	40	23	99	89
S4	**40**	**24**	**100**	**92**

- Excellent bite resistance for all samples tested

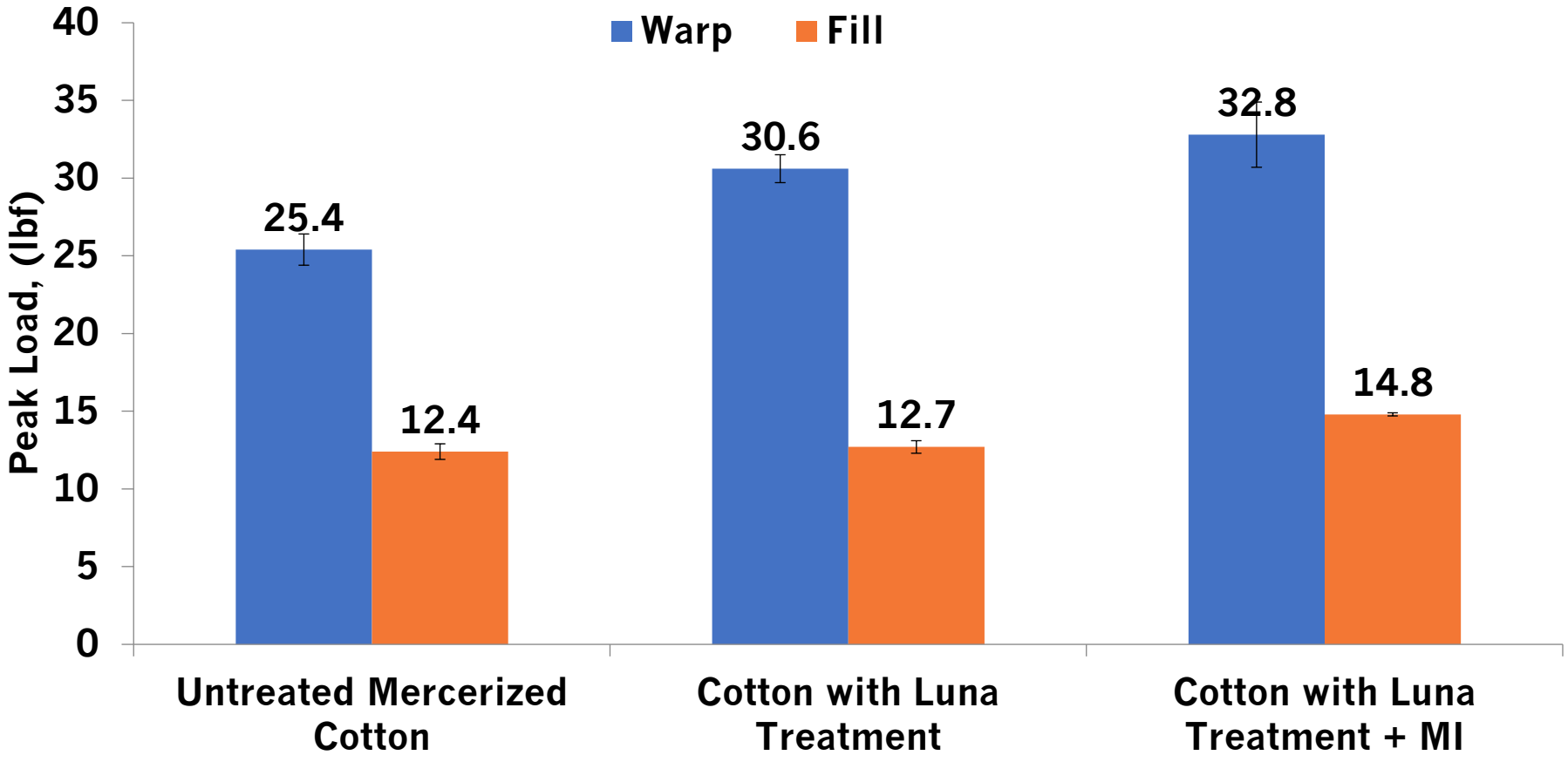
Tier 4 – Laundering durability

- Samples were laundered 10 wash/dry cycles with detergent, and testing repeated

Fabric Treatment + MI	MI Loading (wt. %)	Wash Cycles	Number Landings	Tier 4 Bite Resistance (%)
Control	0	0	21	71
Control	0	10	61	11
S2	**15**	**0**	**54**	**98**
S2	**15**	**10**	**260**	**90**

- Textile treated with mechanical insecticide maintains bite resistance after laundering, demonstrating durability of treatment

Physical Testing: ASTM D5034 grab tensile



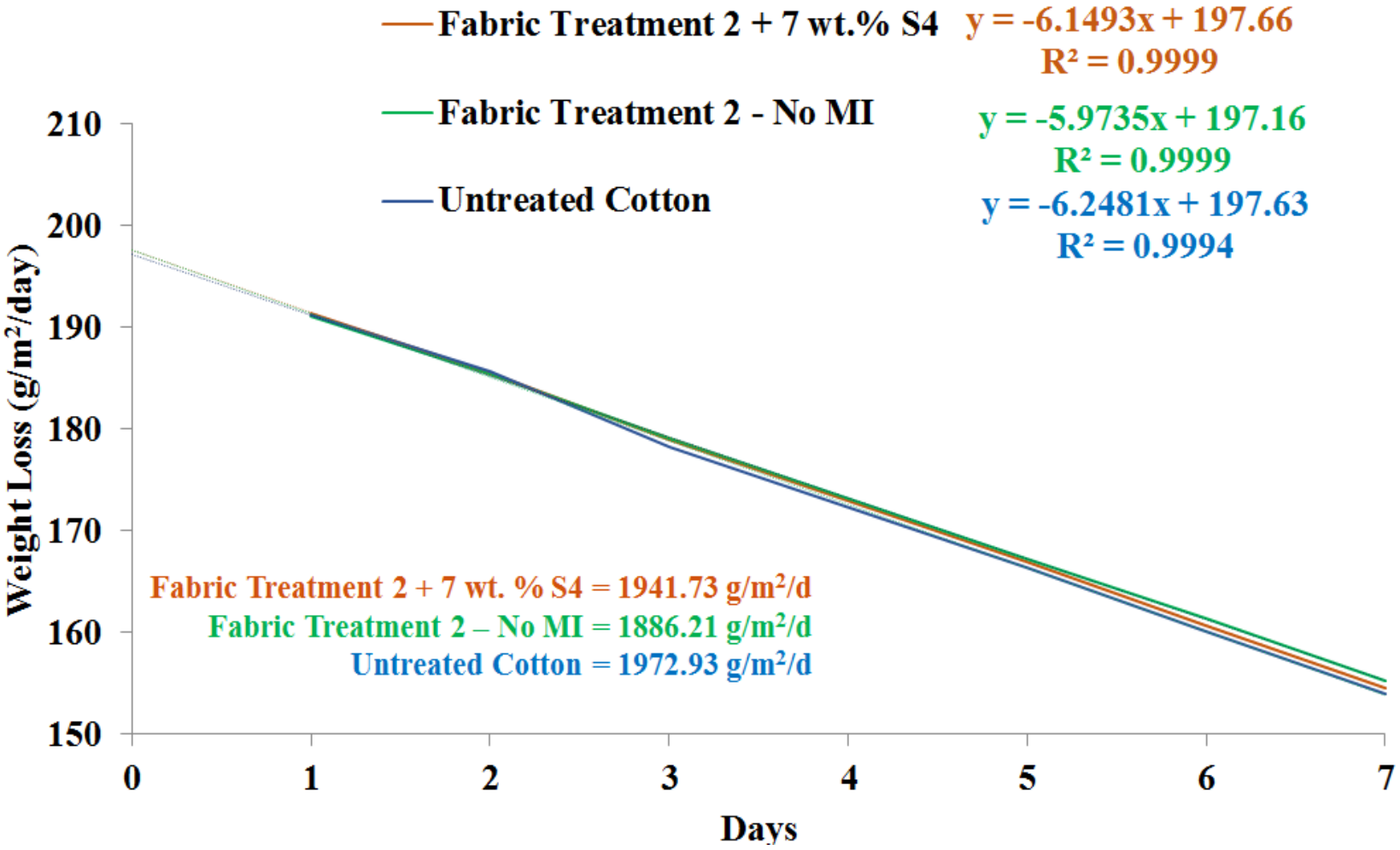
- Luna treated textile has improved breaking strength compared with untreated cotton

Physical Testing: ASTM D737 Air Permeability

Sample	Untreated NYCO	Cotton Control	Fabric Treatment (0% MI)	7 wt. % MI	15 wt. % MI
Air Flow Average (cfm)	10.3	66.6	42.58	55.12	26.08
St. Dev.	0.61	4.36	11.27	7.20	2.90
Total Weight (oz/yd^2)	6.59	3.3	4.6	5.0	5.4

- Air permeability has decreased while Luna treated textile has improved breaking strength compared with untreated cotton, yet still better than NYCO (e.g. current ACU)

Physical Testing: ASTM E96 Water Vapor Transmission Rate



- Moisture vapor transmission (e.g. evaporated sweat) comparable to untreated cotton fabric

Summary

- Luna prototype textile treatments demonstrated >90% insect bite resistance
- Maintained insect bite resistance after laundering
- Note that repellency to insect landings has not decreased significantly
  - This may be a benefit - current repellent treatments (e.g. permethrin) will drive insect away from textile to exposed, unprotected skin
- Maintained mechanical properties
  - Improved tensile strength
  - Equivalent moisture vapor transmission
  - Decreased air permeability on cotton; better air permeability than combat uniform fabric (e.g. Nylon-Cotton blends)
- Demonstrated scalable process
  - Waterborne, non-toxic treatment
  - Evaluated knife blade, spray coating, dip/pad/cure application – all industrially relevant processes
  - Down selected formulation / and application for future development