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Effect of Fabric Characteristics on Pesticide Penetration through Selected Apparel Fabrics

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The minimization of dermal exposure to pesticides is critical in reducing the health risks associated with the handling of toxic chemicals. This can be achieved through the use of protective clothing. Research evaluating the overall barrier property of fabrics has been conducted; however, little has been done to identify specific fabric characteristics contributing to improved barrier performance. Previous research has shown that fiber content, finish (Leonas and DeJonge 1986, Freed et al. 1980, Kawar et al. 1978), and fabric geometry (Raheel and Gitz 1987) influence pesticide penetration.

The primary purpose of this research was to explore the effect and contributions of specific fabric characteristics in fabrics as barriers to pesticide penetration. This was an exploratory investigation to evaluate the influence of the fabric characteristics and not in-depth enough to isolate more than trends.

MATERIALS AND METHODS

Twelve fabrics were selected for this study (Table 1). Ten represent those readily available to agricultural workers and two were experimental fabrics. Previous studies (Leonas and DeJonge 1986, Orlando et al. 1981) showed that protection against pesticide penetration increased when water repellent finishes were applied; therefore denim, chambray, and twill fabrics, which are all commonly found in ready-to-wear apparel, were treated with a commercial water repellent finish. Formulation for this finish was 7% Zepel D®, 10% Norane F, 4% Mykon NRW-3, and 82.6% water. Treated and untreated samples of the woven fabrics were evaluated throughout the study.

Four of the fabrics examined were nonwoven fabrics which are currently available in protective clothing, specially designed

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for the application of pesticides. These are Tyvek®, polyethylene-coated (PE) Tyvek®, Saranex®-coated Tyvek®, and Gore-Tex®. The Gore-Tex® used had a cotton/polyester woven face and a polyester jersey-knit back. The two remaining fabrics were experimental nonwoven fabrics (Ex 1 and Ex 2), treated with repellent finishes. Complete fabric descriptions are listed in Table 1.

Table 1. Fabric descriptions

Common Name	Fiber Content	Construction	Finish
Denim	100% cotton	Woven-twill	None
Denim-Fl	100% cotton	Woven-twill	Fl
Chambray	100% cotton	Woven-plain	None
Chambray-Fl	100% cotton	Woven-plain	Fl
Twill	65/35 cot/poly	Woven-twill	None
Twill-Fl	65/35 cot/poly	Woven-twill	Fl
Tyvek®	100% olefin	Nonwoven-PB	None
Tyvek-PE®	100% olefin	Nonwoven-PB	PE
Tyvek-Saranex®	100% olefin	Nonwoven-PB	Saranex
Gore-Tex®	65/35 cot/poly	Comp-W/NW/K	None
Experiment 1	Polypropylene	Comp-SB/MB/SB	Repellent*
Experiment 2	Polyester	Nonwoven-PB/SB	Repellent*

MB-Melt blown PE-Polyethylene Poly-Polyester
SB-Spun bonded NW-Nonwoven Comp-Composite
PB-Point bonded COT-Cotton FL-Fluorocarbon water repellent
W-Woven K-Knit
*Formulation unknown due to manufacturer's trademarks

Fabric characteristics evaluated in this study included fiber content, fabric construction, surface treatment, yarn count, weight, thickness, air permeability, spray rating, and surface energy. The test methods used to characterize the fabrics and results are listed in Table 2.

The fabric under investigation was exposed to pesticide spray using a four-layer composite sample as described by Leonas and DeJonge (1986). The test fabric is being evaluated for its ability to prevent pesticide penetration by analyzing the amount of pesticides found on the collector and foil layers. The collector layer was a 50% cotton/50% polyester blend tee-shirt fabric. A random order of exposure was determined statistically, using an incomplete block design to minimize any systematic errors in the spray system. A 0.12% concentration of pesticide solution was used to expose the fabric specimens and conditions were as described by Leonas et al. (1989).

After exposure, the fabrics were allowed to dry for 1 hr. A 7.62 x 2.54 cm strip specimen was removed from the center of the fabric and extracted using the procedure developed by Easter et al. (1983). The extract was analyzed using gas chromatographic techniques. The amount of pesticide that penetrated the top layer of fabric, as found on the collector

Table 2. Fabric characteristics

Fabric	Thickness (mm)	Weight (gm/m^2)	Air Permeability ($m^3/sec/m^2$)	Spray Rating	Yarn Warp	Count Fill	Surface Energy	Surface Energy
Den	0.66	274.0	.02	0	52	44	35.00	(1)
Den-Fl	0.66	287.6	.02	50	52	44	30.62	(2)
Cha	0.30	116.9	.07	0	58	52	35.00	(1)
Cha-Fl	0.30	123.5	.49	70	58	52	28.63	(5)
Tw	0.43	235.0	.07	50	50	58	35.00	(1)
Tw-Fl	0.36	233.6	.09	50	50	57	28.63	(5)
Ty	0.10	36.4	.00	60	NA	NA	30.16	(3)
Ty-PE	0.15	56.0	.00	100	NA	NA	22.30	(8)
Ty-Sar	0.18	98.9	.00	100	NA	NA	22.30	(8)
G-Tex	0.38	165.4	.00	0	60	57	35.00	(1)
Ex 1	1.52	64.8	.05	100	NA	NA	22.30	(8)
Ex 2	0.18	42.8	1.29	100	NA	NA	22.30	(8)

The following methods were used:

Thickness--ASTM D177-64
Spray Rating--AATCC 22-1980
Yarn Count--ASTM D3775-79
Surface Energy Rating--AATCC 118-1983
Weight--ASTM D3776-79

Den--Denim
Den-Fl--Denim-Fl
Cha--Chambray
Cha-Fl--Chambray-Fl
Tw--Twill

Ty--Tyvek®
Ty-PE--Tyvek-PE®
Ty-Sar--Tyvek-Sar®
G-Tex--Gore-Tex®
Tw-Fl--Twill-Fl

layer, was determined. A Varion 3600 gas chromatograph equipped with an electron capture detector was used to analyze the chlorinated hydrocarbon pesticides (Captan and Dicofol) and a nitrogen-phosphorous thermionic specific detector to analyze the organophosphate pesticides (Ethion and methyl parathion). For Captan, the glass column was 183 cm x 2 mm with 4% SE 30 and 6% SP 2401 on a 36.58 m Glass Suplecoport packing. The oven temperature was at 200°C, the injector at 240°C, and the detector at 300°C. For Dicofol, the glass column was 183 cm x 4 mm with 3% SP 2100 on a 36.58 m Suplecoport system. The oven was at 210°C, the injector at 240°C, and the detector at 300°C. For Ethion, the glass column was 183 cm x 4 mm with 3% SP 2100 on a 36.58 m Glass Suplecoport system. The oven was at 225°C, the injector at 240°C, and the detector at 300°C. For methyl parathion, the column was 183 cm x 4 mm with 1.5% SP 2250 and 1.95% SP 2401 on a 36.58 m Glass Suplecoport system. The oven was at 220°C, the injector at 200°C, and the detector at 270°C.

The amount of pesticide obtained on the collector and foil layers is listed in Table 3. An Analysis of Variance (ANOVA) showed that the fabrics did provide varying degrees of protection against pesticide penetration. Using Duncan's Multiple Range test, the fabrics were grouped as to the amount of pesticide that penetrated through the test fabric layer to the collector and foil layers (Table 3). Those fabrics in Group A allowed the largest amount of pesticide to penetrate, providing the poorest protection. Fabrics in Group D allowed no penetration of pesticide, providing excellent protection. Fabrics in Groups B and C are classified as having below average and above average protection, respectively.

RESULTS AND DISCUSSION

Spray rating was used to determine the water repellency of the face of the test fabric. The rating, however, did not consistently predict the ability of a fabric to prevent pesticide penetration (Table 2). Tyvek® (PE & Sar) with a spray rating of 100 provided excellent protection against pesticide penetration for all pesticides. However, fabrics with lower spray ratings provided a wide range of protection. For example, untreated chambray had a spray rating of Ø and provided below average or lower protection for all four of the pesticides. But, treated denim, which also had a spray rating of Ø, provided excellent protection for three of the pesticides. This illustrates a discrepancy between spray rating as an indicator of actual protection. The finding that spray rating did not relate directly to pesticide penetration may be attributed to the procedures for determining repellency and penetration. The repellency rating is completed immediately after the application of the liquid, whereas the pesticide penetration is measured 1 hr after applying the pesticide solution. Since penetration can be a function of time, this difference in time may have affected the two measurements. Also, the nature of the pesticide solution may be altered due to environmental conditions, decreasing the surface tension of

Table 3. Pesticide penetration through fabrics and Duncan's multiple range groupings

Fabric	Captan		Dicofol		Ethion		Methyl Parathion	
	Pesticide Amount Penetrated (ug/cm^2)							
	SD	DM	SD	DM	SD	DM	SD	DM
Den	.014(.004)	C	ND(.000)	D	ND(.000)	D	ND(.000)	D
Den-Fl	.021(.007)	C	ND(.000)	D	ND(.000)	D	ND(.000)	D
Cha	.450(.116)	A	.234(.035)	A	.040(.006)	B	.047(.009)	A-B
Cha-Fl	.064(.009)	B	.162(.012)	B	.068(.002)	A	.033(.008)	B-C
Tw	.007(.002)	C	ND(.000)	D	ND(.000)	D	ND(.000)	D
Tw-Fl	.021(.010)	B-C	ND(.000)	D	ND(.000)	D	ND(.000)	D
Ty	.246(.021)	B	ND(.000)	D	ND(.000)	D	.018(.005)	D
Ty-PE	ND(.000)	D	ND(.000)	D	ND(.000)	D	ND(.000)	D
Ty-Sar	ND(.000)	D	ND(.000)	D	ND(.000)	D	ND(.000)	D
G-Tex	.060(.020)	B-C	ND(.000)	D	ND(.000)	D	ND(.000)	D
Ex 1	.007(.017)	C	ND(.000)	D	ND(.000)	D	.017(.040)	D
Ex 2	.078(.021)	B	.084(.017)	C	.012(.006)	C	.055(.020)	A

ND-Non-detectable
DM-Duncan's Multiple Range Grouping
SD-Standard Deviation

the liquid allowing for increased spreading of the droplet and subsequential absorption.

A similar relationship was found for surface energy and penetration. It was not possible to predict the amount of pesticide penetration that occurred. As surface energy decreased, penetration did not always decrease (Table 3). For example, Ex 2 had the lowest surface energy; however, all four of the pesticides penetrated this fabric. This may be a result of the testing methods. The surface energy determination is made after 30 sec, compared with penetration being measured after 1 hr.

Of the 12 fabrics evaluated, seven had some type of surface treatment. Chambray, the lightest weight woven fabric, treated with the fluorocarbon finish showed improvement in protection for only Captan and Dicofol. Since the denim and twill, treated and untreated, fabrics provided excellent protection for three pesticides, it is not possible to determine the degree to which the treated samples changed the penetration mechanism. The surface treatments classified as coatings did prevent penetration of the pesticide, but these coatings are impermeable and may not meet the thermal demands of the pesticide applicator. The coated nonwoven fabrics, Tyvek-Saranex® and Tyvek-PE®, provided excellent protection to all four pesticides and the unfinished Tyvek® allowed penetration for Captan and methyl parathion. The Ex 1 fabric provided excellent protection for Dicofol and Ethion, above average protection for methyl parathion, and average protection for Captan. Ex 2 provided the lowest protection for methyl parathion, above average protection for Dicofol and Ethion, and below average protection for Captan. Therefore, the surface treatments did not consistently reduce pesticide penetration. This points to the need for additional research and testing of more fabrics with and without finishes.

It was difficult to isolate thickness due to the interaction of weight and thickness. There was an apparent trend that untreated woven fabrics of greater thickness provided increased protection against pesticide penetration than did untreated woven fabrics of lower thickness. Chambray, the fabric of the lowest thickness, provided low to below average protection for all pesticides. The heavier woven fabrics, twill and denim, provided excellent protection for Dicofol, Ethion, and methyl parathion and above average protection for Captan.

The two fabrics with the highest air permeability rating, Chambray-Fl and Ex 2, provided from low to average pesticide penetration. For the remaining fabrics, air permeability values did not correlate with the amount of penetration. Air permeability measures the resistance at which air travels through the fabric, which is related to the porosity of the fabric. It was theorized that particle penetration can also be related to porosity of the fabric; the more porous the fabric, the more opportunity for penetration to occur. In this study, a direct comparison between pesticide penetration and air permeability could not be made.

In this study, the construction classifications were woven and nonwoven. Due to the differences in fabric characteristics within the classes of woven and nonwoven fabrics, it was impossible to compare wovens with nonwovens so comparisons were made within each construction class.

Of the six nonwoven fabrics, Saranex® and PE-coated Tyvek® provided excellent protection from all pesticides. Both are 100% spunbonded olefin fabrics with impermeable coatings. Gore-Tex®, the woven/nonwoven composite fabric, provided excellent protection against three of the pesticides but was below average for the pesticide Captan. It is believed that penetration of the Captan through the Gore-Tex® is due to the nature of the interaction between the pesticide solutions and the fabric surrounding the PTFE layer. The composite nonwoven, spunbond/meltblown/spunbond (Ex 1), provided excellent protection for Dicofol, Ethion, and methyl parathion but only above average protection for Captan. It was expected that this fabric would provide excellent protection in all cases because of the repellent finish and the fabric layering. Meltblown fabrics are produced using microfibers which result in excellent filtering potential. The fabrics may act as a filter, trapping the pesticide in the fabric after absorption, thus preventing movement through the fabric and reducing penetration. Ex 2, the point bonded/spunbonded polypropylene with polyester binder fibers nonwoven fabric, was also an experimental fabric and provided poor-to-average protection for all pesticides.

Of the six woven fabrics, the plain woven chambray was much lighter in weight and lower in thickness than the twill woven fabrics. The chambray fabrics, treated and untreated, allowed penetration of all four pesticides and were ranked either poor or below average in each case. The twill fabrics permitted penetration only of the pesticide Captan and were ranked above average and below average. The fabrics of twill construction (denim and twill) were similarly grouped by Duncan's Multiple Range test groupings even though their weights and thicknesses varied. The fact that the chambray fabric allowed more penetration than the twill fabrics indicated fabric construction may have an influence on the ability of the fabric to prevent pesticide penetration. However, only three woven fabrics were evaluated and the plain woven fabric was of the lightest weight and thickness of the woven fabrics. Additional research is needed to determine the influence of fabric construction controlling for other variables such as weight and thickness.

Using the General Linear Model (GLM) statistical analysis procedure, it was possible to determine the percentage that selected fabric characteristics contributed to the overall performance of the fabric as a barrier to pesticide penetration. Only continuous variables of weight, thickness, air permeability, surface energy, and spray rating were included in this model.

The variables of thickness and air permeability contributed a combined 17% to 40% of the total for all four pesticides with thickness being the most significant. Air permeability was the second highest contributor for Ethion, Dicofol, and methyl parathion and the third highest for Captan. However, the variable of air permeability could not be isolated, and it is not possible to determine the degree of how variable interaction affected the results.

The contribution of the remaining measurable independent variables--weight, surface energy, and spray rating--was from 9% to 21% of the total. These variables had little influence on the amount of pesticide that penetrated each fabric, indicating that in this study they were not directly related to the penetration that occurred through a specific fabric. The GLM analysis found that weight did not contribute to the overall performance of the fabric. Fabric weight is dependent on many different fabric properties, including fiber content, finish, and construction. The weight of the woven fabrics was highly correlated with thickness; as weight increased, thickness increased.

The amount not identified by the variables included in the GLM model is thought to be due to variations in construction, surface treatments, and fiber content. Differences between the performance of the untreated woven and nonwoven fabrics were evident. Surface treatments reduced or did not significantly change the amount of penetration that occurred when compared with fabrics that had no surface treatment. The impermeable coatings eliminated penetration and the repellent finishes either reduced or did not change the amount of penetration. Also, the effect of fiber content could not be isolated due to the many variables being examined.

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