

## Exploration of Nano-finished Non-wovens For Potential Use in Protective Clothing for Agricultural Workers in South Africa

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**Abstract:** The global trade requirements have made protective clothing paramount in the agricultural sector. The aim of the study was to find the views of farmers on the use of protective garment for the agricultural sector in South Africa, and to measure the performance of nano-treated fabric structures, which can be utilized as an alternative disposable protective garment. A mini survey was done to gather current practices of farm workers and experiments were conducted on the application of different nano-finishes followed by performance testing of barrier and comfort properties of the selected fabric structures. Findings revealed that current garments of farm workers do not offer adequate protection and there was desire and need for an alternative protective garment. Furthermore, the viscose/flax non-woven fabric with the CNFP/NSAC finish had the highest values for water vapour transmission, oil and water repellency, and air permeability and was reported to be relatively more comfortable.

**Key words:** Comfort properties, disposable products, farm workers preferences, Nano-finishers, pesticide protective clothing

### INTRODUCTION

The bulk of non-woven fabrics and products in South Africa are imported from developed countries. High procurement costs of such products have created a need for local production. In response to the realized need, the Council for Scientific and Industrial Research (CSIR) commissioned a non-woven production line, incorporating Fleissner Aquajet™ spun-lacing machinery, with the view to transfer technology and build research and development (R&D) capacity on product development for the local market. Trial runs produced different samples of spun-laced non-woven fabric using man-made cellulosic/natural fibre blends and cellulosic/synthetic fiber blends. Selected fabric samples produced from the trials were further explored for potential end uses in the agricultural sector.

Agricultural output is continually being challenged by various factors despite recent agricultural practices of growing more healthy produce for consumers, which include organically grown crops; conservation of environment by non-tillage of the soil prior to planting; and the reduction of environmental pollution. While healthier eating is one of the key goals that some United

Nation organizations are espousing, it is also a fact that there is still gross underproduction of food supply and food insecurity especially in many developing countries. Shortage of food in these countries will continuously be a driver in supporting the green revolution paradigm of using hybrid seeds, fertilizers and pesticides to maximize production within the constraints of recent climatic fluctuations.

The agricultural sector was identified as an area of need particularly because there are now more stringent trading rules in the export market for exporters to European Union countries, to specify the production conditions of produce (GLOBALGAP, 2009). Farm workers have been reported to drink or eat food during spray operations (Chalermphol and Shivakoti, 2009). Furthermore, farm workers do not always heed proper procedures in using protective wear. This clearly shows that many farm workers do not take sufficient precaution (DANIDA, 2005). This experience of farm workers not taking proper measures in using protective wear was noted by Branson and Sweeney (1991) who found that a large number of farm workers who were exposed to hazardous pesticides were reluctant to wear protective clothing due to the discomfort experienced particularly in

hot environments. Chalermphol and Shivakoti (2009) reported that the reasons for not using protective equipment were discomfort (43.7%), high expense (22.5%), time-consuming to use (14.7%), unavailability when needed (10.8%), and not necessary for each case (8.47%); yet farm workers should be protected from dermal exposure to pesticides (Lee and Obendorf, 2001). In addition, it was found that farmers replaced work clothes when they were worn out and washed them after several uses and not immediately after spraying (Chalermphol and Shivakoti, 2009). Unfortunately, there is no enforcement of proper pesticide and protective clothing use in the South African Development Community (SADC) region. In the absence of national policies governing the use of protective clothing by farm workers in South Africa and the whole of the SADC region, farm workers are exposed to the long term effects of hazardous pesticides used in farming; given the generally hot humid working conditions of the workers in this part of the world; there is need to explore for an alternative, more comfortable protective wear in the agricultural sector.

Currently, available protective clothing for farm workers who use pesticides in the SADC region is the polyester/cotton or 100% cotton with a twill or plain woven fabric made into two piece suits or one piece coveralls. Both styles have a high percentage of body coverage. Cotton coveralls are comfortable, lightweight, reusable, and reduce the risk of dermal exposure to dust, granule and powder pesticides, but offer less protection against spills, sprays and mists (Cornell University, 2001). Furthermore, thick fabrics that tend to offer more protection through more absorption of mists and fumes also retain more pesticide residue after laundering. Up to three washings may be required to remove nearly all of a diluted emulsifiable pesticide concentrate from the fabric (University of Minnesota, 2005). The fabric interstices are also a major contributing factor to pesticide penetration (Csiszár *et al.*, 1998).

Existing alternative protective clothing is the non-woven disposable coveralls. Generally uncoated non-woven fabrics offer greater protection than woven fabrics and similar protection to soil-repellent finished cotton or cotton/polyester blends (University of Minnesota, 2005). Uncoated non-wovens offer effective protection against dust, granule, powder or dilute liquid pesticides; but are not recommended when using more toxic liquid pesticides (Mississippi State University, 2006). Coated non-wovens on the other hand, like Tyvek® PE a 100% spun-bond polyethylene non-woven coated with polyethylene film produced by DuPont, are used as disposable protective wear against more toxic liquid pesticides. Polyethylene coated Tyvek® can be effective against dry and liquid splashes but not suitable for organo-phosphate and chlorinated hydrocarbon pesticides. Tyvek can also be laminated with saran film, which makes it effective

against dry and liquid pesticides with higher toxicity; even so, it is not effective against chlorinated hydrocarbons such as methoxychlor (University of Minnesota, 2005; Cornell University, 2001). Both types of finishes on Tyvek are generally uncomfortable to wear in hot weather and may cause heat stress (Cornell University, 2001).

Despite some comfort issues, the use of synthetic fibre, spun-bond non-wovens, such as Tyvek® (polyethylene) and Kleenguard® (polypropylene), has continued to increase since they are relatively inexpensive, lightweight, and offer effective protection. Currently, non-wovens are most widely used protective fabrics and their use continues to grow (Fishel, 2006). To examine the potential of electrospun nanofibrous webs as barriers to liquid penetration in protective clothing systems for agricultural workers, layered fabric systems with electrospun polyurethane fibre web layered on spunbonded nonwoven were developed (Lee and Obendorf, 2001). Penetration testing showed that a very thin layer of electrospun polyurethane web significantly improved barrier performance for challenge liquids with a range of physicochemical properties.

## **THEORETICAL FRAMEWORK**

Barrier properties may be achieved through using nanotechnologies, one of the leading areas in textile research (Zhou *et al.*, 2005). Nanotechnology encompasses a wide range of technologies pertinent to structures and processes on a nanometer scale, which is one billionth of a metre (Kathirvelu *et al.*, 2008). Nanotechnologies are the design characterization, production and application of structures, devices and systems by controlling the shape and size at the nanometer scale. A nano-meter is only 10 atoms across. The usual rules of physics and chemistry are greatly affected at the nano-scale and material characteristics like strength, reactivity, colour and conductivity differ substantially at the nano and macro levels (Institute of Nanotechnology, 2006; Anderson, 2006). For example, carbon nano-tubes are 100 times stronger, yet six times lighter than steel.

The application of nanotechnology in textile products is gaining momentum because conventional methods used to impart certain properties on fabrics at times lose their functionality after the laundering or wearing of a garment. Conversely, nanotechnology imparts more durable properties due to the attachment of nano particles to a large surface area to volume ratio. Furthermore, there are low chemical usage and energy costs associated with nanotechnology on textiles (Kathirvelu *et al.*, 2008).

Current applications of nanotechnology in textiles include fibres, yarns fabrics, non-wovens, finishings, electronic textiles, and fibre modification (Kathirvelu *et al.*, 2008). Nano-finishes are usually

applied on textiles by a coating method using a composition of nano-particles, a surfactant, other ingredients and a carrier medium. The coating technique may be done through spraying the composition on the textile, dipping/soaking the textile followed by drying, transfer printing, washing using a washing solution containing nano-particles during a wash/rinse cycle in a washing machine or padding using a padder under pressure followed by drying and curing (Wong *et al.*, 2004). The prevalent applications are for wrinkle resistance, stain, soil and water repellency, antistatic, antibacterial and anti-ultraviolet protection.

The NanoTex Company, a subsidiary of the United States based Burlington Industries has developed two water and oil repellent products called nano Pel, applied to all major apparel fabrics, and nano Care, applied on 100% cotton for wrinkle resistance, oil and water repellency (Kathirvelu *et al.*, 2008). Both products do not affect the hand and the breathability of textiles. Water repellent nano-finishes, for example, modify the surface of fibres and do not block the interstices, hence the fabric allows air and moisture vapour to pass through but not water molecules. They are also environmentally friendly (Wong *et al.*, 2004).

Nano finishes comprise of nano whiskers (Frey *et al.*, 2003) of oligomeric or polymeric side branches and latent 'hooks' attached to a flexible spine. It is the hook portion in the colloidal state that forms covalent bonds with the functional groups on the fabric surface after drying and curing, thus exposing the pollar backbone with wiskers that protect the fabric against water and oil intrusion (Kathirvelu *et al.*, 2008).

The purpose of this study was to gather information regarding the currently utilized protective clothing of South African farm workers and prospects of acceptance of a new disposable protective garment. The information gathered would then be used to determine if there is a need for an alternative protective garment that is disposable; testing the trial samples of non-woven fabrics with nano-finishes applied for initially barrier and comfort properties would help narrow the febric choices for a potential, disposable, protective garment.

**Research questions:** In light of increased international pressure for the basic requirement of farm worker safety, the following research questions were posed:

- What are the views of farm workers on currently used protective clothing and the prospects of considering an alternative protective garment?

- How do nano-treated non-wovens perform on barrier and comfort properties?

## METHODOLOGY

The study had a qualitative component that used a small sample size but gave valuable information to consider in product development, and a quasi experimental approach that was utilized on the performance of the fabrics. Details of the data collecting instrument, fabric choice, nano-treatments and test methods are given in this section.

**Survey:** Current practices of farm workers were gathered from South African farm owners in a survey using a questionnaire that was developed with input, on content validity, from a South African pesticide distributor that keeps a database of South African commercial farmers. The questionnaire was first translated to Afrikaans (one of the local languages), since most of the farm owners were Afrikaans speaking. The questionnaire was distributed by either fax or mail by the pesticide distributor, to a convenience sample of 23 farmers, who had agreed to participate in the study. The farmers were located in Mpumalanga, Free State, North West and Limpopo provinces of South Africa. The purposively selected provinces have hot and humid weather conditions particularly in summer. A response rate of 61% was received on completed questionnaires.

**Fabrics:** The experimental component involved treatment of 100% viscose and 90/10 viscose/flax spun-laced non-woven fabrics. The cellulosic fabrics were selected for the study to exploit the comfort properties of both the fibres and the spun-laced fabrics - comfort being an important consideration for protective wear. A cotton drill woven fabric, the fabric identified in the responses to the questionnaire as currently used for protective clothing, was used for comparison. A 100% polyethylene classic spun-bond non-woven fabric of the type used for protective wear was also used for comparison. Fabrics were purposively selected and had the following characteristics, shown in Table 1.

**Nano-Finishes:** Different nano-finishes, supplied by an industry partner, were applied on the selected cellulosic substrates using a pad, dry and cure processes. Curing

Table 1: Untreated fabric characteristics utilized in the experiments

Fabric	Fibre content	Fabrication method	Average fabric weight (g/m <sup>2</sup> )	Average fabric thickness (mm)	Air permeability (mL/s/cm <sup>2</sup> /98Pa) S.D. in parentheses
Viscose	100% viscose	Spun-lace	85	0.52	56.5 (5.09)
Viscose/flax	90% viscose 10% flax	Spun-lace	80	0.44	129.2 (10.21)
Polyethylene	100% polyethylene	Spun-bond	41	0.21	<0.5
Cotton drill	100% cotton	Woven	234	0.49	11.1 (1.09)

S.D: Standard deviation

was done at 150°C for 3 min. The finishes used for coating the spun-laced fabrics included a Cationic Nano-molecular Fluoro-Polymer (CNFP); a Cationic Nano-molecular Fluoro-Polymer/Nano-structured Silicic Acid Combination (CNFP/NSAC), and a Cationic Fluorocarbon Resin (CFR) with polymeric, hyperbranched dendrimers in a hydrocarbon matrix. Application of nano-finishes was as per instructions provided by an industry partner.

**Performance testing:** The treated fabrics were tested in an air conditioned laboratory for water and oil repellency, air permeability and Water Vapour Transmission (WVT). Water vapour transmission and air permeability were used as indicators of the relative comfort of the fabrics. The AATCC 22-2001, Water Repellency: Spray Test, was used for testing water repellency and the AATCC 118-2002, Oil Repellency: Hydrocarbon Resistance Test, used for oil repellency of the fabrics. In the spray test, a measured volume of water was sprayed onto the fabric surface and the degree of wetting of the upper and lower surfaces of the fabric was assessed. In the oil repellency test, the fabric's resistance to wetting by a selected series of liquids with differing surface tension was determined.

For air permeability and WVT, the SANS 5265:2002, Air Permeability of Textile Fabrics, an airflow test method, using a WIRA Air Permeameter, and FNM 817 (1999), Determinación de la Permeabilidad Estática en Tejidos al Vapor de Agua (Determination of the Static Permeability of Textiles to Water Vapour) were used respectively. The FNM 817 (1999) is a combination desiccant/water method, a variation of ASTM E96 (1984), Standard Test Method for Water Vapour Transmission in Materials, in which the desiccant is located above the test fabric which is located above a volume of water at 37°C. The method has been used extensively in the CSIR laboratories. Water vapour transmission was calculated in g/m<sup>2</sup>/24 h.

Protection against the liquid pesticides was carried out using a gutter test, ISO 6530:2005(E), Protective Clothing - Protection against Liquid Chemicals - Test Method for Resistance of Materials to Penetration by Liquids, where the apparatus, in Fig. 1, was built by the CSIR. The selection of the above test was based on a comparative analysis study of the gutter, atomizer, and pipettes tests conducted by Shaw *et al.* (2001), where the gutter test was appropriate for pesticide spills. Responses to the questionnaire indicated that organophosphates pesticides were an area of concern as far as protective clothing was concerned, and two commercial emulsifiable liquid organophosphate pesticides, chlorpyrifos and mercaptothion, were used for the gutter test. Both pesticides are used on a wide range of crops including citrus, deciduous fruits and vegetable crops. Gutter testing was conducted on selected nano-finished viscose/flax

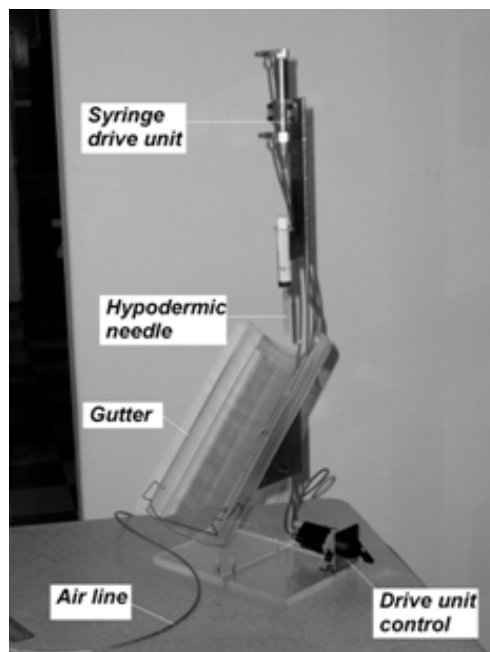


Fig. 1: Apparatus to conduct a gutter test. In the test, a measured volume of pesticide, located in the syringe, is forced through the hypodermic needle onto the test fabric, by steady pressure from the syringe drive unit

fabrics which had shown good levels of water and oil repellency during preliminary testing and, for comparison, on an untreated viscose/flax fabric, the polyethylene and cotton drill fabrics. The pesticides used were bought and diluted according to the manufacturer's instructions to levels used for crop application.

## RESULTS AND DISCUSSION

Findings on current practices in the use of protective clothing by farm workers will be followed by the performance of fabrics after applying nano-finishes.

**Current protective clothing practices:** Findings on the qualitative portion showed that a wide range of crops, including a variety of fruits, nuts, potatoes, tobacco and cotton, were farmed in the four provinces. A wide variety of pesticides, herbicides and fungicides were used. The type of protective clothing worn by farm workers was mainly cotton coveralls indicated by 77% of the respondents. Sometimes, the coveralls were supplemented with PVC jackets or aprons. Eighty-five percent (85%) of the respondents reported that the protective clothing was generally worn on average for 5 to 8 h a day. Washing frequency varied from daily, indicated by 31% of respondents, to once a week, stated by 39% the majority of respondents. Eighty five percent (85%) of the

Table 2: Performance of treated fabrics on protective and comfort qualities

Fabric	Nano-finish	AATCC Spray rating (ISO values)	Oil repellency rating	Air permeability (mL/s/cm <sup>2</sup> /98 Pa) (S.D)	Water vapour transmission (g/m <sup>2</sup> / 24 h) (S.D)
Viscose	CNFP	80 (3)	7	105.0 (20.64)	5013 (82.73)
Viscose	CNFP/NSAC	80 (3)	5	86.8 (9.85)	5051 (136.47)
Viscose/flax	CNFP	90 (4)	7	112.9 (21.47)	5315 (43.13)
Viscose/flax	CNFP/NSAC	100 (5)	7	93.4 (13.11)	5384 (41.01)
Viscose/flax	CFR	95 (4-5)	7	87.1 (11.06)	5244 (287.46)
Polyethylene	None	80 (3)	0	<0.5	3952 (31.11)
Cotton drill	None	0 (0)	0	11.1 (1.09)	4603 (70.57)

S.D: Standard deviations; AATCC spray rating: 0 for complete wetting of the surface, and 100 for no sticking/wetting; AATCC Oil repellency: grading from 0-8, where 8 is the highest grade

respondents washed the coveralls by hand, which exposed the workers to adverse effects of pesticide residue overtime (University of Minnesota, 2005).

The protective clothing used costs between Rands (R) 80 (\$11.60) and R 200 (\$ 29.00), and lasted between four and 24 months. Respondents felt that the coveralls were more or less comfortable to wear; however, there were concerns reported by 85% of the farm owners regarding the level of protection offered against the pesticides used, in particular organophosphate pesticides. Another strong concern expressed by some respondents was the practice of wearing ordinary (non-protective) garments, which did not comply with the instructions for use on the package for optimal protection of pesticide application, and was consistent with Lee and Obendorf (2001). The reason for not wearing the protective coveralls was mainly due to the discomfort experienced by workers, at times, in a hot humid working environment. Similar results, of agricultural workers being reluctant to use protective clothing due to discomfort, were reported by Chalermphol and Shivakoti (2009).

Views by 100% of the respondents on an alternative proposed disposable product indicated their willingness to try it having seen the fabric sample, despite price related concerns expressed by a few respondents. Anticipated benefits of the disposable product were convenience, savings on water costs for washing and improved worker safety by not worrying about pesticides remaining in garments after washing, as is the case with the current protective clothing. Respondents also hoped that the comfort of workers would improve, which should ensure wearing of the new protective product especially in hot humid conditions. According to the farmer's perspective, the envisaged alternative protective garment would be of a light weight coverall type, with non-absorbent properties, having limited re-use of twice per week, disposability, more comfort, and offering greater protection at a reasonable cost, given that the use of pesticides is not done everyday but once or twice a month or so.

Suggestions expressed by the respondents will feed into the prototype development phase of the project. Environmental working conditions in summer require a light weight "breathable" fabric that could be loose fitting

for air circulation to cool the body's micro environment, but with elasticized sleeve and pant hems. This would provide body coverage in order to reduce dermal exposure to the pesticides. Protection and comfort are key qualities for protective clothing that should be safe guarded (Watkins, 1995). Issues of disposal of the envisaged alternative product were not addressed because the fibre content on the sample fabrics would be biodegradable when disposed off with other refuse in land fills.

**Performance of nano-coated fabrics:** Results showed a high level of water and oil repellency of the nano-coated non-woven fabrics as illustrated in Table 2 and Fig. 2. The viscose/flax blend treated with the CNFP/NSAC nano-finish had the highest spray rating of 100 when compared to the other fabrics and it showed excellent water shedding capability, where there was no sticking or wetting of the upper fabric surface. The viscose/flax fabric treated with the CFR nano-finish also performed well, having a spray rating of 95. When compared to the 100% viscose fabrics, the viscose/flax blend fabrics had a higher level of water repellency and it appeared from the experiments that the blending of flax with viscose in the spun-laced fabric improved the effectiveness of the nano-finish. The polyethylene fabric had a similar spray rating to the nano-finished viscose fabrics whereas the cotton drill fabric had a spray rating of 0 and there was complete wetting of the fabric.

The nano-finished viscose/flax blend fabrics and the CNFP treated viscose fabric all had oil repellency values of 7, indicating a low surface energy and very high resistance to wetting by oils of different surface tensions. The cotton drill and polyethylene fabrics had the lowest oil repellency values of 0. The ease of wetting of these fabrics could be of concern when protective-wear is made from these fabrics and in circumstances where the wearer comes in contact with pesticide concentrates which have a different surface tension compared to the diluted solution of the pesticide.

The results gave a clear indication that the nano-finish effectively coated the fiber surfaces and prevented liquid penetration of the non-woven structure. Nano-finishes can impart high levels of oil and water repellency on fabrics because individual fibers are evenly and

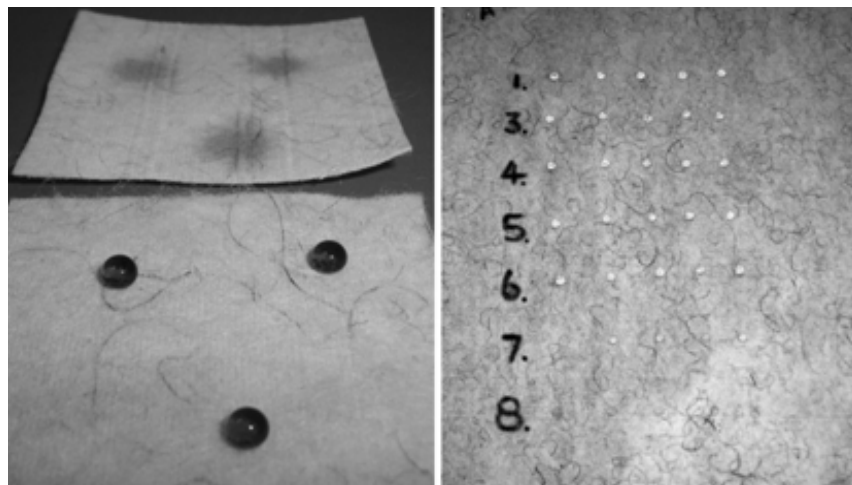


Fig. 2: Water and oil repellency of nano-finished viscose/flax fabric. Left: Water droplets (colored) on nano-finished fabric (front) and untreated fabric (back). Note the wetting of the untreated fabric and the droplets on the face of the treated fabric. Right: AATCC oil repellency test liquids, numbered 1, 3-8, on nano-finished viscose/flax fabric. Note the droplets of liquid 7, still visible on the surface of the fabric

precisely coated by the finish through a process of molecular self-organization (Qian, 2004; Thiry, 2004).

The air permeability of the nano-finished viscose/flax fabrics, ranged from 87.1 to 112.9 mL/s/cm<sup>2</sup>/98 Pa, and it was lower than that of the untreated fabric (129.2 mL/s/cm<sup>2</sup>/98 Pa, Table 1). The opposite was true for the nano-finished viscose fabrics where air permeability values were higher, from 86.8 to 105.0 mL/s/cm<sup>2</sup>/98 Pa, when compared to the value of 56.5 mL/s/cm<sup>2</sup>/98 Pa for the untreated fabric. The reason for these differences was not determined but it may have to do with physical differences that are on the fabric structures. The air permeability values of the nano-finished fabrics were, however, all higher than that of the cotton drill at 11.1 mL/s/cm<sup>2</sup>/98 Pa, and the polyethylene fabric at <0.5 mL/s/cm<sup>2</sup>/98 Pa (Table 1). Lee and Obendorf (2001) reported that air permeability decreased with increasing electro-spun web area density, but was still higher than most of protective clothing materials currently available.

The nano-finished fabrics all had WVT greater than 5000 g/m<sup>2</sup>/24 h, with the viscose/flax fabrics having values of greater than 5200 g/m<sup>2</sup>/24 h. These values were all higher than the WVT values of the polyethylene (3952 g/m<sup>2</sup>/24 h) and cotton drill (4603 g/m<sup>2</sup>/24 h) fabrics. The viscose/flax fabric treated with the CNFP/NSAC nano-finish had the highest WVT value of 5384, reflecting good WVT quality. Unlike some other coatings, the nano-finishes have little or no effect on breathability of the fabric (Wong *et al.*, 2004). The high WVT scores for the viscose/flax fabric suggests that moisture vapour generated from body sweat can easily permeate the fabric structure, leaving the individual wearing the garment feeling drier, cooler and less prone to heat stress. Water

vapour transmission and air permeability are key properties when considering garment comfort (Watkins, 1995). In general, the greater the WVT and air permeability the more comfortable a fabric will be. Wearer comfort is obviously very important to ensure that protective clothing is worn when required.

The higher air permeability and WVT results obtained for the viscose and viscose/flax blend fabrics suggest the potential of being more comfortable than the polyethylene and cotton drill fabrics. However, Lee and Obendorf (2001) observed no significant change in moisture vapour transport of the system from electrospun nonfibrous web layers.

Similar results were obtained for both organophosphate pesticides which were tested on the fabrics in the gutter test. Untreated viscose/flax fabric (fabric details in Table 1) provided very little repellency of chlorpyrifos, indicated by a low index of repellency ( $I_R$ ) of 0.5, and a high proportion of the pesticide was either absorbed by the fabric, index of absorption ( $I_A$ ) of 70.8, or penetrated through the fabric, index of penetration ( $I_p$ ) 24.6. The performance of the untreated fabric against mercaptothion was similar. If such a fabric was worn as protective clothing, the fabric would be completely wet with the pesticide and a large proportion of the pesticide would wet through to underlying garments or to the skin of the wearer. Compared to the untreated fabric, both of the nano-finished viscose/flax fabrics had higher levels of repellency with  $I_R$  of 72.5 and 74.0 for chlorpyrifos, and of 78.5 and 73.2, for mercaptothion. These values were closer to the  $I_R$  values of 92.8 (chlorpyrifos) and 97.3 (mercaptothion) recorded for the polyethylene fabric, Table 3. The cotton drill fabric,

Table 3: Gutter test: Resistance indices of fabrics to penetration by organophosphate pesticides. Standard deviations in parentheses

Fabric: treatment	Pesticide	Index of repellency ( $I_R$ )	Index of absorption ( $I_A$ )	Index of penetration ( $I_p$ )
Viscose/flax	Chlorpyrifos	0.5 (0.57)	70.8 (1.06)	24.6 (2.19)
Viscose/flax: CNFP/NSAC	Chlorpyrifos	72.5 (0.21)	2.5 (1.06)	15.3 (0.14)
Viscose/flax: CFR	Chlorpyrifos	74.0 (4.10)	1.6 (0.35)	21.7 (5.02)
Polyethylene	Chlorpyrifos	92.8 (7.85)	2.7 (1.27)	0.4 (0.0)
Cotton drill	Chlorpyrifos	29.7 (4.67)	40.7 (1.84)	28.2 (1.63)
Viscose/flax	Mercaptothion	0.1 (0.07)	73.3 (1.77)	26.3 (1.48)
Viscose/flax: CNFP/NSAC	Mercaptothion	78.5 (2.44)	2.3 (0.21)	18.7 (5.37)
Viscose/flax: CFR	Mercaptothion	73.2 (6.86)	2.8 (0.21)	19.9 (4.31)
Polyethylene	Mercaptothion	97.3 (1.56)	1.6 (0.42)	0.1 (0.07)
Cotton drill	Mercaptothion	18.0 (3.54)	45.5 (0.99)	32.9 (1.84)

$I_R = (M_t/M_i) \times 100$ ;  $M_t$  is the mass of the test liquid discharged onto the specimen (g)

$I_A = (M_a/M_i) \times 100$ ;  $M_a$  is the mass of pesticide absorbed by the fabric (g)

$I_p = (M_p/M_i) \times 100$ ;  $M_p$  is the mass of pesticide run-off collected (g);  $M_p$  is the mass, of the pesticide accumulated by the absorbent paper/film combination below the fabric (g)

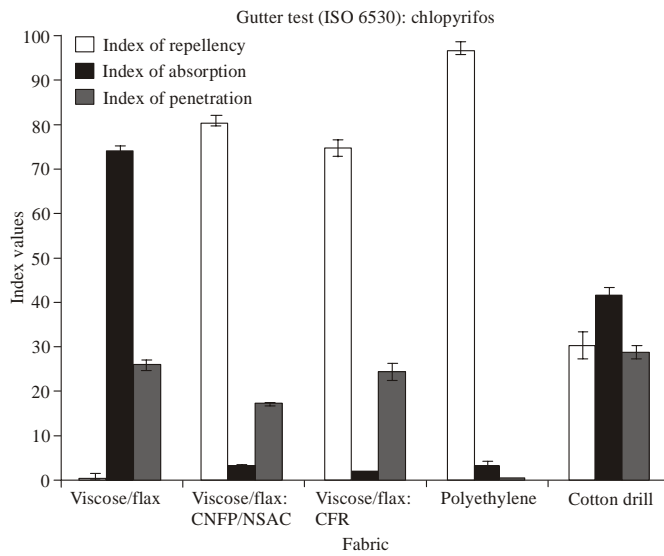


Fig. 3: Resistance indices of fabrics to an organophosphate pesticide: chlorpyrifos

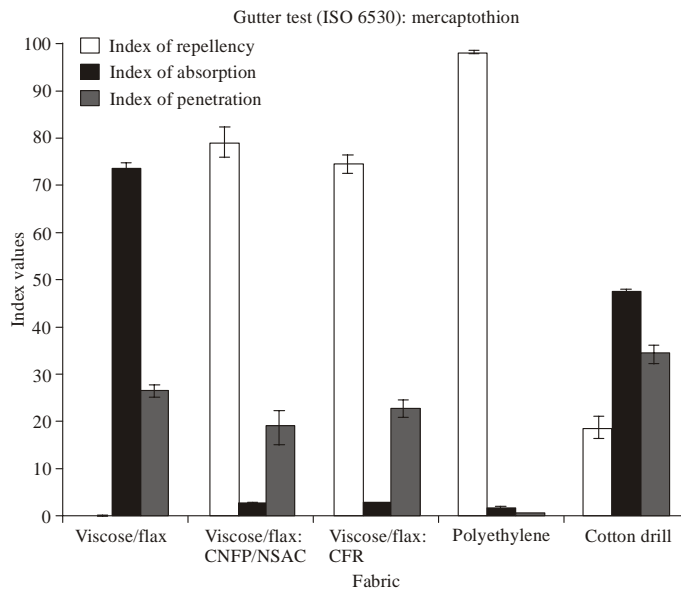


Fig. 4: Resistance indices of fabrics to an organophosphate pesticide: mercaptothion

which had  $I_R$  values of 29.7 and 18.0 for chlorpyrifos and mercaptothion respectively, had a lower level of repellency compared to the nano-finished viscose/flax fabrics. In addition, the cotton drill fabric, having an  $I_A$  of 40.7 and 45.5 for chlorpyrifos and mercaptothion respectively, and an  $I_p$  of 28.2 and 32.9 for chlorpyrifos and mercaptothion respectively, absorbed more pesticide and allowed more pesticide through the fabric than either of the nano-finished viscose/flax fabrics. The effectiveness of the nano-finished fabrics in providing increased repellency and reduced absorption and penetration of the organophosphate pesticides when compared to the cotton drill fabric is further illustrated in Fig. 3 and 4.

Adequate protection and comfort are key attributes for protective clothing. Generally, air permeability is inversely related to barrier performance (protection), but directly correlated with comfort (Oakland *et al.*, 1992). The protection property (Lee and Obendorf, 2001) can be calculated as:

$$\text{Protection (\%)} = 100 - \text{penetration (\%)}$$

The calculated protection levels are given in Table 4.

The polyethylene fabric, which had poor air permeability of less than 0.5 mL/s/cm<sup>2</sup>/98 Pa provided the highest level of protection, above 99%, for both pesticides. The cotton drill fabric which had an air permeability of 11.1 mL/s/cm<sup>2</sup>/98 Pa, was likely to be more comfortable to wear than the polyethylene fabric but offering relatively lower protection levels of 67.1 and 71.8 percent for the two pesticides. The nano-finished viscose/flax fabrics, in contrast to the polyethylene and cotton drill fabrics, had a higher air permeability of approximately 87 to 113 mL/s/cm<sup>2</sup>/98 Pa. It would be expected that these fabrics would have increased comfort but lower protection levels, however, the fabrics provided a high level of protection, which ranged from 78.3% to

Table 4: Protection levels of fabrics

Fabric: treatment	Pesticide	Protection level (%)
Viscose/flax: CNFP/NSAC	Chlorpyrifos	84.7
Viscose/flax: CFR	Chlorpyrifos	78.3
Polyethylene	Chlorpyrifos	99.6
Cotton drill	Chlorpyrifos	71.8
Viscose/flax: CNFP/NSA	Mercaptiothion	81.3
Viscose/flax: CFR	Mercaptiothion	80.1
Polyethylene	Mercaptiothion	99.9
Cotton drill	Mercaptiothion	67.1

84.7%, higher than the protection provided by the cotton drill fabric.

Penetration of liquid through porous materials is complex and involves the inherent properties of the material and the liquid, the liquid-medium interchange and pore structure in the material (Hsieh, 1995). It was noted that the index of absorption values were similar for the polyethylene and nano-finished viscose/flax fabrics ( $I_A < 3$ , Table 3), however, the viscose/flax fabrics had a higher range of pesticide penetration ( $I_p$  of 15.3-26.3) compared to the polyethylene fabric ( $I_p$  of 0.1-0.4.) Although porosity was not measured in this study, examination of the samples after the gutter test suggested that the higher penetration of pesticide was due to the construction of the spun-laced viscose/flax fabric (Fig. 5). It is thought that thinner places in some areas, a more open construction compared to the polyethylene fabric, and an uneven surface allowed more pesticide to penetrate or be drawn through the fabric to the underlying absorbent paper layer.

The penetration of a pesticide through a non-woven fabric can be decreased by decreasing the level of air permeability of the fabric. One way of lowering air permeability is to increase the fabric weight and hence the density of the fabric (Wadsworth and Salamie, 1991).

The varied linear density of flax fibres and the method of manufacture and treatment of the spun-laced viscose/flax non-woven contributed to the variability in fabric thickness and structure, a typical property of

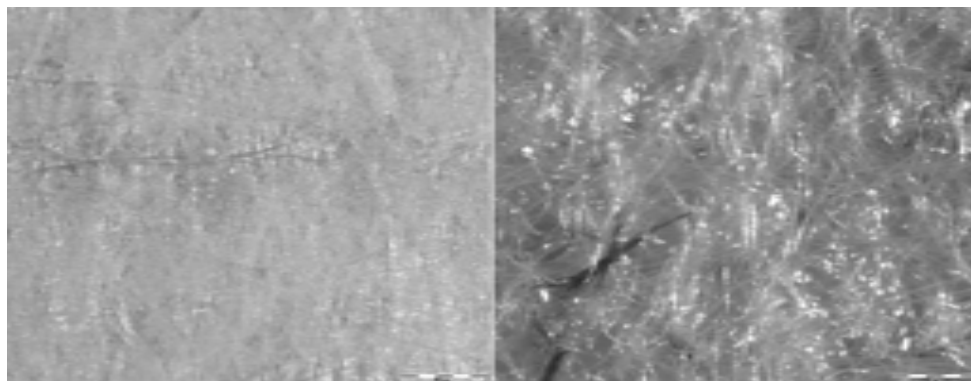


Fig. 5: Images of fabric structure. Left: Polyethylene, Right: Viscose/flax. Note the more open construction of the viscose/flax fabric, which possibly contributed to its higher air permeability and water vapour transmission but also allowed increased penetration of pesticide through the fabric



mechanically processed flax textile products. This variation, besides providing good air permeability and water vapour transmission, and having an influence on the level of protection, also contributed to the unique aesthetic appeal of the fabric, which was preferred by the South African distributor of pesticides.

### CONCLUSION

Generally protective clothing was worn by farm workers although washed once a week by hand is the majority, which exposed the workers to long term pesticide residue effects. There was a relatively positive response towards the idea of an alternative protective garment for the sector that would be more comfortable, while disposable.

The exploration, although relatively new in South Africa, on imparting barrier properties on spun-lace non-woven fabrics using nano-finishes yielded promising results. From the performance tests, the nano-finished viscose/flax blend fabric had the highest oil, water repellency and water vapour transmission scores, and had similar air permeability compared to the viscose fabric. For protection from the two organophosphate pesticides, it outperformed the currently used cotton drill fabric but offered a lower level of protection compared to the polyethylene fabric. It was found that the nano-finishes improved the protection performance of the fabric without unduly influencing comfort properties, as indicated by air permeability and water vapour transmission values. The CNFP/NSAC nano-finish would be the preferred finish on the fabric. From the perspective of both comfort and protection, it can be concluded that the nano-finished viscose/flax fabric would be the most suitable fabric to use for the product development.

### IMPLICATIONS

An apparent need has been realized to train farm workers on the importance or proper wearing of protective wear, when applying pesticides for the benefit of their health status. The non-woven spun-laced fabric blend samples of viscose and flax were the first to have been produced in South Africa; there is need to further explore robust fabrication that would be ideal for commercial farmers who may use the knapsack sprayers. Furthermore, there is need to explore the restoration of performance of applied finishes on protective garments that are lost post the laundry process. Findings from the study will be shared with the South Africa Non-Woven Association, which has recently been constituted, for possible fabric products to try out on a larger scale. They will also be shared with the Department of Agriculture to influence policy formulation in this area.

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