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Original Research

Effects of Modified Textile Floor Coverings on House Dust Mites

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Abstract

Textile floor coverings (TFC), an important element of equipment in homes and public buildings, are regarded as a settlement of house dust mites, and thus the cause of mite-induced allergy. It is believed that TFC should be removed from premises used by persons with a diagnosed allergy to house dust mites. On the other hand, TFC removal is associated with an increased air concentration of dust particles and dust-containing allergens. It is feasible to equip TFC with properties that can prevent the settlement and development of dust mites. The aim of this study was to evaluate TFC properties designed to protect against dust mite generation. The culture of *Dermatophagoides farinae* was used to test the efficacy of the direct anti-mite action. TFC acquired anti-dust mite properties through the addition of biologically active agents to the coated backing and mounting the same acaricides and anti-adhesive fluorocarbon dispersion on pile fibers. The results of our studies show that modified TFCs are characterized by anti-dust mite properties that protect against *Dermatophagoides farinae*.

Keywords: house dust mites, *Dermatophagoides farinae*, textile floor coverings, allergy

Introduction

A growing number of persons with allergic reactions has been observed over recent years. House dust mites are an important source of indoor allergens. The results of the third National Health and Nutrition Examination Survey (NHANES III) show that 27.5 percent of the US population aged 6-59 years had a positive skin test response to dust mite allergy. The impairment of immune systems caused by allergens may lead to atopic inflammation of rhinal mucous membrane and bronchial asthma [1–4, 6–8]. It should be added that infants and small children form the major group at risk for mite-induced allergy [4, 8, 9].

House dust mites are found in almost all continents [3, 4, 10–14]. It is well known that this allergy is largely induced by mites of the family *Pyroglyphidae*. The studies of *Pyroglyphidae* acarifauna, carried out in Poland in 1989–2001, showed that *Dermatophagoides farinae* (DF) predominates in apartments (67%), whereas *Dermatophagoides pteronyssinus* (DP) occurs in 17.6% and *Euroglyphus* (EM) in 1.6% of such cases [14, 15].

Textile floor coverings (TFC), an important element of equipment in homes and public buildings, play an essential role not only in shaping the esthetics and comfort of interiors. However, they are also regarded as a settlement of house dust mites, and thus the cause of mite-induced allergy [4, 5, 16].

It is believed that TFC should be removed from premises used by persons with a diagnosed allergy to house dust mites. On the other hand, TFC removal is associated with the increased air concentration of dust particles and dust-contained allergens. Even barely noticeable movement of the air generates dust rising from the smooth floor

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surface to the breathing zone, leading finally to increased exposure of respiratory systems. The studies performed in Sweden indicate that a limited use of TFC in favor of hard floor coverings (mainly floor panels) contributed to a substantial increase in the number of persons with diagnosed allergic reaction [17]. Thus it appears that TFC performs the function of a specific "filter" and, like all other filters, must be kept clean.

In general, house dust mites are periodically controlled using chemical and physical methods [18–21]. The former group of methods employs acaricides or denaturants applied temporarily in the form of solutions, foams and powders (e.g. benzyl benzoate, permethrin derivatives, tannic acid, benzyl alcohol and tannic acid mixture). However, the effectiveness of periodic chemical cleaning procedures is rather limited. The aforesaid agents not only hardly contribute to about a 50% decrease in allergen concentration, but they have to be applied at intervals of 1–2 months. Physical methods involve the application of very low (sub-zero or liquid nitrogen treatment) or very high (hot vapour) temperatures and the maintenance of specific climatic conditions (low humidity and high or low temperature), which inhibit the development and reproduction of mites.

Various forms of mite control mostly depend on the place of their existence. Encasings with barrier properties are most frequently used to protect mattresses and bedding, bed linen is frequently washed, periodical chemical disinfection or low- and high-temperature treatment is applied [21–29]. Some of these methods can be applicable to floor coverings, but only to a very limited extent. Specialized vacuum cleaning and high-temperature treatments also are practiced. However, these procedures cannot be applied too often, and in some types of TFC they are even not applicable in view of their usable durability [22, 23, 30]. Periodical disinfection mostly with use of benzyl benzoate-based agents (Acarosan) is most frequently practiced. The efficacy of periodically applied acaricides, based on this compound, is well documented in the literature [19, 31–35]. Bearing in mind extensively developed TFC structures, it is obvious that penetration of such applied acaricides is impeded. In addition, removal of dead and still allergenic mites and their feces is still a problem to be solved. Without systematic application of Acarosan, the concentration of allergens can return shortly to the initial level [19].

Development of specific properties able to protect TFC against the settlement, reproduction and growth of house dust mites as well as against their impurities and allergenic fecal pellets would be much more beneficial.

The aim of this study was to evaluate anti-dust mite properties of TFC designed a specially for this purpose.

Materials and Methods

Textile floor coverings were produced using a tufting technique and composed of the woven polypropylene primary backing and the usable layer of loop pile made of polyamide yarn. The coated backing layer was composed of butadiene-styrene resin. Lending of anti-mite properties involved the application of two different biologically active agents, Actigard® AM 21-16 and Actigard® AM 98-12 (Sanitized AG, Burgdorf, Switzerland). These acaricides are approved by the International Association for Research and Testing in the Field of Textile Ecology (Öko-Tex Association) for use in textiles tested for hazardous substances. They also meet high requirements of Öko-Tex Standard 100. The agents were applied to the coated backing layer and mounted along with anti-adhesive fluorocarbon dispersion, Texguard AS (Deurotex GmbH, Hard, Austria), on TFC pile. Two versions of anti-mite modification were investigated:

- Sample PA – pile: 3% Actigard® AM 21-16 and 10% Texguard AS; coated backing layer: 3% Actigard® AM 21-16;
- Sample PB – pile: 3% Actigard® AM 98-12 and 10% Texguard AS; coated backing layer: 3% Actigard® AM 98-12.

The assessment of the efficacy of anti-mite action was based on the culture test performed according to standard procedures [36].

The studies were carried out on a non-modified sample PO (control) and two modified samples, PA and PB, applying *Dermatophagoides farinae*, the most common species of house mites in Poland.

House dust mites used in the study were obtained from the Department of Medical Parasitology, London School of Hygiene and Tropical Medicine (London, UK). The culture was produced according to the method developed by Arlian et al. [37] of the Department of Biological Sciences, Wright State University, Dayton, OH, USA.

Dishes containing mite culture were placed onto a hot plate at 45°C. After 30 min. mites were collected from the sides of the dish and the inside of the lid, where they aggregated to escape the heat [38]. Each time about 200 specimens were collected.

The culture test was performed on TFC samples placed along with auxiliary fabric on Petri dishes neutral to mites and equipped with a ventilation system. Three repetitions were performed for each TFC version, using about 200 DF specimens for each of 9 samples.

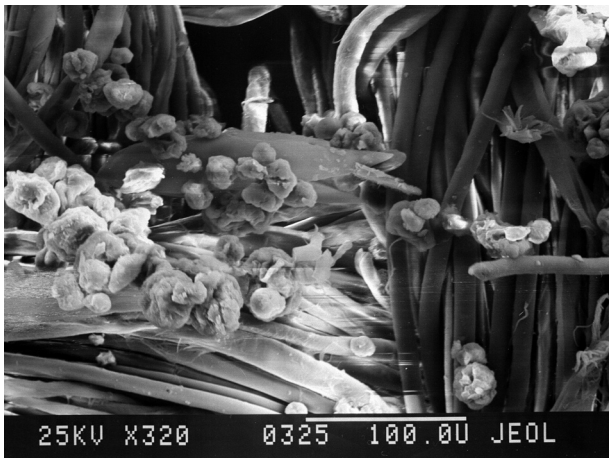
The culture was kept in chambers with constant humidity (75%) and temperature (25°C) stabilized by saturated sodium chloride solution. Mites were fed "Tropical" Super-Vit Basic Fish Flake Food (Tropical, Chorzów, Poland), replenished each time if its distinct shortage on dishes was noticed, but always before its complete exhaustion.

During a 47-day experiment, 9 measurements of population size in each TFC sample were performed to estimate the number of live mites in each sample and assess the diversification of developmental stages, eggs, and mite mobility, using an Olympus stereoscopic microscope SZ 60 with a digital camera DP 10 and the soft imaging system for Olympus. On the last day of the culture

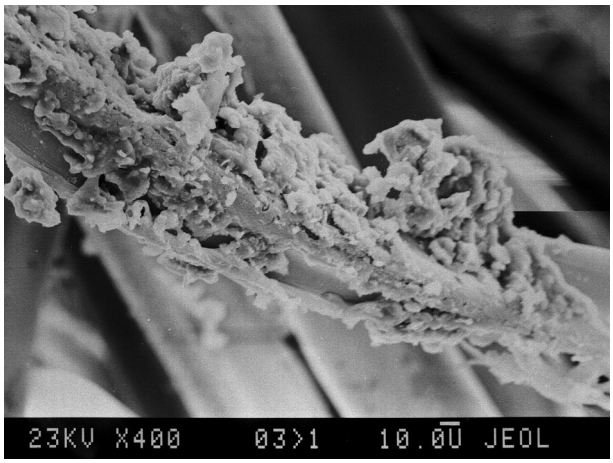
test potential mite allergen exposure was measured by the *Acarex test*® (Allergopharma, Reinbek, Germany) used in practice for a semi-quantitative guanine determination [1]. The altered content of guanine derived from mite feces evidenced the changed number of fecal pellets, and thus the changed size of the mite population in 1 g of dust.

After termination of the culture test, the samples were also analyzed using a scanning electron microscope JSM 35C (JEOL) to evaluate impurities of fibers that the usable layer was made of.

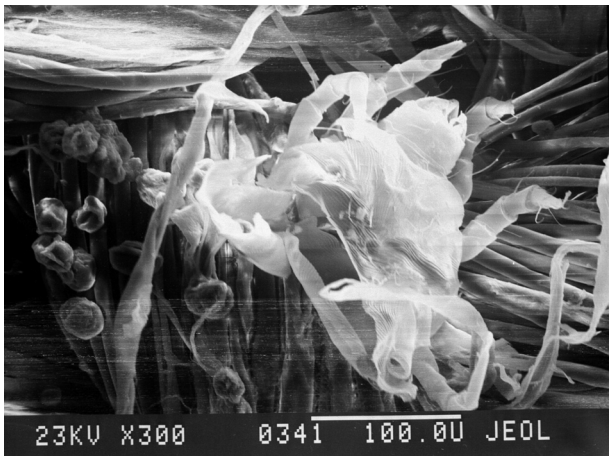
The assessment of an anti-adhesive effect induced by added Texguard AS was based on the comparison of free



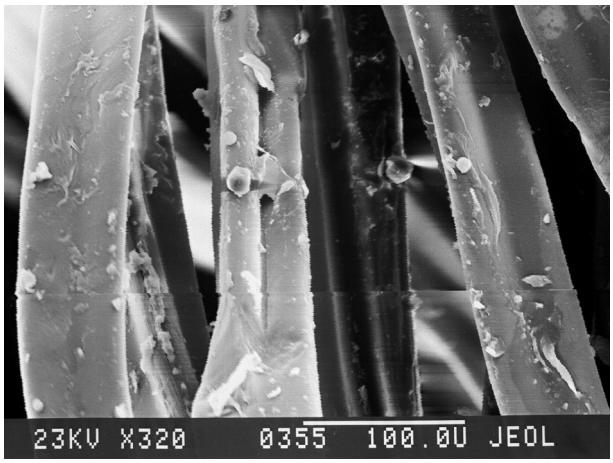
PO A



D



PA B



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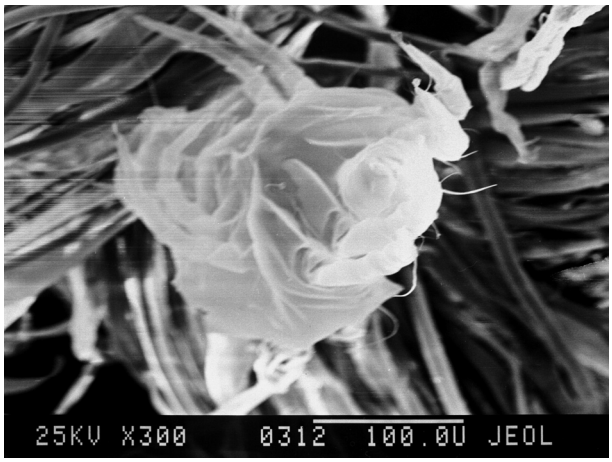
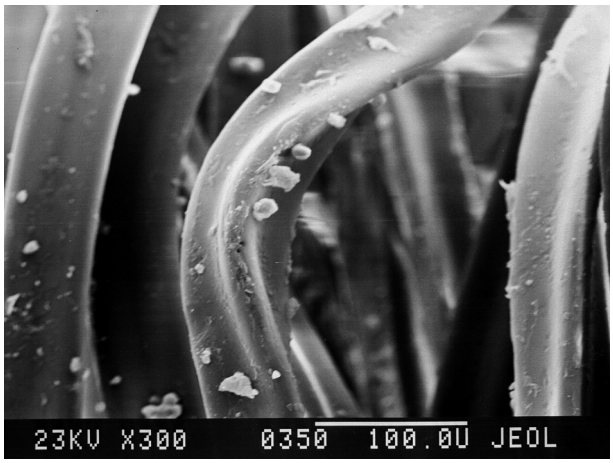


PB C



F

Fig. 1. Microscopic images of samples after termination of the culture test (the left column – fecal pellets and mites present on auxiliary fabric, right column – impurities on pile fibers of TFC samples).

surface energy (γ) and reversible work of adhesion (W) calculated for both modified and non-modified pile fibers of TFC samples. The surface energy of pile fibers was defined with the method of wetting angle measurement. The contact angle was measured on microscopic images of liquid drops applied onto pile fibers (contact angle goniometry method). Water and methylene iodide were used as reference liquids [39].

Statistical Analysis

Arithmetic means and standard deviations were defined for individual sets of data concerning the size of mite populations. Student's t-test was performed to define statistically significant differences between the mean values of compared sets, and the Mann-Whitney U test was used as an alternative. The results were also analyzed with stepwise regression model. Linear correlation coefficients were calculated according to Pearson. A value of $p < 0.05$ was considered to indicate statistical significance.

Results

During microscopic analysis live mites in various developmental stages as well as large numbers of fecal pellets, small amounts of food, fibers with fecal impurities, and food ingredients attached to their surface were observed in the PO (control) sample. In modified samples, especially in the PB sample, we found a small number of fecal pellets and dead mites (mostly adult ones settled in samples at the beginning of the experiment) and a rather slight decline in food. The surface of fibers was almost free from impurities. Microscopic images of samples performed after termination of the culture test are given in Fig. 1. Panels A,B, and C show differences in the amount of fecal pellets present on auxiliary fabric. Panels D,E, and F show differences in impurities of TFC pile fibers.

Changes in the size of the mite population during the culture test are presented in Fig. 2.

In the PO (control) sample, a statistically significant increase in the number of mites was revealed on individual days compared to the 9th day of the experiment (except day 12). In the PA and PB samples, a statistically significant decline in the size of the mite population was also shown on individual days compared with the amount of mites observed in the PO sample. The mean size of mite populations in the PA and PB samples was significantly lower than that in the PO sample. Statistically significant differences in the size of mite populations between samples PA and PB were also shown (Table 1, Fig. 2).

Fig. 3 illustrates the kinetics of changes in the size of the mite population defined until the population's extinction in sample PB. The analysis of data shows that during the experiment, changes in the population size were indicated by highly significant linear correlations with respec-

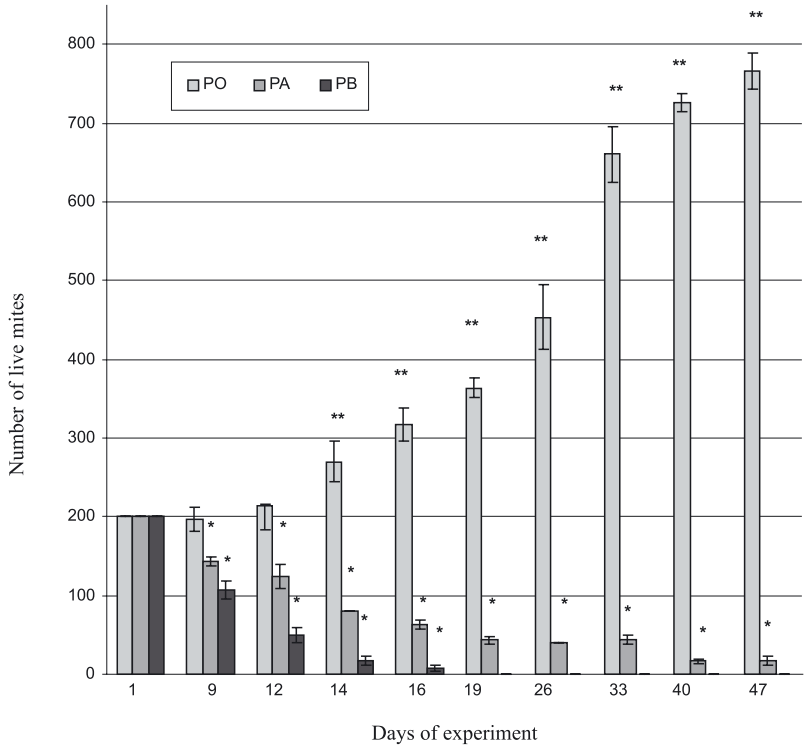


Fig. 2. The size of mite populations in the course of the culture test.

* – Statistical significance in comparison with the amount of mites in the control (PO) for individual readings of the population size in the same days of experiments.

** – Statistical significance in the comparison to the control sample (PO) in 1st day of experiment.

Table 1. Statistical significance (p value) between mean values of live mites in the PO (control) sample and the modified PA and PB samples.

Days of experiment	PO	PA	PB
9		0.01[b]	0.001[b]; 0.0001[c]
12	NS[a]	0.01[b]	0.0001[b];0.0001[c]
14	0.01[a]	0.01[b]	0.0001[b]; 0.0001[c]
16	0.001[a]	0.001[b]	0.0001[b]; 0.0001[c]
19	0.0001[a]	0.0001[b]	ND[d]
26	0.001[a]	0.01[b]	ND[d]
33	0.0001[a]	0.001[b]	ND[d]
40	0.0001[a]	0.0001[b]	ND[d]
47	0.0001[a]	0.0001[b]	ND[d]

[a] Statistical significance in comparison with the amount of live mites in the PO (control) sample for individual readings of the population size on the same day of the experiment. [b] Statistically significant in comparison with the PO (control) sample on the 9th day of the experiment. [c] Statistically significant difference in the size of mite populations between samples PA and PB. [d] Absence of live mites. NS – not significant. ND – not detected.

tive correlation coefficients: $r_{PO} = 0.836$ ($p < 0.05$); $r_{PA} = 0.985$ ($p < 0.001$); and $r_{PA} = 0.980$ ($p < 0.001$).

The results of the Acarex test were: + 3 for sample PO, guanine content of at least 10.0 mg/g of dust; + 1 for sample PA, guanine content between 0.6 and 2.5 mg/g; and –2 for sample PB, guanine content lower than 0.6 mg/g of dust.

Free surface energy γ of fibers that formed TFC loop pile was 52.98 mJ/m^2 for the PO sample γ_{PO}, and 33.81 mJ/m^2 for modified samples $\gamma_{PA,\ PB}$. The proportion of dispersion γ^d and polar γ^a components changed and amounted to 47.85 mJ/m^2 for γ^d_{PO}, 5.13 mJ/m^2 for γ^a_{PO}, 16.96 mJ/m^2 for $\gamma^d_{PA,PB}$, and 16.85 mJ/m^2 for $\gamma^a_{PA,PB}$.

Discussion

In current practice of reducing exposure to house dust mites, chemical and physical methods are applied to immediately eliminate them from places of their existence. In the presented study, an attempt was made to equip TFC with properties able to create conditions unfavorable for the settlement and development of dust mites and define the kinetics of the effects of newly developed properties on the basis of the culture test. The efficacy of anti-adhesive modification of TFC fibers, aimed at limiting the contamination with allergenic feces and facilitating the removal of impurities from TFC, was also assessed.

The mite population developed on the control sample and large quantities of mites in early developmental stages (larva, protonymph, tritonymph) and eggs were observed in the course of the whole experiment. In samples PA and PB, a distinct decrease in the number of early developmental stages was found, and in sample PB only adult mites (eggs and larva stages were absent) occurred following the 16th day of the experiment. In the PO sample, food was supplemented four times because of its intense consumption. In sample PA, food was supplemented only once, and in sample PB, there was no need to supplement food, because of its evidently limited consumption. The mobility of mites in sample PB was also evidently reduced compared with sample PO.

An analysis of kinetics of changes in the size of mite populations (Fig. 3), based on the comparison of the slope of straight line coefficients defined for time intervals covering the period of the mite population extinction in sample PB, showed the development of the mite population in sample PO (coefficient of slope of a straight line = 9.2),

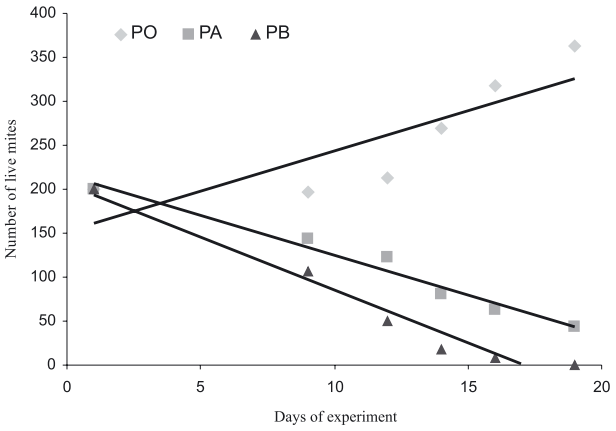


Fig. 3. Kinetics of changes in the size of mite population defined until its extinction in the PB sample.
PO; $y_{PO} = 9.2x + 151.5$; $r_{PO} = 0.836$; $p<0.05$
PA; $y_{PA} = -9.1x + 216.2$; $r_{PA} = 0.985$; $p<0.001$
PB; $y_{PB} = -12.0x + 205.7$; $r_{PB} = 0.980$; $p<0.001$

and its decline in sample PB, which was faster (–12.0) than in sample PA (–9.0). This means that the modification with Actigard® AM 98-12 was more effective than that with Actigard® AM 21-16. Therefore, it may be supposed that the time of the mite population extinction in samples modified with appropriate acaricides could be predicted on the basis of calculated regression curves. However, the kinetics of extinction of mite populations has not as yet been studied. As a matter of fact, Lau-Schadendorf et al. [32] have investigated the effect of acaricides on the content of allergens (Der p I and Der F I) in dust samples, mattresses or carpets, determining it at four time points, but they failed to perform the regression analysis of the obtained results.

The knowledge of material surface properties is an essential issue in various fields of science. Surface energy parameters are important and useful due to their controlling effect on practical applications, e.g. polymer adhesion, wetting by liquids, or soiling propensity. They are also used to understand and control bio-processes [40, 41].

The free surface energy of microorganisms and substances secreted by them is an important parameter that influences their adhesion to the surface of solids [40]. Chitin and polymer polysaccharide, along with a large number of groups able to form hydrogen bonds and thus of high free surface energy, especially of its polar component, is the major constituent of peritrophic membrane, surrounding allergic mite fecal pellets that contain undigested food debris. The free surface energy of non-modified fibers is equally high. The applied anti-adhesive modification decreased the free surface energy of fibers in samples PA and PB and changed initial proportions of dispersive and polar components.

Assuming after Sharmo et al. [40] the mean values of wetting angles $\Theta_w = 45.81$ for water and $\Theta_{jm} = 52.63$ for methylene iodine, a theoretical value of free surface energy for fecal pellets was calculated: $\gamma_{fp} = 53.75$ mJ/m^2 ($\gamma^d_{fp} = 24.23$ mJ/m^2, $\gamma^a_{fp} = 29.52$ mJ/m^2), and taking into account dependence given by Dupré, a reversible work of adhesion for the scheme fecal pellets and fiber of the PO, PA, PB samples were estimated [39]. The reversible work of adhesion is a measure of adherence to the solid surface. The increase of W value causes growing adherence to the surface of solids. It accounted for 23.22 mJ/m^2 for the PO sample and 11.84 mJ/m^2 for modified samples. Such a decline in the value of reversible work of adhesion reflected the limited adherence and facilitated removal from floor coverings of allergenic feces excreted by mites, which may find their way to TFC from other sources (e.g., bed) and stay there until modified acaracides exert their effect. In practice, this anti-adhesive modification will limit the susceptibility of TFC to attract impurities and consequently will make it possible to remove them easier.

All samples were cleaned after termination of the culture test using a vacuum cleaner (smooth nozzle, power 1000 W, air flow rate 45 dm^3/s) using five forward and backward motions for five seconds in each direction.

Microscopic images of the control sample after termination of the culture test clearly showed the most extensive pollution with feces and food ingredients. Fibers of modified samples contained single fecal pellets and fragments of impurities. The removal of dead mites, their feces and food debris from both anti-adhesive modified samples with vacuum cleaner was easy. In the non-modified control sample, there were still large amounts of feces attached to fibers forming the usable layer of TFC.

Conclusions

The results of our studies show that Actigard® acaricide-modified textile floor coverings are characterized by anti-dust mite properties that protect against *Dermatophagoides farinae*. These properties were evidenced on the basis of culture and Acarex tests. The PB sample modified with the use of Actigard® AM 98-12 proved to be most effective in reducing mite populations and allergens. They were also fastest in blocking the development of mite populations, showing at the same time the lowest content of guanine. Anti-adhesive modification protected the surface of pile fibers against pollution with fecal pellets and food ingredients and facilitated removal of these impurities and dead mites from TFC. The culture method allowed for assessing the dynamics of changes in the size of mite populations in TFC and estimating the pace of exerting desirable effects by acaricides in optimum climatic and nutritional conditions for *Dermatophagoides farinae*.

Acknowledgements

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