

Article

New Possibility of Human Protection Against Tick Bites Using Textiles Items

Joanna Szkudlarek ^{1,*} , Marcin Jachowicz ¹ , Joanna Witecka ²  and Marek Asman ³ 

¹ Department of Personal Protective Equipment, Central Institute for Labour Protection—National Research Institute, 48 Wierzbowa Street, 90-133 Lodz, Poland; majac@ciop.lodz.pl

² Department of Microbiology, Faculty of Pharmaceutical Sciences in Sosnowiec, Medical University of Silesia in Katowice, Jagiellońska 4, 41-200 Sosnowiec, Poland; jwitecka@sum.edu.pl

³ Department of Medical and Molecular Biology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia in Katowice, Jordana 19 St., 41-808 Zabrze, Poland; masman@sum.edu.pl

* Correspondence: joszk@ciop.lodz.pl

Abstract

The high incidence of tick-borne diseases (particularly Lyme disease) and the challenges associated with their serious health consequences motivated us to undertake research aimed at developing robust protection against ticks. There is still no effective method for preventing or treating Lyme disease, and humans who spend time outdoors—whether for occupational or recreational purposes—remain unprotected. This paper presents an innovative design of anti-tick textile bands intended for standalone use or integration into protective trousers. The bands are designed to receive repellent-sprayed inserts and provide a barrier layer separating the chemical from the user. In the research, the protective performance of the bands was evaluated using a novel test stand specially constructed for tick repellency testing. Experiments involving live ticks demonstrated the highest effectiveness for bands incorporating an insert impregnated with 20% DEET. Two limitations were noted: peak protection was achieved approx. 15 min after DEET application, and repellent reapplication was required after three hours to maintain protection. These findings are directly relevant to protective equipment design, offering a practical solution for high-risk groups such as forestry workers. By providing an experimentally validated strategy for tick bite prevention, this work addresses an urgent need in occupational and public health.



Academic Editor: Adem Gharsallaoui

Received: 29 September 2025

Revised: 17 November 2025

Accepted: 17 November 2025

Published: 24 November 2025

Citation: Szkudlarek, J.; Jachowicz, M.; Witecka, J.; Asman, M. New Possibility of Human Protection Against Tick Bites Using Textiles Items. *Appl. Sci.* **2025**, *15*, 12460. <https://doi.org/10.3390/app152312460>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: Lyme disease; prevention of tick-borne diseases; *Ixodes ricinus*; *Dermacentor reticulatus*; Personal Protective Equipment; protective clothing; repellents

1. Introduction

Reports from recent years attest to a dynamic increase in the number of tick-borne disease cases worldwide [1–7]. According to data published by scientists and government institutions, the incidence of tick-borne diseases in Europe (including Poland) has increased nearly 2–3 fold over the past decade [1,3,8]. In Europe the most popular tick-borne diseases are tick-borne encephalitis (TBE) and Lyme disease (less common: babesiosis, anaplasmosis, ehrlichiosis and Crimean–Congo hemorrhagic fever). These diseases are often difficult to diagnose; for instance, TBE, caused by a virus in the *Flaviviridae* family, presents with symptoms that typically appear 7 to 14 days after a tick bite and resemble the common flu. After several days of apparent recovery, the disease may progress to a second stage, affecting the central nervous system and manifesting as cognitive impairment, coma, or limb paralysis. The consequences of the disease can be severe, including muscle weakness

or atrophy, impaired concentration, depression, and, in some cases, even death. The most widely recognized preventive measure is vaccination, specifically with inactivated vaccines against TBE [8].

Another tick-borne disease is Lyme disease, caused by spirochetes of the *Borrelia burgdorferi* sensu lato complex, which poses a risk of irreversible health consequences and can often be fatal to both humans and animals [5,8,9]. This disease is also difficult to detect, as it is often characterized by prolonged dormancy without symptoms. Currently, no pharmacological measures are available to protect against Lyme disease, and no prophylactic vaccines have been developed [10,11].

To date, no effective methods for the prevention and treatment of tick-borne diseases have been developed. Therefore, any form of protection against the consequences of tick bites represents an important improvement in safety for many people, especially those working in forestry and agriculture. Richardson and colleagues [11], who reviewed 16 prevention methods, found only 5 of them to be effective. These include the use of protective clothing, national strategies (including landscape modification and chemical control), education, vaccination, and educational programs. A well-known form of tick prevention is the use of pesticides (mainly permethrin) and repellents (DEET), usually in the form of sprays and lotions. However, pesticides may have adverse effects on human health; their use on clothing or direct application to the skin can be hazardous, especially with prolonged exposure [9,10].

As part of the national strategy, information campaigns are organized to promote the use of clothing that covers the entire body. Preventive programs conducted by governmental agencies, both in Europe and the USA, include guidelines on how to dress properly. They primarily target high-risk occupational groups, such as foresters, gamekeepers, loggers, and farmers. They are advised to wear long sleeves and trousers tucked into boots, as well as closed, high-cut footwear (e.g., rubber boots). This form of tick prevention aims to protect the wearer by creating a barrier against ticks by means of clothing, including trousers. However, work trousers and protective trousers typically connect to the footwear only via an elastomeric strap [11,12].

Preventive recommendations include the application of tick-repellent products directly to clothing prior to potential exposure [13,14]. There are also commercially available clothing items treated with chemical tick repellents, such as socks and gaiters. However, direct contact with repellents may adversely affect users [11,12]. Furthermore, such products are not very reliable, as their effectiveness tends to deteriorate significantly during use, particularly after washing [15,16]. It is also difficult to determine their performance level at a given time [17] or monitor their decline, as they are not typically tested in this respect. Such studies would require recreating real-life conditions and conducting tests with live ticks.

As part of its research task, the Department of Personal Protective Equipment, Central Institute for Labour Protection—National Research Institute in Poland, developed a protective textile band as well as a model of trousers designed to protect against tick bites, which was granted protection rights in 2022. The objective of the research project was to develop a user-safe, tick-repellent solution that retains its effectiveness after washing.

The aim of this study is to present a universal tick-repellent band and the design of protective trousers with such bands integrated. The textile band, as a component of protective clothing, provides effective protection for individuals working outdoors. When used as part of everyday clothing, it can offer protection for both children and adults during excursions, sports activities, and other forms of recreation. The study also presents a method for evaluating its effectiveness under real-life conditions. The tests were conducted in Department of Microbiology, Faculty of Pharmaceutical Sciences in Sosnowiec using a

specially constructed test stand by Department of Personal Protective Equipment, Central Institute for Labour Protection—National Research Institute. The results presented in this work have a significant impact on improving the safety of individuals at risk of tick bites, especially workers in the forestry and agricultural sectors.

2. Materials and Methods

2.1. Research Material

The main objective of the study was to develop an effective solution for protection against ticks that would be safe for users and enable unrestricted washing. To this end, we designed a textile band functioning as a pocket for inserts treated with tick repellents or acaricidal agents. The outer side of the pocket features a knitted polyester mesh, enabling the free release of the agent. The sorptive inserts are made of a composite material consisting of hydrophobic foam and a barrier layer that prevents the chemical agent from coming into contact with the user's skin. An illustration of the designed band for inserts with tick-repellent agents is presented in Figure 1.

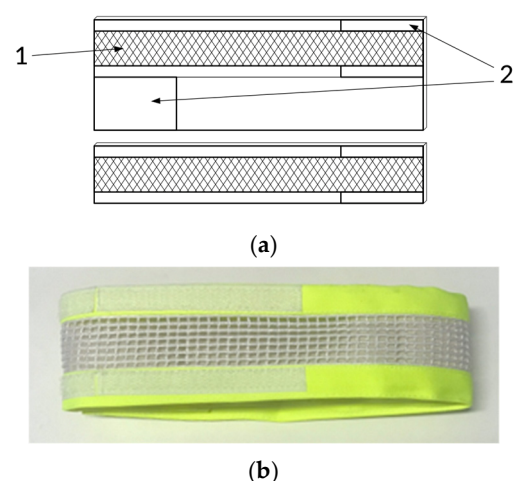


Figure 1. Protective band design: (a) design schematic with (1) knitted mesh and (2) textile velcro; (b) actual view.

The sorptive insert is replaceable and can be easily removed and treated with a repellent agent. It consists of several layers designed to isolate the user's skin from the harmful substance while facilitating the release of the agent to the exterior. The construction of the insert used in the protective band packet is shown in Figure 2.

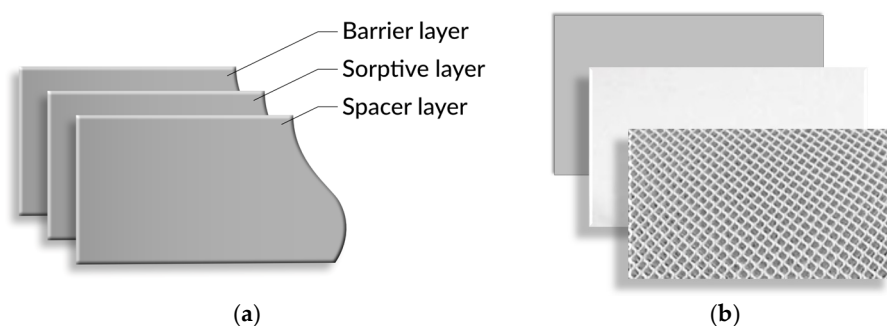


Figure 2. Design of sorptive insert—a replaceable carrier of tick-repellent agents: (a) triple-layer design and (b) actual view of the layers.

The application of barrier materials, preventing the direct contact of the skin with the textile material carrying repellents or pesticides, in a triple-layer design, resulted in a product that is entirely safe to use.

The band can be used independently as an accessory worn over everyday or protective clothing, or it can be integrated into the design of protective trousers. Trousers with integrated bands are recommended for occupational use (meet the Regulation (EU) 2016/425 [18] and the EN 13688 standard [19] requirements), as this solution prevents the bands from slipping off or being lost during occupational activities. The developed protective trousers were granted utility model protection no. Ru.072702. The design of trousers preventing tick bites is presented in Figure 3.

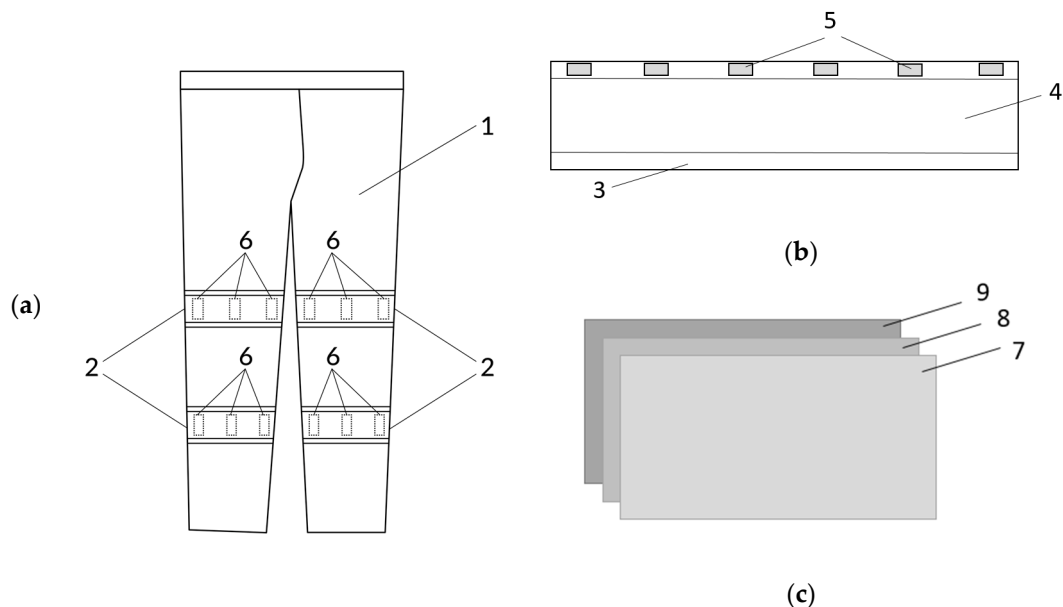


Figure 3. Design of protective trousers preventing tick bites: (a) trouser legs with pockets for sorptive inserts; (b) pocket with elements securing a sorptive insert; (c) three-layer sorptive insert; (1) trousers legs; (2) the lower part of the pocket for insert; (3) the upper part of the pocket; (4) the middle part of the upper part of the pocket; (5) and (6) textile hook-and-loop fasteners; (7) spacer layer of the insert; (8) absorbent layer of the insert; (9) barrier layer of the insert.

The protective trousers are equipped with four insert pockets (2) permanently attached to the trouser legs (1) along the entire circumference of the legs, both below and above the knee. The lower part of the pockets (2) is made of polyester fabric with a surface weight of 170 g/m^2 , while the middle part (4) is made of knitted textile mesh. The upper part of the pockets (3) is secured with textile hook-and-loop fasteners (5) spaced out along the perimeter. The pockets also contain fasteners securing the sorptive inserts (6) to the trouser legs.

The sorptive inserts consist of three layers: a barrier layer (9), an absorbent layer (8), and a spacer layer (7). The spacer layer is made of 1 mm thick polyester spacer knit fabric; the absorbent layer is from 2.5 mm thick hydrophilic polyurethane foam, serving as a carrier for the repellent. The barrier layer is made of polypropylene film, preventing the repellent from coming into contact with the user's skin. The textile mesh (4) protects the sorptive insert from external factors. The special design of the pockets facilitates the release of the repellent to the outside. An illustration of the protective trousers designed to prevent tick bites is presented in Figure 4.

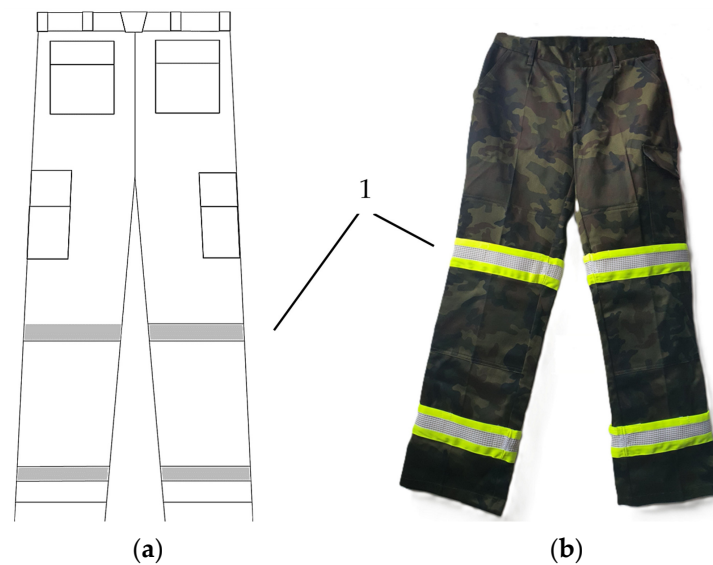


Figure 4. Protective trousers preventing tick bites with pockets (1) for absorbent inserts: (a) design schematic; (b) actual view.

2.2. Test Stand and Methodology

As mentioned in the introduction, there are many commercially available anti-tick products treated with repellents or pesticides. However, there is a lack of objective methods for verifying the effectiveness of tick repellents applied onto or integrated into clothing items.

The design of the test stand with a lower leg model was inspired by Dautel et al. [20,21], who developed a laboratory model called the moving object bioassay (MOB) for investigating the mechanism of tick invasion, incorporating a host body temperature attractant. The model consisted of a thermostated cylinder heated to 35–36 °C, containing absorbent tissues soaked with the test repellent solution. The test involved observing the movement of ticks toward the cylinder. An advantage of that method is the ability to measure the distance over which the repellent exerts its effect.

Due to the potentially harmful effects of repellents and pesticides on human skin and the associated risk of tick-borne diseases, studies involving human participants would be ethically problematic and are generally not permissible.

The effectiveness of the designed protective bands was confirmed using a newly developed test method. The method involves placing adult ticks in a chamber that simulates optimal conditions for their invasion, together with a protective band containing an insert treated with a repellent. The test evaluated how the ticks responded to the repellent-treated clothing. Their response was used to infer the effectiveness of the developed barrier against tick invasion. The repellent used in the tests was DEET (N,N-diethyl-m-toluamide). A view of the test stand is presented in Figure 5.

The test stand consists of a cylindrical chamber measuring 100 cm in diameter and 80 cm in height, with adjustable humidity and temperature to create optimal conditions for tick habitation and parasitic invasion, simulating their natural environment. The apparatus features a lower leg model (1) equipped with a zonal thermostatic system (2) with settings of 25 °C, 30 °C, and 37 °C, which represent the temperature of the naked human skin and the clothed leg.

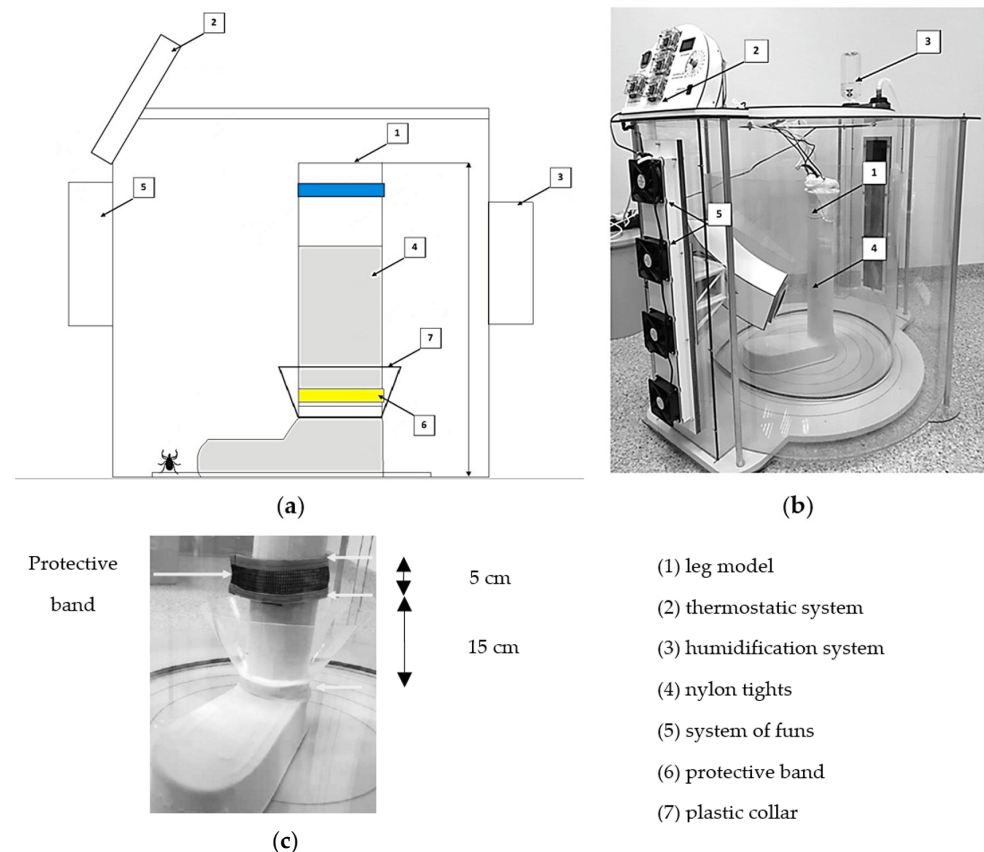


Figure 5. Test stand for evaluating the effectiveness of clothing materials treated with repellents: (a) schematic diagram of the test stand; (b) photograph of the actual test stand; (c) photograph of the lower leg model fitted with a tick-repellent band and a protective collar prepared for testing.

During the experiments, air humidity in the test chamber was maintained between 70% and 90% using a humidification system (3). The leg model was fitted with nylon tights (4) made from 92% polyamide and 8% elastane, which served as a textile carrier for host-mimicking scent substances, known as attractants.

In experiments involving *Ixodes ricinus* ticks, the attractant was a 6% aqueous solution of lactic acid ($C_3H_6O_3$), which is a component of human sweat. For *Dermacentor reticulatus* ticks, the attractant was a 10% solution of squalene, a component of the secretion of human sebaceous glands. Both attractants were applied using an atomizer, with a total volume of 1.34 ± 0.01 mL.

The chamber was also equipped with a system of four fans (5) with continuous power adjustment, allowing for air exchange within the chamber and preventing repellent accumulation. At the base of the lower leg model, a funnel-shaped plastic collar (7) was installed at ankle height to prevent ticks from dispersing and to guide them toward the test surface of the lower leg model. The developed textile band model (6), containing an absorbent insert with the repellent (see Figure 1), was tested. The repellent was a 10% DEET solution in ethanol applied in a volume of (1 ± 0.1) mL. The tick-repellent band, prepared in this way, was mounted 5 ± 1 min after the application of the repellent, at a height of 15 cm from the base of the lower leg model. A view of the tick-repellent band during the tests, as well as the effect of the repellent band on tick behavior, is shown in Figure 6.

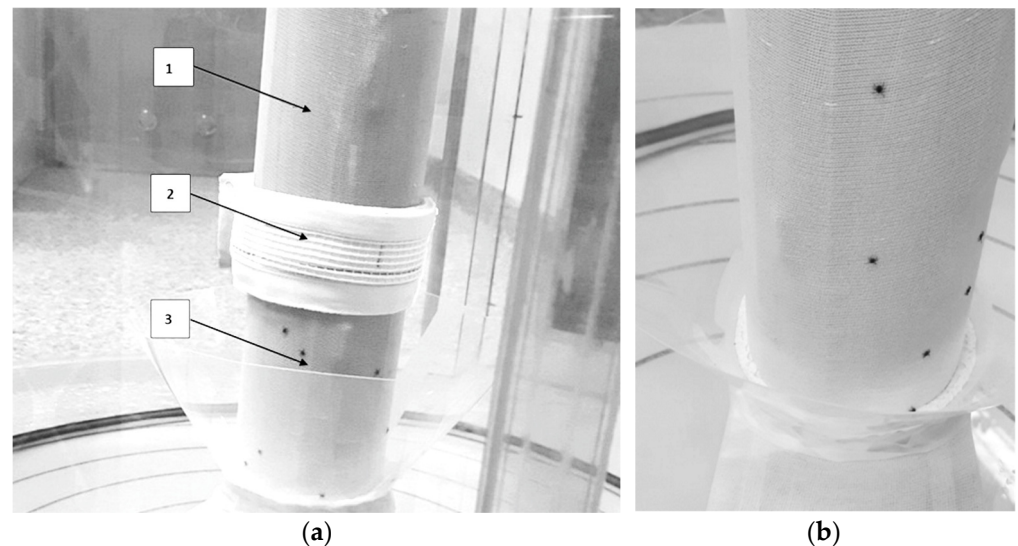


Figure 6. Repellency test using a phantom leg and ticks: (a) experiment with band (1) view of the lower leg model above the protective band—no ticks (lower leg fitted with tights treated with an attractant); (2) protective band with a repellent-treated insert; (3) view of the lower leg below the protective band—ticks during the invasion; (b) control test without band.

2.3. Repellent Tests

Ticks were collected from their natural environment using the flagging method. Specimens of *Ixodes ricinus* were gathered in Poland from forested areas and forest edges in the Silesian Province. In contrast, *Dermacentor reticulatus* ticks were collected in the Lublin Province (samples obtained from the Department of General Biology and Parasitology, Medical University of Lublin), as well as from the Warmian–Masurian Province.

The collected ticks were maintained in rearing containers (desiccators) with a saturated aqueous solution of MgSO_4 under high humidity conditions (approximately 90%). The containers were refrigerated at 8 °C. Rearing containers with *Ixodes ricinus* and *Dermacentor reticulatus* ticks are shown in Figure 7.



Figure 7. *Ixodes ricinus* and *Dermacentor reticulatus* ticks stored in laboratory conditions.

Prior to testing, the ticks were acclimatized for 1 h at room temperature (20–22 °C), at high H_2O concentrations. Following acclimatization, ticks intended for testing were stimulated by blowing exhaled air containing elevated CO_2 levels into the rearing container. Individuals showing the highest activity indicative of host-seeking were selected for tests.

The repellent concentration was determined in preliminary studies (see Figure 8). To identify a minimum effective concentration of DEET for use in tick-repelling bands, we conducted tests using Petri dishes. For this purpose, circles with diameters of 200 mm and

150 mm were drawn on a cotton fabric. A 1 mL volume of repellent was applied to the resulting ring using a pipette, creating a repellent barrier with a width of approximately 10–15 mm. Thirty adult ticks of the species *Ixodes ricinus* were placed on the surface of the inner circle; the same procedure was repeated for *Dermacentor reticulatus*. DEET solutions in 94% ethanol were tested at concentrations of 2.5%, 5%, 10%, and 20%. Each experiment lasted 15 min, with intervals of one hour. We measured the time it took for the ticks to begin crossing the barrier formed by the repellent (moving from the central circle to the outside). A control trial was carried out under the same circumstances, but with 94% ethanol without DEET.

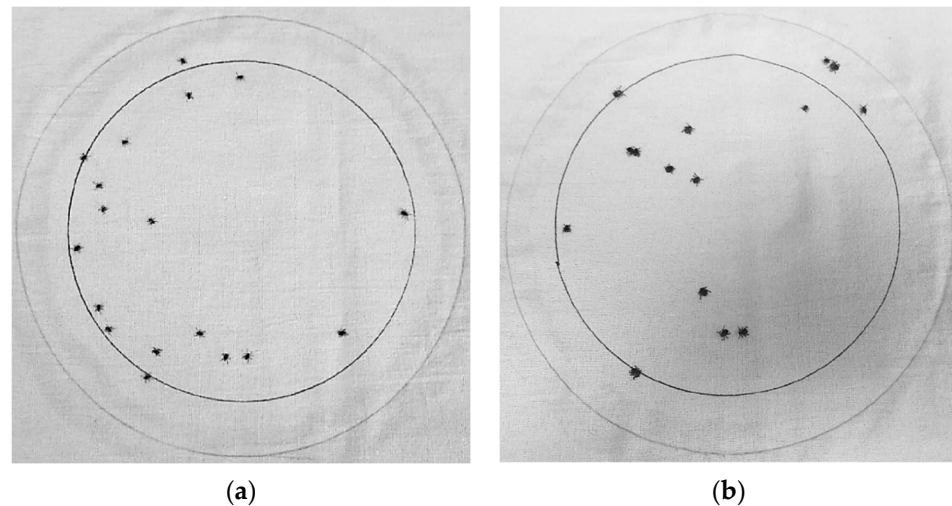


Figure 8. View of ticks *Ixodes ricinus* (a) and *Dermacentor reticulatus* (b) during preliminary tests conducted to optimize repellent concentration.

In the course of the experiments conducted for both species, the ticks tended to move towards the edges of the circle, but DEET prevented them from crossing the repellent-treated ring.

Tests of the repellent band effectiveness began with 10% DEET. Each test involved 30 adult *Ixodes ricinus* and *Dermacentor reticulatus* ticks showing the highest levels of activity and host-seeking behavior.

For comparison purposes, control studies of tick behavior were conducted without a band mounted on the lower leg model. Observations were conducted for 3 h. A comparison of the movement of ticks on the leg model without the repellent band (control trial) versus the leg model fitted with the band (test trial) enabled the evaluation of the effect of the tick-repellent band on the host-seeking behavior of ticks.

In the second part of the experiment, the concentration of DEET in an ethanol solution was increased to 20%, and the observation time was extended to 8 h to evaluate changes in the effectiveness of the band over time.

We identified seven types of tick activity:

1. Present on the band (background fabric);
2. Present on the band (knitted mesh);
3. Present on the band (hook-and-loop fasteners);
4. Present below the band;
5. Fallen off the band;
6. Crossed the band (over);
7. Crossed the band (under).

The effectiveness of the protective band was determined based on the number of ticks that moved upward past the band on the lower leg model (activity types 6 and 7). Ticks that moved outside the test area were not counted.

3. Results

The results of tick activity observations were recorded 15 min after the band was put on and then at 60 min intervals (9 time points in total, over a period of 0 to 480 min). In a preliminary analysis focused on tick reactions depending on the repellent concentration, the minimum concentration of the repellent applied to the band was determined, which should be no less than 10%. Therefore, the experiment started with 10% DEET, and later the concentration was increased to 20% DEET in ethanol.

The results for the two DEET concentrations applied to the insert of the tick-repellent band, 10% and 20%, over a period of 0–180 min are presented in Tables 1 and 2. Table 3 summarizes observations conducted from 240 h to 480 min.

Table 1. Percentage of ticks observed for the various types of activity in experiments involving 10% DEET in ethanol solution; results from observation time points 1–4.

No.	Ticks (%)	Time (min)							
		0–15		60		120		180	
		<i>D.rec.</i> *	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>
1.	Present on the band (background fabric)	23.33	13.33	26.66	20.00	26.66	6.66	23.33	3.33
2.	Present on the band (knitted mesh)	10.00	3.33	13.33	16.66	6.66	0	0	3.33
3.	Present on the band (hook-and-loop fasteners)	0	0	3.33	0	26.66	0	23.33	0
4.	Present below the band	20	20	23.33	16.66	16.66	13.3	30	23.33
5.	Fallen off the band	0	10.00	13.33	10.00	0	3.33	3.33	0
6.	Crossed the band (over)	10.00	0	0	0	0	0	0	0
7.	Crossed the band (under)	0	6.66	0	0	0	3.33	0	0

* *D.rec.*—*Dermacentor reticulatus*; *I.ric.*—*Ixodes ricinus*.

Table 2. Percentage of ticks observed for the various types of activity in experiments involving 20% DEET in ethanol solution; results from observation time points 1–4.

No.	Ticks (%)	Time (min)							
		0–15		60		120		180	
		<i>D.rec.</i> *	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>
1.	Present on the band (background fabric)	6.66	6.66	3.33	3.33	6.66	0	3.33	0
2.	Present on the band (knitted mesh)	3.33	3.33	0	0	0	0	0	0
3.	Present on the band (hook-and-loop fasteners)	0	0	0	0	0	0	0	0
4.	Present below the band	0	3.33	0	0	0	0	0	0
5.	Fallen off the band	10.00	6.66	3.33	3.33	6.66	0	3.33	0
6.	Crossed the band (over)	0	0	0	0	0	0	0	0
7.	Crossed the band (under)	0	0	0	0	0	0	0	0

* *D.rec.*—*Dermacentor reticulatus*; *I.ric.*—*Ixodes ricinus*.

An analysis of the effectiveness of protective bands with an insert containing 10% DEET is presented in Figure 9.

Analysis of tick responses to the band with an insert soaked with 10% DEET over four observation cycles lasting a total of 3 h. revealed differences in tick behavior within a given species. *Ixodes ricinus* ticks did not cross the band throughout the entire experiment. However, 10% of *Dermacentor reticulatus* ticks crossed the band and entered the lower leg model within the first 15 min of the experiment (Table 1). *Ixodes ricinus*, probably due to their significantly smaller size, passed under the band onto the lower leg model (6.66% of ticks after 15 min and 3.33% of ticks after 120 min). For *Dermacentor reticulatus*, the

percentage of ticks in direct contact with the band ranged from 23.3% to 26.6%, while for *Ixodes ricinus* it ranged from 3.3% to 20%. Some even made direct contact with the repellent, entering the central part of the band. Furthermore, 10% of *Ixodes ricinus* and 26.6% of *Dermacentor reticulatus* detached themselves from the band as a result of the repellent.

Table 3. Percentage of ticks observed for the various types of activity in experiments involving 20% DEET in ethanol solution; results from observation time points 5–9.

No.	Ticks (%)	Time (min)									
		240		300		360		420		480	
		<i>D.rec.</i> *	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>	<i>D.rec.</i>	<i>I.ric.</i>
1.	Present on the band (background fabric)	20.00	16.66	16.66	3.33	16.66	0	26.66	3.33	20.00	0
2.	Present on the band (knitted mesh)	3.33	3.33	3.33	0	0	3.33	0	6.66	0	0
3.	Present on the band (hook-and-loop fasteners)	0	0	3.33	0	13.33	0	13.33	0	6.66	0
4.	Present below the band	0	3.33	0	6.66	0	3.33	0	0	0	3.33
5.	Fallen off the band	6.66	6.66	13.33	3.33	3.33	0	10.00	0	3.33	0
6.	Crossed the band (over)	0	0	0	0	0	0	0	0	0	0
7.	Crossed the band (under)	3.33	3.33	3.33	0	0	0	16.66	20.00	6.66	16.66

* *D.rec.*—*Dermacentor reticulatus*; *I.ric.*—*Ixodes ricinus*.

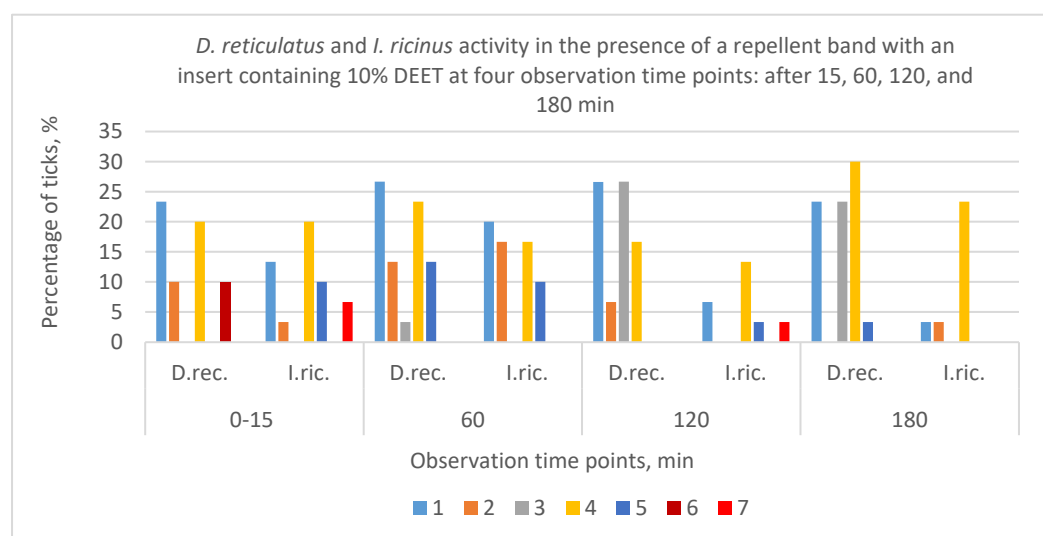


Figure 9. Summary of tick activity in the presence of a repellent band with an insert containing 10% DEET. Activity types 1–7 are described in Table 1.

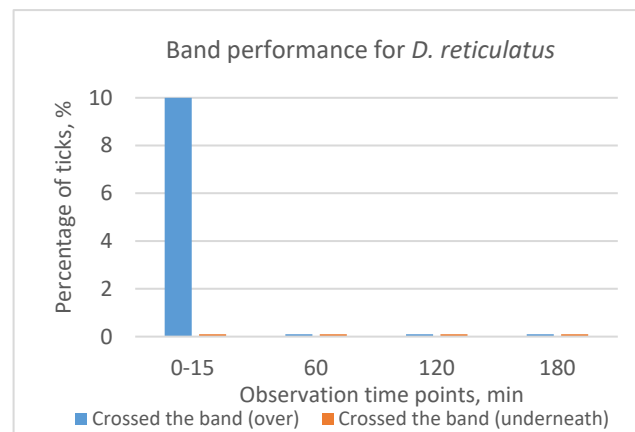
According to the adopted criterion, band effectiveness is defined as the percentage of ticks that crossed the band. Figure 10 presents an analysis of the activity types defined in points 6 and 7 of Table 1 for both tick species over a period of 0 to 180 min.

An analysis of the effect of DEET concentration on protective band effectiveness, understood as the percentage of ticks that crossed the band on the lower leg model in both the control and test groups after 3 h of the experiment, is presented in Figure 11.

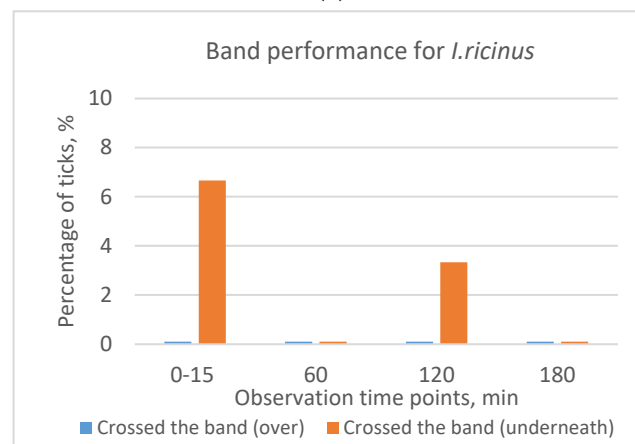
In addition, the decline in the protective effectiveness of the band over time was evaluated. Tick activity was analyzed over 8 h of the experiment (at nine observation time points) for the band insert treated with 20% DEET. The results of the analysis are presented in Figure 12.

Our observations of tick activity and their reactions to a band with a repellent-soaked insert indicate that protection declines after 3 h and is lost after 6 h (Figure 12). To ensure adequate protection, it is recommended to re-soak the insert within 3 h. Moreover, early-phase observations (0–15 min) suggest the need to extend the conditioning time of the band

insert before applying it. Moreover, the results of observing tick activity suggest extending the insert conditioning time from 0 to 15 min before application.



(a)



(b)

Figure 10. The percentage of ticks of both species: (a) *Dermacentor reticulatus* and (b) *Ixodes ricinus* that crossed the repellent band, broken down by time and movement strategy.

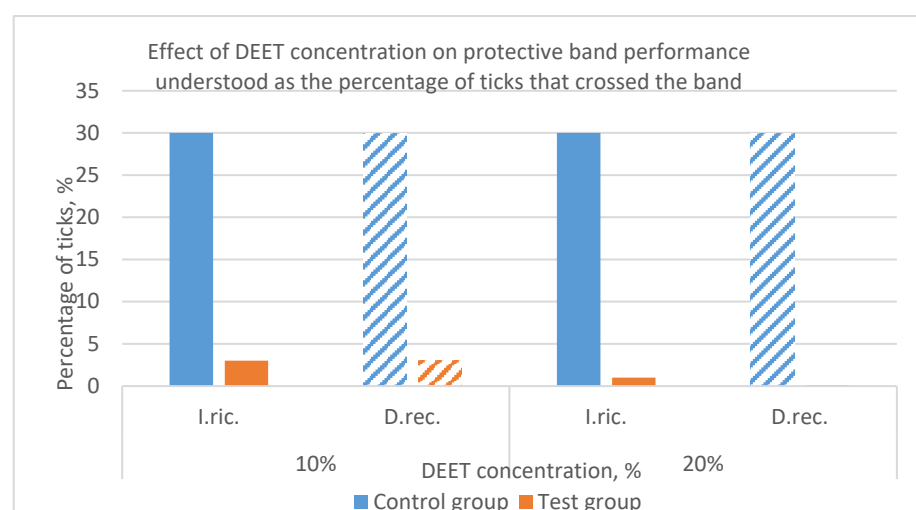


Figure 11. The percentage of ticks of both species that crossed the protective band, broken down by time and movement strategy. Legend: *I. ric.* = *Ixodes ricinus*, *D. rec.* = *Dermacentor reticulatus*.

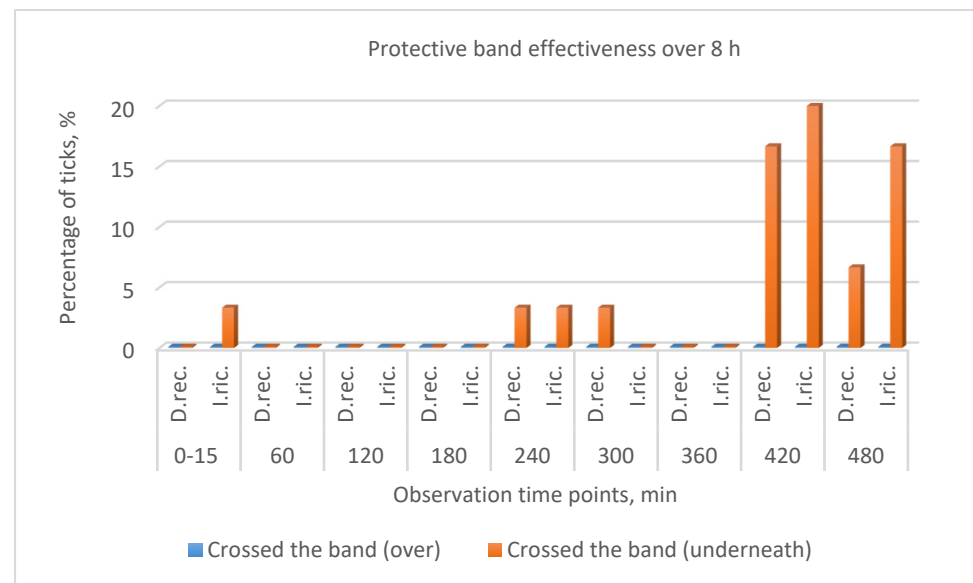


Figure 12. Percentage of ticks that crossed the protective band with 20% DEET on the lower leg model at 9 time points. Legend: *D.rec.* = *Dermacentor reticulatus*; *I.ric.* = *Ixodes ricinus*.

4. Discussion

In the study, we evaluated the protective performance of the proposed bands using a novel test stand. To date, repellency testing has relied on environmental methods, in vitro laboratory assays, and in vivo tests. We developed a new tool that combines the advantages of these approaches. For the first time, key environmental parameters, such as temperature, airflow, and host-mimicking attractants, were reproduced in laboratory conditions. Based on Dautel [18], the readiness of *Ixodes ricinus* ticks to infest a host depends on ambient temperature. Moreover, temperature acts as an attractant that initiates host-seeking. Therefore, we standardized the experimental temperature and, for the first time, installed a heated leg phantom with host-mimicking scent substances, known as attractants. To date, no comparable model has been standardized for as many factors as ours. This ensures repeatable and reproducible testing. Furthermore, the prototype could in the future replace human participation in such studies, preventing exposure to potentially harmful or skin-irritating test substances and avoiding direct contact with ticks or other arthropods.

Our tick observations demonstrate significant inter-species differences and varying levels of repellent sensitivity. In view of the above, band effectiveness is reduced by incorrect application for both the *Ixodes ricinus* and *Dermacentor reticulatus* species. The bands should be fitted snugly against the lower leg and adjusted to eliminate gaps (taking into account the small size of the ticks). Therefore, integrating bands into protective trousers is an effective solution (see Figure 4). On the other hand, standalone bands are versatile and convenient, as they can be carried and donned as needed before work or recreational activities. The effectiveness of both standalone and trouser-integrated bands declines over time, underscoring the need for repellent reapplication.

5. Conclusions

This study evaluated the effectiveness and usefulness of anti-tick protective bands (used either as standalone devices or integrated into protective trousers). The textile bands optimized in terms of repellent concentration and reapplication time were found to be effective. It should be noted that a key advantage of the proposed design with repellent-soaked inserts is that the repellent does not come into contact with the user's skin, and the textile insert can be cleaned.

The findings also support the suitability of the developed test stand for evaluating textiles in terms of their effectiveness regarding protection against ticks under near-real-world conditions.

The proposed methodology can be applied to a wide range of textile fabrics and complete garments, such as leggings and socks, under conditions similar to natural ones. As with all methods for testing tick-protective products, a limitation is the seasonal and insufficient availability of ticks. Even field-collected ticks selected for activity can introduce variability and influence study outcomes.

Author Contributions: Conceptualization, J.S. and J.W.; methodology, J.S., J.W. and M.A.; software, M.J., J.S. and J.W.; formal analysis, J.S. and J.W.; investigation, J.S. and J.W.; resources, J.W.; data curation, J.S. and J.W.; writing—original draft preparation, J.S. and J.W.; writing—review and editing, J.S., J.W., M.A. and M.J.; visualization, M.J.; supervision, M.A.; project administration, J.S.; funding acquisition, J.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by internal grants from the Medical University of Silesia in Katowice, financed by the POLISH MINISTRY OF SCIENCE AND HIGHER EDUCATION grant number “BNW-1-024/N/3/I” and Young Scientist grant number “BNW-2-023/N/4/F”, and financed by the MINISTRY OF FAMILY, LABOUR AND SOCIAL POLICY, task number “3.G.07”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: This paper is based on the results of a research task carried out within the scope of the 4th stage of the National Programme “Improvement of Safety and Working Conditions.” The Central Institute for Labour Protection—National Labour Institute (CIOP-PIB) was the Programme’s main coordinator.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

CIOP-PIB	Central Institute for Labour Protection—National Labour Institute
TBE	Tick-borne encephalitis
MOB	Moving object bioassay
DEET	N,N-diethyl-m-toluamide
I.ric.	Ixodes ricinus ticks
D.rec.	Dermacentor reticulatus

References

1. Petit, M.J.; Johnson, N.; Mansfield, K.L. Vectorial dynamics underpinning current and future tick-borne virus emergence in Europe. *J. Gen. Virol.* **2024**, *105*, 002041. [CrossRef] [PubMed]
2. Zanzani, S.A.; Rimoldi, S.G.; Manfredi, M.T. Lyme borreliosis incidence in Lombardy, Italy (2000–2015): Spatiotemporal analysis and environmental risk factors. In *Book Ticks and Tick-borne Diseases*; Elsevier GmbH: Amsterdam, The Netherlands, 2019; Volume 10, pp. 1–8. [CrossRef]
3. Gilbert, L. The Impacts of Climate Change on Ticks and Tick-Borne Disease Risk. *Annu. Rev. Entomol.* **2021**, *66*, 373–388. [CrossRef] [PubMed]
4. US Centers for Disease Control and Prevention (CDC). The 2022 National Inventory of Tick-Borne Diseases and Associated Illnesses. Available online: <https://www.hhs.gov/sites/default/files/tick-borne-national-inventory-2022.pdf> (accessed on 25 September 2025).

5. Kmiecik, W.; Ciszewski, M.; Szewczyk, E.M. Tick-borne diseases in Poland: Prevalence and difficulties in diagnostics. *Med. Pr. Work. Health Saf.* **2016**, *67*, 73–87. [CrossRef] [PubMed]
6. Telford, S.R.; Stewart, P.E.; Bloom, M.E. Increasing risk for tick-borne disease: What should clinicians know? *JAMA Intern. Med.* **2024**, *184*, 973–974. [CrossRef] [PubMed]
7. Le Dortz, L.L.; Rouxel, C.; Polack, B.; Boulouis, H.-J.; Lagrée, A.-C.; Deshuillers, P.L.; Haddad, N. Tick-borne diseases in Europe: Current prevention, control tools and the promise of aptamers. *Vet. Parasitol.* **2024**, *328*, 110190. [CrossRef] [PubMed]
8. Kuchar, E.; Zajkowska, J.; Flisiak, R.; Mastalerz-Migas, A.; Rosińska, M.; Szenborn, L.; Wdówik, P.; Walusiak-Skorupa, J. Epidemiologia, diagnostyka i profilaktyka kleszczowego zapalenia mózgu w Polsce i wybranych krajach europejskich-stanowisko polskiej grupy ekspertów. *Med. Pr.* **2021**, *72*, 193–210. [CrossRef] [PubMed]
9. Faulde, M.K.; Rutenfranz, M.; Keth, A.; Hepke, J.; Rogge, M.; Gerner, A. Pilot study assessing the effectiveness of factory-treated, long-lasting permethrin-impregnated clothing for the prevention of tick bites during occupational tick exposure in highly infested military training areas, Germany. *Parasitol. Res.* **2015**, *114*, 671–678. [CrossRef] [PubMed]
10. Devchand, R.; Koehler, L.; Hook, S.; Marx, G.E.; Hooks, H.; Schwartz, A.; Hinckley, A. Understanding consumer and clinician perceptions of a potential Lyme disease vaccine. *Health Educ. Res.* **2022**, *36*, 494–504. [CrossRef] [PubMed]
11. Richardson, M.; Khouja, C.; Walker, R.; Sutcliffe, K.; Stansfield, C.; Harden, M.; Sowden, A.; Thomas, J. *Prevention Interventions for Lyme Disease: A Systematic Review*; EPPI-Centre, Social Science Research Unit, UCL Institute of Education, University College London: London, UK, 2017; ISBN 978-1-911605-02-7. Available online: <https://eppi.ioe.ac.uk/CMS/Portals/0/PDF%20reviews%20and%20summaries/Lyme%20disease%20prevention%202017%20Richardson.pdf> (accessed on 25 September 2025).
12. Brochocka, A.; Kasprzak, J.; Barczak, T.; Bennewicz, J.; Klimberg, A. Działania mające na celu ochronę przed kleszczami i przenoszonymi przez nie patogenami. *Hygeia Public Health* **2018**, *53*, 70–73.
13. Selles, S.M.A.; Kouidri, M.; González, M.G.; González, J.; Sánchez, M.; González-Coloma, A.; Sanchis, J.; Elhachimi, L.; Olmeda, A.S.; Tercero, J.M.; et al. Acaricidal and repellent effects of essential oils against ticks: A review. *Pathogens* **2021**, *10*, 1379. [CrossRef] [PubMed]
14. Nguyen, Q.D.; Vu, M.N.; Hebert, A.A. Insect repellents: An updated review for the clinician. *J. Am. Acad. Dermatol.* **2023**, *88*, 123–130. [CrossRef] [PubMed]
15. Neeta, P.; Connally, N.P.; Rose, D.A.; Breuner, N.E.; Prose, R.; Fleshman, A.C.; Thompson, K.; Wolfe, L.; Broeckling, C.D.; Eisen, L. Impact of Wearing and Washing/Drying of Permethrin-Treated Clothing on Their Contact Irritancy and Toxicity for Nymphal *Ixodes scapularis* (Acari: Ixodidae) Ticks. *J. Med. Entomol.* **2019**, *56*, 199–214. [CrossRef]
16. Davidson, S.A.; Nun, D.J.; Chellaraj, A.H.; Johnson, J.Y.; Burgess, A.M.; Dehemer, S.; Milner, E.E. Reduced effectiveness of permethrin-treated military uniforms after prolonged wear measured by contact irritancy and toxicity bioassays with *Ixodes scapularis* (Acari: Ixodidae) nymphs. *J. Med. Entomol.* **2024**, *61*, 1181–1189. [CrossRef] [PubMed]
17. Schwartz, A.M.; Mackeprang, J.M.; Mead, P.S.; Hinckley, A.F. Effectiveness of personal protection measures against Lyme disease: A review of epidemiologic studies from the United States. *Zoonoses Public Health* **2022**, *69*, 777–791. [CrossRef] [PubMed]
18. European Parliament. Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on personal protective equipment and repealing Council Directive 89/686/EEC. *Off. J. Eur. Union* **2016**, 51–98. Available online: <https://eur-lex.europa.eu/eli/reg/2016/425/oj/eng> (accessed on 31 October 2025).
19. EN ISO 13688:2013/A1:2021; Protective Clothing—General Requirements. European Committee for Standardization: Brussels, Belgium, 2021.
20. Dautel, H.; Kahl, O.; Siems, K.; Oppenrieder, M.; Müller-Kuhrt, L.; Hilker, M.A. Novel test systems for detection of tick repellents. *Entomol. Exp. Appl.* **1999**, *91*, 431–441. [CrossRef]
21. Dautel, H. Test systems for tick repellents. *Int. J. Med. Microbiol.* **2004**, *293* (Suppl. S37), 182–188. [CrossRef] [PubMed]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.