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Development and Performance Evaluation of Fluorine-Free Saliva-Proof Cotton Knitted Fabric for Kids' Protection

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Abstract
Using ASUPERLE PWR, a fluorine-free treatment intended to improve moisture resistance without sacrificing comfort or mechanical qualities, this study explores the creation of water-repellent cotton textiles. Because cotton is naturally hydrophilic, it cannot be used in areas that are prone to moisture, necessitating the investigation of sustainable water-repellent materials. Water repellency tests (AATCC 22), scanning electron microscopy (SEM), colourfastness to rubbing (ISO 105-X12), and bursting strength tests (ISO 13938-2) were used to evaluate ASUPERLE PWR on scoured and bleached cotton knit fabric. The results showed that treated textiles had a continuous hydrophobic coating visible in SEM images and an ISO 5 water-repellency grade. Although ASUPERLE PWR improves water repellency, there is a little trade-off in durability, as seen by the minor decreases in colourfastness and mechanical strength that were observed. This study positions ASUPERLE PWR as a promising, eco-friendly alternative to fluorine-based treatments for textiles.

Keywords
Saliva-Proof, Cotton Knitted Fabric, Kids' Protection, Water Repellency, Fluorine-free treatment

1. Introduction
Cotton is still a mainstay in the textile business because of its comfort, breathability, and biodegradability (S. U. Islam, Majumdar, & Butola, 2023). However, its high moisture absorption limits its use in water-resistant applications, such as home furniture and outdoor clothing (Czerwinska, 2024). Fluorine-based compounds, which have a low surface energy and good hydrophobic performance, have been a major component of traditional methods for improving water repellency (Hossain, Newby, & Ahmed, 2024). These fluorinated chemicals are useful, but they also present serious health and environmental problems because they may remain in ecosystems and break down into perfluoroalkyl substances (PFAS), which can be harmful (Schreder & Goldberg, 2022).

Fluorine-free water-repellent coatings that are safe for the environment and effective have been increasingly popular in recent years (Saleem & Zaidi, 2020). An inventive method for giving cellulosic fibres like cotton hydrophobic qualities is ASUPERLE PWR, a fluorine-free agent based on modified fatty molecules. Non-fluorinated coatings can achieve significant water repellency, according to prior studies, albeit durability issues may arise (Hossain et al., 2024; Lone, Malik, Dhani, & Anjum, 2022; Olsen, 2019). This study uses a variety of tests, such as colourfastness and mechanical strength tests, to analyse the durability of cotton fabric and determine how well ASUPERLE PWR performs in increasing its water-repellency.

2. Materials and Methods
2.1 Materials
The 200 GSM scoured and bleached cotton knit fabric used in this investigation was purchased from P. A. Knit Composite Ltd. in Valuka, Mymensingh, Bangladesh. The main hydrophobic agent used was ASUPERLE PWR, a cationic liquid emulsion with modified fatty components that is fluorine-free. Additional auxiliary chemicals were purchased locally and were of laboratory quality for pre-treatment and colouring.

2.2 Pre-treatment and Dyeing Process

Reactive dyes such as Sunfix Yellow S3R, Red S3B, and Blue 3R were used to colour the cotton cloth. To guarantee colour fixing and stability, the cloth was heated in a dye bath at 60°C before caustic soda and hydrogen peroxide were added one after the other. To get it ready for further treatment, the cloth was completely cleansed and neutralized after dying.

2.3 Application of ASUPERLE PWR Coating

After adjusting the pH of the solution to 6–7, 60 g/L of ASUPERLE PWR was added. To guarantee homogeneous coating, a stenter machine set to 120°C and a feeding speed of 15 rpm was used for the application. To aid in the development of the hydrophobic layer, the treated cloth was then cured.

2.4 Water Repellency Testing (AATCC 22)

AATCC 22 spray test was used to assess water repellency. Before testing, fabric samples were conditioned for four hours at 21 ± 1°C and 65 ± 2% relative humidity. The amount of water penetration and surface wetness was visually evaluated after 250 mL of water was sprayed onto the cloth surface for 30 seconds. The ISO scale was used to assign ratings, with ISO 1 denoting total soaking and ISO 5 denoting no wetting.

2.5 SEM Analysis

Scanning electron microscopy was used to analyse the surface morphology (SEM). SEM stubs were used to mount 1x1 cm fabric samples, which were then examined at magnifications ranging from 40x to 2000x. The goal of SEM imaging was to determine the ASUPERLE PWR coating's consistency and dispersion.

2.6 Durability Testing

Colourfastness to Rubbing: Using the ISO 105-X12 standard, tests were performed for both dry and wet situations to assess the colourfastness of the treated cloth. Throughout ten cycles, a white cotton sample was rubbed against the treated fabric, and the colour transfer was graded from 1 (poor) to 5 (Excellent).
Bursting Strength: Using the ISO 13938-2 pneumatic technique, the mechanical strength of both treated and untreated fabric samples was measured. The findings were reported in kilopascals (kPa).

3. Results

3.1 Water Repellency Performance

With an ISO 5 grade on the AATCC 22 spray test, the cotton fabric treated with ASUPERLE PWR showed a notable increase in water repellency. Untreated samples, on the other hand, had an ISO 1 grade, which denotes total wetness. These outcomes demonstrate how well ASUPERLE PWR works to create a strong hydrophobic barrier on cotton fibres.

Table 1 Water Repellency Ratings (AATCC 22)

Sample Type	Rating (ISO Scale)
Treated Fabric	ISO 5
Untreated Fabric	ISO 1

3.2 SEM Analysis

The surface morphology of treated and untreated samples differed noticeably, according to SEM analysis. Water absorption was facilitated by the smooth and porous surface of the untreated cloth. On the other hand, treated samples had a consistent, continuous hydrophobic layer, indicating that ASUPERLE PWR was present on the fibre surfaces.

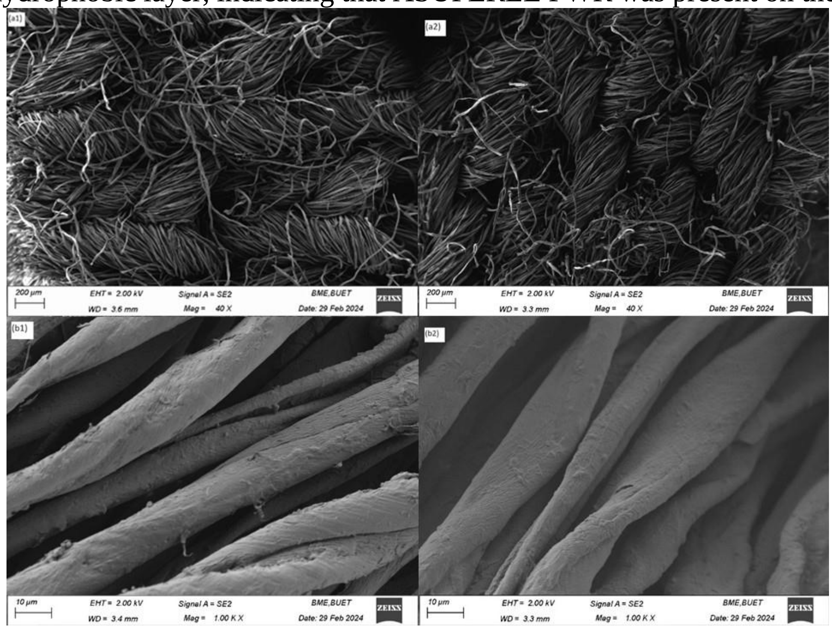

Figure 1: SEM images of (a1, a2) untreated and (b1, b2) treated cotton fabrics, illustrating the formation of a hydrophobic coating. Scanning electron microscopy (SEM) was used to examine the surface morphology of cotton textiles that had been treated and those that had not (a1) 40x magnification SEM picture of untreated cotton cloth. Liquid absorption is made possible by the fibres' inherent, rough, and porous nature. (a2) 40x magnification SEM picture of treated cotton cloth. The use of ASUPERLE PWR for water repellency is shown by the fibres' more compact arrangement and visible coating layer. (b1) A 1000x magnification SEM picture of individual cotton fibres that have not been treated. There are noticeable surface roughness and imperfections, which support hydrophilic behaviour. (b2): A 1000x magnification SEM picture of individual cotton fibres that have been treated. There is a consistent, smooth layer of coating that improves water-repellent qualities by forming a hydrophobic barrier.

3.3 Durability and Colourfastness

According to the colourfastness findings, the treated cloth showed a modest colour transfer after wet rubbing, maintaining a grade of 4 in dry conditions and 3 in wet conditions. In both tests, untreated cloth maintained a grade of 5. This implies that while ASUPERLE PWR improves water repellency, colourfastness may need to be improved by adjusting dye fixation.

Table 2 Colourfastness to Rubbing Results (ISO 105-X12)

Test	Treated Fabric	Untreated Fabric
Colourfastness (Dry)	4	5
Colourfastness (Wet)	3	5

3.4 Bursting Strength

According to bursting strength tests, the mechanical strength of the treated cloth was slightly lower at 345 kPa than that of the untreated samples, which were 355 kPa. The strength stayed within reasonable bounds despite this decrease, suggesting that ASUPERLE PWR does not jeopardize the fabric's structural soundness.

Table 3 Bursting Strength of Treated and Untreated Cotton Fabric (ISO 13938-2)

Sample Type	Bursting Strength (kPa)
Treated Fabric	345
Untreated Fabric	355

4. Discussion

With an ISO 5 rating that is similar to findings from research on fluorine-free hydrophobic agents, the application of ASUPERLE PWR to cotton fabric effectively improved water repellency (Klar, Gunnarsson, Prevodnik, Hedfors, & Dahl, 2014). The substantial water resistance is seen as a result of the consistent hydrophobic layer shown by SEM examination, which validated efficient coating adherence and distribution (Guha et al., 2021; Irfan, 2018; S. U. Islam et al., 2023).

While colourfastness scores somewhat declined in damp circumstances, durability evaluations showed that overall performance was still sufficient for moderate-use applications. This is consistent with research on non-fluorinated water-repellent treatments, which frequently show a balance between durability and hydrophobic performance (Ghazal & Elshamy, 2024; T. Islam, Khan, Karim, Hossain, & Jalil, 2024). Although noticeable, the modest decrease in bursting strength did not jeopardize the structural integrity, indicating that ASUPERLE PWR has the potential to be used in useful textile applications including household textiles and children's clothing.

5. Future Research Directions

5.1 Long-Term Durability Studies

Further investigation into the treatment's long-term durability is advised to confirm ASUPERLE PWR's viability for commercial application. To simulate real-world use, this should involve testing the treated fabric's mechanical qualities and water resistance following several washing cycles. A thorough grasp of the treatment's durability and usefulness would be possible by testing across a range of laundry circumstances, such as different detergents and temperatures (Kwok, 2012; Sanjeevana & Thenmozhi, 2022).

5.2 Performance under Environmental Stressors

The degree to which the hydrophobic coating maintains its qualities in adverse circumstances may be determined by investigating the fabric's performance during extended exposure to UV rays, high temperatures, and humidity. Applications incorporating protective apparel and outdoor equipment would particularly benefit from such evaluations. Tests for UV exposure may reveal if the ASUPERLE PWR coating deteriorates or loses its effectiveness over time, which is important to guarantee the durability of treated fabrics (Bainbridge, 2023).

5.3 Compatibility with Multi-Functional Finishes

To generate multipurpose textiles, further research should examine the viability of coupling ASUPERLE PWR with other environmentally friendly functional finishes, such as UV-protective or antibacterial chemicals. This would increase the range of applications for treated textiles, allowing them to be used in high-performance outdoor gear, athletics, and healthcare environments. Formulation techniques might be improved by investigating possible interactions or synergies between ASUPERLE PWR and other chemical therapies.

5.4 Application on Diverse Textile Substrates

Although the focus of this study was cotton, it would be helpful to assess ASUPERLE PWR's efficacy on other fibre types, such as mixed garments, polyester, and wool. By determining if comparable hydrophobic qualities and durability can be attained across different substrates, such a study might increase the usefulness of ASUPERLE PWR in the textile sector. It could be necessary to modify application methods to customize the treatment for non-cellulosic fibres.

5.5 Life Cycle Assessment (LCA) for Environmental Impact

A thorough life cycle assessment (LCA) would measure the effects of the production, use, and disposal of textiles treated with ASUPERLE PWR on the environment. ASUPERLE PWR's standing as an environmentally benign substitute may be strengthened by contrasting its environmental impact with that of fluorine-based therapies. For the LCA to offer a thorough sustainability profile, information on emissions, resource consumption, and end-of-life biodegradability should be included.

5.6 Wash Fastness and Repellency Retention Analysis

It would be advantageous to do more research on the treatment's wash fastness, with an emphasis on maintaining water repellency even after several wash cycles. Standardized wash fastness tests, such as ISO 105-C06, might be used to determine how well the hydrophobic layer endures over time. Furthermore, assessing the effects of fabric softeners and other typical laundry additives may shed light on possible incompatibilities.

5.7 Scalability and Cost-Effectiveness

Future research should evaluate the treatment process's scalability and cost-effectiveness in comparison to traditional fluorine-based finishes to guarantee that ASUPERLE PWR can be extensively used in the textile sector. It should be investigated if the existing application process can be modified for large-scale manufacture without materially raising production costs or sacrificing performance.

5.8 Consumer Safety and Non-Toxicity Verification

Even though ASUPERLE PWR is made to be environmentally friendly, more toxicological research is required to verify that it is safe for direct skin contact, particularly in goods meant for children and medical settings. Verifying the fabric's appropriateness for delicate applications would need testing for skin irritation and allergenicity following guidelines such as ISO 10993 for biocompatibility.

6. Conclusion

For cotton fabrics, ASUPERLE PWR has shown itself to be a successful and environmentally friendly water-repellent finish that maintains mechanical strength and colourfastness while offering potent hydrophobic qualities. The overall performance justifies its usage in applications including children's clothes, outdoor wear, and home textiles, despite the slight durability trade-offs that were noted. Its feasibility as an environmentally acceptable substitute for conventional fluorine-based therapies will be further established by on-going research centred on long-term durability, multifunctionality, and environmental evaluations.

Declaration of Conflict

Authors declare that no conflict of interest.

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