論文 EyesOn

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Safeguarding the Skin Microbiome: A Preventive Approach in Textile Development for Hygiene and Personal Care Products

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Introduction: From Science to Market Impact

The skin microbiome is no longer a purely academic subject of dermatological research; it has become a **key driver of product innovation and regulatory scrutiny** within the hygiene textile and cosmetic industry. Consumers, healthcare professionals, and regulators alike increasingly recognize that the integrity of the skin microbiome is essential not only for skin health but also for overall systemic well-being[1].

For industries producing **feminine hygiene products, baby care textiles, intimate wipes, medical textiles, and cosmetics**, the skin microbiome represents both a risk and an opportunity. Conventional approaches that rely heavily on antimicrobial finishes or chemical additives may reduce odor or infection risks in the short term, but they risk disrupting the delicate microbial balance that underpins healthy skin. At the same time, consumer expectations are shifting toward **gentler, science-backed, and sustainable products**. The result is an innovation race: manufacturers who succeed in safeguarding the microbiome can differentiate themselves through stronger safety claims, enhanced consumer trust, and future-proof compliance with evolving regulatory frameworks.

This article synthesizes the latest research on **textile–microbiome interactions**, the risks posed by chemical additives, the gaps in current testing protocols, and the **emerging opportunities for microbiome-friendly innovations**. It outlines how new scientific approaches can empower the hygiene textile and cosmetic industry to move from reactive product design toward **preventative, microbiome-conscious strategies** that will shape the future of personal care.

The Role of the Skin Microbiome in Skin Health

The skin microbiome, a complex and diverse community of microorganisms residing on the skin, plays a pivotal role in maintaining both skin and overall health. It serves as a primary barrier against pathogens, modulates immune responses, and contributes to systemic immune programming[1~3]. Beyond local skin effects, the microbiome's influence extends to whole-

body states, with disruptions linked to inflammatory and non-communicable diseases[4) 5)].

Additionally, environmental factors such as biodiversity and the built environment play a crucial role in shaping microbiome stability, with ecological changes contributing to microbial imbalances[4) 5)]. As research continues to uncover the intricate relationship between the skin microbiome and health, microbiome-friendly interventions offer promising pathways for disease prevention and skin health optimization. Understanding and preserving microbiome integrity will be instrumental in advancing dermatological and systemic health strategies.

The Major Functions of the Skin Microbiome

1. Barrier Protection: The skin microbiome strengthens the skin's defense against environmental insults, dehydration, and pathogens[7)].

2. Immune Regulation: It modulates immune responses, reducing inflammation and lowering the risk of conditions like atopic dermatitis and psoriasis[2)].

3. Pathogen Defense: Commensal bacteria compete with harmful microbes, preventing infections[3)]. *Staphylococcus epidermidis*, for example, produces antimicrobial peptides that protect against pathogens[8)].

From an **industry standpoint**, this knowledge underscores a key principle: **products that preserve microbial balance not only maintain skin comfort but also protect long-term consumer health**. Skincare products, detergents, and textiles that destabilize this balance risk causing irritation, inflammation[4) 9) 10)], and ultimately eroding consumer trust. By contrast, companies that create products which protect the microbiome gain a competitive edge through credible, health-oriented claims.

24/7 Environmental and Textile Influences on the Microbiome

Environmental factors such as urbanization, biodiversity exposure, and indoor environments strongly influence microbiome stability[4)]. Within this context, textiles are uniquely important because of their **constant, intimate contact with skin**.

Influence of Textiles on Skin Microbiome

The relationship between textiles and the skin microbiome is increasingly recognized as significant due to the direct and constant contact between clothing and skin. Textiles can influence the skin microbiome by affecting factors such as pH, moisture content, and odor generation. The skin microbiome plays a crucial role in maintaining skin health, and any disruption can lead to skin conditions. Textiles with antimicrobial properties, while beneficial in reducing odor and infection, can also disrupt the natural balance of the skin microbiome, potentially leading to adverse skin conditions[11)].

Scientific research underscores the need to assess the effects of textile dyes and functionalized chemicals on human health, particularly their influence on the skin microbiome[12)]. Chemicals in textiles can significantly alter microbial composition, with potential long-term consequences[13)]. Some microorganisms may even adapt to these

chemical exposures, raising concerns about microbial resistance[14].

Textile-bacteria interactions play a crucial role in evaluating functional textiles' impact on the skin microbiome. Research indicates that fabric properties such as fiber composition and weave structure affect bacterial adhesion and proliferation[15]. For instance, denser textile structures and twill weaves provide surfaces that promote bacterial adherence[16]. Additionally, fiber type influences microbial growth, contributing to malodor and microbiome alterations[17]. The exchange of microorganisms between skin and textiles necessitates further investigation into both textile impact and microbial health[18].

Consumer Trends 2025

Market research indicates that microbiome-conscious products are no longer niche. According to Euromonitor[19] and Mintel[20], **microbiome-friendly skincare and hygiene products are among the fastest-growing categories** in personal care. Consumers increasingly look for:

- **Evidence-based claims:** Trust in "dermatologically tested" has eroded; microbiome-specific claims resonate more strongly.
- **Preventative health benefits:** Beyond symptom relief, consumers demand products that support long-term health.
- **Natural and sustainable positioning:** Products that avoid harsh chemicals and align with environmental values gain preference.

For feminine hygiene and infant care, in particular, consumer expectations are shifting rapidly. Parents are highly cautious about exposing infants to chemicals, while women seek **gentle, microbiome-supportive solutions** to avoid recurring infections and irritation. This trend creates fertile ground for **microbiome-active textiles** as a premium market segment.

Textiles for hygiene, female and infant care

Recent research in textiles for hygiene, female care, and infant care highlights a shift toward materials that support skin health by considering the skin microbiome. There is growing recognition that traditional antimicrobial textiles may disrupt the skin's natural microbial balance, and new opportunities exist for developing microbiome-friendly or bioactive textiles.

Leveraging Pro-, Pre-, and Postbiotics

An emerging innovation in the feminine hygiene and infant care textiles market is the integration of probiotics, prebiotics, and postbiotics to actively support and restore the vaginal microbiome. Maintaining a healthy vaginal ecosystem is critical for infection prevention, modulation of immunity, and the reduction of conditions such as vaginal atrophy. Scientific evidence demonstrates that introducing beneficial bacteria and their supportive compounds can create a protective environment directly at the site of contact.

Probiotics, such as *Lactobacillus rhamnosus GR-1, Lactobacillus reuteri RC-14*, and *Lactobacillus crispatus spp.*, are well-documented for their ability to increase the population of protective Lactobacilli, reduce pathogenic col-

onization, and modulate local immune responses[21) 22)]. Incorporating these strains into hygiene products presents a unique preventative strategy against common vaginal infections, including bacterial vaginosis and candidiasis.

Prebiotic oligosaccharides act as a nutrient source for Lactobacilli, supporting their growth and helping to restore microbial balance disrupted by hormonal changes or external irritants[20) 23)]. Meanwhile, postbiotic lactic acid bacteria-derived gels have shown efficacy in improving bacterial vaginosis symptoms, enhancing Lactobacilli presence, and reducing pathogen load[24) 25)].

For the feminine hygiene products market, these strategies unlock opportunities to move beyond passive protection and towards active microbiome restoration. Integrating pro-, pre-, and postbiotics into sanitary pads, pantyliners, and intimate wipes could position brands as pioneers in microbiome-conscious care, offering functional textiles that not only absorb and protect but also maintain vaginal health. This approach aligns with the growing consumer demand for preventative, science-backed solutions in personal care.

Chemical Exposures in Conventional Textiles

Despite progress in product safety, conventional textiles continue to contain chemical additives with significant health implications.

Table 1 highlights several chemicals commonly used in textile manufacturing summarized by *Rovira et al.* (2025), remain in the final consumer products. Benzothiazoles, benzotriazoles,

Tab. 1 Summary of Key Chemical Groups in Textiles and Their Health Risks by *Rovira et al.* (2025)

Chemical Group	Common Uses	Exposure Routes	Health Risks	Regulatory Status
Phthalates	Plasticizers in fibers	Dermal, inhalation	Endocrine disruption, reproductive toxicity, carcinogenicity	Restricted in some regions (e.g., EU REACH); substitution trends observed
PFAS	Water/oil repellents	Dermal, inhalation	Carcinogenicity, thyroid dysfunction, immune suppression	Some PFAS banned / restricted; debates on short-chain PFAS ongoing
Metals	Dyes, Pigments, Antimicrobials	Dermal, ingestion	Neurotoxicity, carcinogenicity (e.g., Cr, Cd), skin sensitization	Variable regulation; strict limits for Pb and Cd in textiles
Azo Dyes	Colorants	Dermal, ingestion	Release carcinogenic amines, allergic dermatitis	Certain azo dyes banned in EU; others remain unregulated
Bisphenols	Non-intentional additives	Dermal	Endocrine disruption, developmental effects	BPA restricted; increasing use of substitutes like BPS and BPF
Formaldehyde	Wrinkle-resistant finishes	Dermal, inhalation	Carcinogenicity, skin irritation, respiratory issues	Legal limits exist but enforcement varies globally

formaldehyde, and phthalates are among the most prevalent, with potential health risks such as skin irritation and endocrine disruption. The presence of these chemicals in consumer textiles underscores the importance of monitoring and regulating chemical use in the textile industry to protect both human health and the environment.

From a regulatory perspective, the **EU REACH framework** already restricts several of these substances, with further bans under debate. For manufacturers, proactive substitution is not only a legal safeguard but also a **branding opportunity**: positioning products as "beyond compliance" strengthens consumer trust (see Table 1).

Current Testing Practices and Gaps

Testing methods for textile-skin compatibility primarily focus on evaluating the potential toxicity and irritation caused by textiles when in contact with human skin. Common methods include *in vitro* skin toxicity tests using reconstructed skin models, which assess parameters like skin tissue viability and pro-inflammatory responses[26]. Other methods involve optical techniques to characterize textile materials and their interaction with skin, assessing properties like barrier function and tactile sensation[27]. Additionally, the Cilitatetest is used for detecting toxic substances through calorimetric detection of microorganism metabolism[28].

Gap in Textile Testing for Skin Microbiome

The primary gap in textile testing concerning the skin microbiome is the lack of comprehensive methods that consider the complex interactions between textiles and the diverse microbial communities on human skin. Traditional testing methods often focus on the antibacterial properties of textiles without considering their impact on the skin's natural microbiota. This oversight can lead to unintended consequences, such as disrupting the skin's microbial balance, which is crucial for maintaining skin health[3) 5)].

Moreover, while some studies have begun to explore the transfer and persistence of skin microbiota on textiles, there is still a need for standardized methods to evaluate how textiles affect the skin microbiome over time and under various conditions. This includes understanding the long-term effects of wearing antimicrobial textiles and their potential to alter the skin's microbial ecosystem[7) 9)].

In summary, while several methods exist to test the compatibility of textiles with human skin, there is a significant gap in understanding their impact on the skin microbiome. Addressing this gap requires developing standardized testing protocols that consider the complex interactions between textiles and the skin's microbial communities.

Opportunities for Innovation & Certification

Literature collectively emphasizes the important role textiles play in the interaction with bacteria, and how the skin microbiome needs to be safeguarded[18) 29)].

Current research on the skin microbiome emphasizes the importance of preserving its steady state to maintain skin health and resilience. Disruptions caused by external factors, including textiles, can lead to microbial imbalances with potential implications for skin conditions and overall well-being.

To address this, MyMicrobiome introduces an innovative testing protocol designed to assess how textiles interact with and safeguard the skin microbiota − a novel approach not previously seen in the industry. Using a scientific, *in vitro* testing method, this protocol evaluates textile impact across four key dimensions:

1. **Quality Test**, ensuring textiles are sterile before microbiome assessment

2. **Balance Test**, measuring shifts in the ratio of *Staphylococcus epidermidis* (beneficial) to *Staphylococcus aureus* (harmful) bacteria

3. **Diversity Test**, analyzing microbial diversity across different skin areas

4. **Vitality Test**, ensuring textiles do not negatively affect microbial survival

By systematically testing textiles against these parameters, MyMicrobiome provides a groundbreaking way to verify whether textiles preserve microbiome equilibrium. This approach enables manufacturers to create microbiome-friendly textiles that promote skin health, setting a new industry standard for responsible and science-backed textile innovation.

Investing in microbiome-friendly certifications can differentiate brands in the competitive hygiene and personal care market, providing transparency, credibility, and long-term consumer trust.

Regulatory Landscape

The regulatory climate around chemicals and microbiome safety is tightening. Key developments include:

- **EU REACH:** Expanding restrictions on phthalates, PFAS, and azo dyes[30].
- **FDA Guidance:** Emphasizing safety substantiation in cosmetics and skin-contact products[31].
- **SCCS Opinions (EU):** Increasing focus on microbiome implications in safety assessments[32].

Industry stakeholders must anticipate a future in which **microbiome safety is a regulated standard**, not just a marketing claim. Early adoption of microbiome-friendly testing thus represents both risk management and competitive advantage.

Strategic Benefits for Industry

By integrating microbiome safety into product development, companies can unlock multiple advantages:

- **Consumer Trust:** Certification signals scientific integrity in an era of skepticism.
- **Market Differentiation:** Microbiome-friendly products create premium categories.
- **Regulatory Preparedness:** Testing antici-

pates compliance requirements.

- **Sustainability:** Reducing chemical reliance aligns with ESG and corporate responsibility.

In a marketplace where consumers demand both performance and proof, microbiome certification provides a **unique differentiator**.

Future Directions

The intersection of textile science, cosmetics, and microbiome research is creating unique platforms for innovation:

- **Personalized functional textiles:** Custom fabrics for different skin types/microbiomes using AI and omics methods.
- **Circular economy & sustainability:** Microbiome-friendly products encourage both skin health and bio-diversity preservation.
- **Cross-sector synergies:** Movement between the textile and cosmetic industries enables new hybrids e.g. cosmetic fibers with skincare properties or wearables that monitor the microbiome.

2025 is the time for companies, both large and small, to move forward:

1. **Research & Development:** Invest in microbiome-friendly materials, reliable test methodologies, and innovative product design.

2. **Supply Chain:** Work with suppliers and partners to set and uphold rigorous requirements for chemical management and full transparency.

3. **Communication:** Use independent certifications to demonstrate value to retailers, stakeholders, and end users in a clear and credible way.

4. **Knowledge Transfer:** Create strong links between research, application, and consumers to encourage optimal use and broad acceptance.

Those who develop and implement a concrete, actionable plan for microbiome-centric innovation today will enjoy a lasting lead – economically, with regulators, and in the hearts and minds of consumers – for a better, microbiome-friendly world.

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