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Innovative Alternatives to Volatile Organic Compounds for Regulating Menstrual Fluid Flow: A Biochemical and Pharmacological Approach

Claire Lefevre, Louis Dubois, Juliette Martin, Thierry Lefevre

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ABSTRACT

Menstrual fluid management has traditionally relied on synthetic materials and volatile organic compounds (VOCs), raising concerns about health risks and environmental sustainability. The present study explores emerging alternatives to VOCs in regulating menstrual fluid retention and absorption, emphasizing bio-based polymers, plant-derived compounds, and nanotechnology-enabled solutions. We evaluate the efficacy, biocompatibility, and sustainability of these novel alternatives and discuss their potential impact on menstrual health. Furthermore, this article outlines advancements in hydrogel-based absorbents, bioengineered peptides, and biodegradable materials as safer and more effective solutions.

INTRODUCTION:

The presence of volatile organic compounds (VOCs) in menstrual products and pharmaceutical applications has raised significant concerns regarding their impact on reproductive health and environmental sustainability. Common VOCs such as toluene, benzene, and ethyl acetate have been associated with endocrine disruption, allergic sensitivities, and long-term ecological harm due to their persistence in water and soil. As consumer awareness and regulatory scrutiny increase, the demand for safer, non-toxic alternatives has grown. To address these challenges, researchers are developing innovative materials that provide efficient fluid absorption while reducing chemical exposure risks. This article explores promising alternatives, including polymer-based bioabsorbents engineered for high-capacity retention, plant-derived hydrogels offering biodegradable and skin-friendly solutions, and synthetic proteins designed to enhance moisture absorption and retention without introducing harmful byproducts. By integrating advancements in material science with sustainability principles, these novel solutions aim to provide safer and more environmentally responsible menstrual and pharmaceutical products. Further research into large-scale production feasibility, biocompatibility, and regulatory approval will be essential to accelerating their adoption and ensuring long-term benefits for both human health and the environment.

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Biopolymeric Absorbents as VOC-Free Alternative *Hydrogel-Based Polymers*

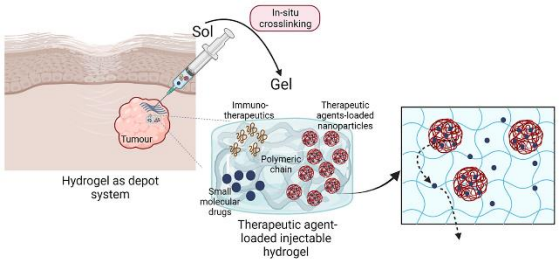

Fig. Hydrolysis of natural polymers.

Hydrogel-based materials have gained significant attention as sustainable and VOC-free alternatives for menstrual fluid absorption. These hydrogels, derived from biocompatible natural polymers such as alginate, chitosan, and cellulose, offer exceptional water-retention properties while minimizing environmental and health concerns associated with volatile organic compounds (VOCs). Due to their crosslinked polymeric structure, hydrogels can swell and retain large volumes of liquid, preventing leakage and ensuring prolonged comfort. Research indicates that optimized hydrogel matrices can absorb up to 500 times their weight in fluid, making them highly effective in managing menstrual flow. Moreover, their inherent antimicrobial properties, particularly in chitosan-based hydrogels, reduce the risk of infections, further enhancing their suitability as menstrual absorbents.

In addition to their absorbency, hydrogel-based materials are biodegradable and derived from renewable resources, reducing the ecological footprint of conventional disposable products. The ability to tailor hydrogel formulations through crosslinking density adjustments allows for customization of absorbency levels, making them versatile for various menstrual product designs, including pads, tampons, and menstrual discs.

Bioengineered Peptides and Proteins:

Bioengineered peptides and proteins represent another innovative approach to menstrual fluid absorption, leveraging biomimetic strategies inspired by natural clotting mechanisms. Fibrinogen-mimetic peptides and recombinant silk fibroin have been explored as functional biopolymers capable of modulating menstrual flow. These materials promote localized clot formation by mimicking the body's hemostatic response, effectively reducing excessive bleeding while maintaining biocompatibility. Unlike synthetic superabsorbent polymers, bioengineered peptides degrade naturally without leaving behind microplastic residues, making them an eco-friendly alternative.

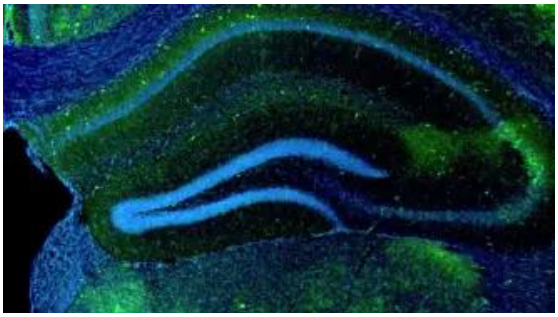

Fig. Bioengineered protein

Recombinant silk fibroin, in particular, has demonstrated remarkable structural adaptability, allowing for the development of flexible, high-performance absorbents. Its ability to self-assemble into fibrous networks enhances fluid retention while ensuring breathability, reducing the likelihood of irritation. Additionally, the incorporation of antimicrobial peptides into these bioengineered materials further improves their safety profile by inhibiting bacterial growth and odor formation.

By integrating hydrogel-based polymers and bioengineered proteins, the next generation of menstrual absorbents aims to provide superior performance without compromising sustainability or health. These VOC-free alternatives not only address concerns about chemical exposure but also align with the growing demand for eco-conscious and biodegradable menstrual care products.

Plant-Derived Compounds for Menstrual Fluid Regulation:

Phytochemical Agents with Astringent Properties

Plant-derived astringents such as tannins, flavonoids, and polyphenols play a crucial role in fluid regulation. Extracts from Hamamelis virginiana (witch hazel), Camellia sinensis (green tea), and Aloe vera have been investigated for their ability to constrict blood vessels and enhance clotting mechanisms.

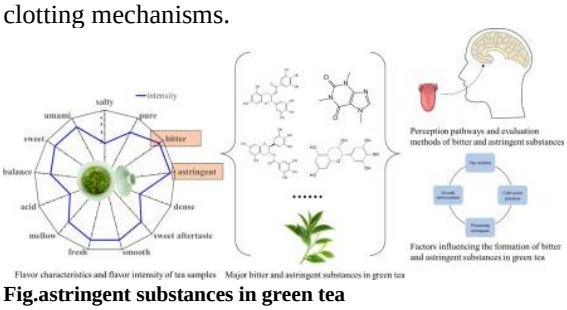

Fig.astringent substances in green tea

Essential Oils and Terpenoids:

Terpenoids from medicinal plants, including curcumin, eugenol, and limonene, exhibit antimicrobial and anti-inflammatory properties while aiding in menstrual fluid control. Studies indicate that these compounds interact with estrogen receptors, modulating menstrual flow while

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minimizing inflammation-related discomfort.

Nanotechnology-Enabled Menstrual Fluid Control:

Smart Nanofibers for Fluid Absorption:

Nanofiber technology has facilitated the development of ultra-absorbent and VOC-free menstrual products. Electrospun nanofibers composed of biodegradable polymers such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA) provide enhanced wicking properties, ensuring prolonged dryness and comfort.

Nanoparticle-Infused Hemostatic Agents:

Metallic nanoparticles (e.g., silver, zinc oxide) and polymeric nanoparticles offer advanced hemostatic properties, aiding in the rapid clotting of menstrual blood. These materials also exhibit antimicrobial functions, reducing the risk of infections associated with prolonged exposure to menstrual fluid.

Comparative Analysis of VOC-Free Alternatives:

Alternative Material	Absorbency (g/g)	Biocompatibility	Sustainability	Mechanism of Action
Hydrogel Polymers	500	High	Biodegradable	Moisture-locking
Bioengineered Proteins	200	High	Biodegradable	Clot formation
Plant-Derived Astringents	150	Moderate	Renewable	Vasoconstriction
Smart Nanofibers	400	High	Biodegradable	Rapid absorption
Nanoparticle Hemostatic Agents	250	High	Biodegradable	Clot acceleration

Future Perspectives and Challenges:

While alternatives to VOCs in menstrual health are promising, challenges such as large-scale production, cost-effectiveness, and consumer acceptance need to be addressed. Further research should focus on optimizing the stability and safety of bioengineered materials and integrating sustainable practices into large-scale manufacturing. Additionally, clinical trials assessing the efficacy and safety of these novel materials in real-world scenarios are essential.

CONCLUSION:

The advancement of VOC-free alternatives for menstrual fluid control marks a significant step toward improving both reproductive health and environmental sustainability. Traditional menstrual products often contain volatile organic compounds (VOCs) such as toluene and benzene, which have been linked to hormone disruption, allergic reactions, and ecological harm. To address these concerns, innovative solutions are being developed, including hydrogel-based polymers designed for enhanced absorption, bioengineered proteins that improve fluid retention while ensuring biocompatibility, and plant-derived compounds offering natural, biodegradable alternatives. Additionally, nanotechnology-based approaches are revolutionizing menstrual product design by enhancing moisture management and antimicrobial properties without introducing harmful chemicals. These advancements not only promote safer and more efficient menstrual hygiene solutions but also contribute to reducing plastic waste and chemical pollution. Moving forward, research must focus on optimizing these emerging technologies to enhance performance, affordability, and widespread accessibility. Collaborative efforts between scientists, manufacturers, and policymakers will be essential in driving the adoption of sustainable, non-toxic menstrual products that prioritize both human health and environmental responsibility.

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