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RECENT ADVANCES IN FUNCTIONAL TEXTILES- AN OVERVIEW

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ABSTRACT

The growing demand for multifunctional and sustainable textiles has led to a surge in research integrating nanotechnology into fabric systems. This review explores recent advancements in nanotechnology-enabled textiles, focusing on three core functionalities: electromagnetic interference (EMI) shielding, self-cleaning, and aroma-releasing properties. With increased environmental awareness and the rise in smart device usage, textile-based EMI shielding using metallic nanoparticles like silver and copper has become essential. Simultaneously, photocatalytic nanoparticles such as TiO_2 and ZnO provide durable self-cleaning effects, while silver and herbal-based antimicrobials offer eco-conscious hygiene solutions. Aroma-releasing textiles, enhanced through Nano- or micro-encapsulation of essential oils, show promise in wellness and cosmeto-textile applications. The review identifies key research gaps, including the need for standardized testing protocols, long-term safety assessments, and scalable, cost-efficient production methods. Current trends reveal a shift toward green synthesis, biodegradable carriers, and plant-based functional agents. The study also highlights real-world applications across healthcare, defense, sportswear, and therapeutic fashion. Looking forward, smart textiles combining sensory technology, AI-driven design, and sustainable nanomaterials represent a transformative direction for the industry. This paper underscores the importance of interdisciplinary collaboration to translate laboratory innovations into practical, commercially viable products that align performance with sustainability.

KEYWORDS: *Nanotechnology, Electromagnetic Radiation Shielding, Self-Cleaning Fabric, Textile Nano finishes, Aroma Finishing, Metal Nanoparticles*

INTRODUCTION

The increasing demand for smart, sustainable, and multifunctional textiles has driven research into innovative materials and fabrication techniques that enhance fabric performance. With the rise in environmental awareness, personal health concerns, and technological dependence, there is a growing interest in textiles that not only protect the user but also offer additional functional benefits such as electromagnetic interference (EMI) shielding, self-cleaning, antimicrobial, and aroma therapeutic properties. Nanotechnology has emerged as a transformative solution, allowing the integration of nanoparticles and nanostructured materials into fibers and fabrics to create advanced textiles. In a recent study, Ibrahim, Moussa, and Abd El-Aziz (2025) used a simple and eco-friendly chemical method called the sol-gel process to create titanium dioxide (TiO_2) nanoparticles combined with carbon. These nanoparticles were applied to cotton and viscose fabrics. The treated fabrics became multifunctional—they could clean themselves, kill harmful bacteria, and possibly block UV rays. This

method is not only effective and sustainable, but it also has the potential to be used on a larger scale in the textile industry. (Mohamed Gouda et al., 2025) developed an eco-friendly way to create silver nanoparticles (AgNPs) using Spirulina extract and applied them to cotton fabric. These treated fabrics showed strong photocatalytic and antibacterial properties. The silver nanoparticles were very small—around 8.6 nanometers—and had a round shape, confirmed using advanced imaging techniques. The fabric was able to remove 100% of Congo red dye under specific conditions and remained effective after five reuse cycles. It also showed strong antibacterial effects against several harmful microbes, even performing better than standard antibiotics like ciprofloxacin. This study shows that AgNPs-coated cotton fabric could be a powerful and sustainable solution for water treatment and medical uses.

Hua-Bin Yuan et al. (2024) developed a new eco-friendly and water-repellent cotton fabric using natural materials like tung oil and behenic acid, along with a metal-organic framework (MOF) called ZIF-8. This innovative fabric, named BTZC, forms a unique flower-like surface structure that makes it super hydrophobic—it effectively repels water, resists stains, and prevents ice from forming. Importantly, it avoids the use of harmful fluorinated chemicals and retains fabric breathability, making it ideal for outdoor use in cold and wet environments. This advancement significantly contributes to the field of functional textiles, particularly in the development of sustainable and high-performance materials. It aligns well with the recent advances in functional textiles that integrate nanotechnology for multi-functional properties such as self-cleaning, water resistance, and thermal stability. The use of MOFs like ZIF-8 not only enhances surface roughness for super hydrophobicity but also supports breathability and mechanical strength—key requirements in smart textiles. Thus, this research supports broader innovations in textiles that aim to combine features like electromagnetic shielding, self-cleaning, and aroma finishing using eco-friendly nanomaterials.

There is a study continues earlier research on how well a special woven cotton fabric can block electromagnetic radiation (EMR). The fabric uses regular cotton threads and special "hybrid" threads in the weft (side-to-side direction). These hybrid threads are made by wrapping stainless steel yarn with copper wire. In the fabric, the threads alternate between one hybrid and one cotton yarn.

Among all the fabric designs tested earlier, this one gave the best shielding results. In this new study, researchers tested how adding more fabric layers and changing the angle between them affects the shielding.

They found that using three layers stacked at the same angle (0°) gives good protection—about 56 dB—which is more than double the protection of a single layer. However, adding more than three layers doesn't improve it further. Also, arranging layers at a 45° angle only improves shielding at low frequencies, like 30 MHz.(Marciniak et al., 2019)

THEMATIC AND SYSTEMATIC LITERATURE REVIEW

A comprehensive literature review was conducted using databases such as Scopus, Science Direct, Web of Science, and Google Scholar. The review focused on peer-reviewed articles published from 2015 to 2025, specifically targeting developments in nanotechnology-enabled textile functionalities.

Electromagnetic Interference Shielding The increased usage of electronic devices has heightened concerns over EM radiation exposure. Polymeric textiles with metallic nanoparticle coatings (e.g., silver, copper) have shown promise in EMI shielding (Faiza Safdar et al., 2021; Sarnaitė-Žuravliova et al., 2015). These fabrics are lightweight, flexible, and can be designed in various forms for everyday use. Protecting people and devices from electromagnetic interference (EMI) is

becoming more important as more machines give off electromagnetic waves. While hard shields can be used, flexible and stretchable materials like textiles are better for comfort and ease of use. However, normal fabrics don't naturally block EMI because they lack conductivity or magnetic properties. To make them work, special materials like conductive yarns, coatings, or fibers are added. Recent research shows that MXenes—a new material—are very promising because they are highly conductive and block EMI well. Other materials like metal coatings, carbon fibers, and conductive polymers are also still useful for making EMI-shielding fabrics.(Blachowicz et al., 2023)

Self-Cleaning and Antimicrobial Textiles Nanoparticles like TiO2 and ZnO impart photocatalytic properties, offering self-cleaning capabilities by degrading organic pollutants under light (Kartick K. Samanta et al., 2015). Silver and copper nanoparticles have broad-spectrum antimicrobial effects (Azam Ali et al., 2023; Amisha Verma et al., 2023). Herbal and biopolymer-based antimicrobial agents provide eco-friendly alternatives (A. El-Shafei et al., 2018; J. Banupriya & V. Maheshwari, 2019). The idea of self-cleaning surfaces comes from nature, especially from the lotus leaf, which stays clean even though it grows in muddy water. This is because its surface is covered with tiny structures and a waxy layer that makes it very water-repellent. When water drops fall on it, they roll off easily, carrying away dirt—this is known as the "Lotus Effect." In textiles, scientists are using this concept to create fabrics that clean themselves using special coatings. These can be either hydrophobic (water rolls off) or hydrophilic (water spreads and washes dirt away, sometimes breaking it down with sunlight using photocatalysts). Nanotechnology is helping to improve these effects by adding tiny particles to fabrics, giving them extra benefits like softness, durability, waterproofing, and even antibacterial properties.(Saad et al., 2016)

Aroma-Releasing and Cosmeto-Textiles: Aromatherapy-infused textiles aim to improve user comfort and wellness. Natural essential oils encapsulated using nano or micro techniques offer controlled and sustained aroma release (Sunidhi Mehta & Maureen MacGillivray, 2022; Sumera Naz et al., 2025). Innovations using chitosan and biodegradable polymers for EO encapsulation show promising results in wash durability and antimicrobial activity (Fernanda Cristina da Rosa et al., 2025; Carla Salinas et al., 2022).

Analysis of Trends and Comparison of Findings: Recent studies indicate a clear trend toward integrating sustainability with functionality. For instance, green synthesis methods for nanoparticles and the use of biodegradable polymers are increasingly preferred. Silver nanoparticles remain popular for antimicrobial use, but copper is gaining traction due to cost-effectiveness (Luz E. Román et al., 2020). Herbal extracts are being validated scientifically for fabric applications, bridging traditional medicine with modern textile technology.

Applications and Real-World Relevance

Functional textiles have practical applications in healthcare (antibacterial scrubs, hospital linens), sportswear (odor control, moisture management), defense (EMI protective gear), and wellness (aromatherapy garments). Cosmeto-textiles and Ayurvastra integrate beauty and health treatments into clothing.

CONCLUSION

The integration of nanotechnology into textiles has revolutionized the field of functional fabrics. Key advances in EMI shielding, self-cleaning, and aroma-finishing applications demonstrate significant progress toward sustainable and intelligent clothing. Despite some challenges regarding scalability, regulation, and long-term safety, the future of

nanofunctional textiles is promising. Continued interdisciplinary research and industrial collaboration will be crucial to translate laboratory findings into commercial, eco-friendly products. Emphasizing eco-conscious innovation and multifunctionality ensures that textile advancements not only enhance performance but also contribute to health, comfort, and environmental sustainability. To make a fabric that can block electromagnetic (EM) waves, clean itself, and release a pleasant smell (aroma), we need to carefully choose and combine special tiny particles called nanoparticles. Some nanoparticles can do more than one job at the same time. For example, silver or copper nanoparticles can block EM radiation and also kill bacteria. Titanium dioxide (TiO_2) or zinc oxide (ZnO) can break down dirt when exposed to sunlight, helping the fabric clean itself. To add a nice smell, we can use nano-sized capsules filled with essential oils or herbal extracts. These capsules slowly release the scent when the fabric is worn or rubbed.

One smart way to combine all these functions is by using a layer-by-layer approach. First, we apply the EM shielding layer (like silver or graphene) to the fabric. On top of that, we can add the self-cleaning layer (like TiO_2). Lastly, we coat the fabric with aroma capsules. This makes sure that each function works without affecting the others. Some materials, like graphene mixed with TiO_2, can perform two or more functions at once, making the fabric lighter and more flexible.

It's important that these layers don't block air or make the fabric uncomfortable. So, we use breathable binders or apply the layers in ways that still let air pass through. This kind of smart fabric can be very useful for people who work outdoors, such as soldiers or repair workers, because it can stay clean, smell fresh, and protect them from harmful EM radiation. By using eco-friendly materials and combining different types of nanotechnology, we can create advanced fabrics that are safe, practical, and helpful in real life.

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