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Commentary

Bioinspired Nanomaterials for Surface Decontamination

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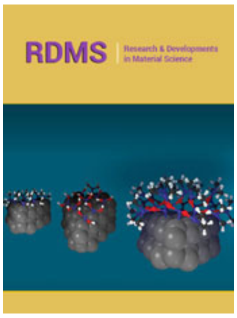

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Commentary

Nanomaterials (NMs) have been widely applied in multidisciplinary fields, mainly because of their versatile physicochemical properties. Greener, eco-friendly synthesized nanomaterials have several benefits, including safe applications, low environmental impact, cost- effectiveness, and versatile yet unchallenged fabrication. Given the potential environmental impact, biodegradable NMs, or NMs coated with biodegradable or natural, bio-driven materials, have recently received attention, particularly for their application in environmental remediation. There has been a significant concern regarding emerging contaminants (e.g., coronavirus, antibiotic-resistant bacteria, other emerging pathogens, and xenobiotic micro and nanoplastics), particularly those that have a strong affinity on the surface.

However, there is little information regarding the potential applications of biodegradable nanomaterials for surface decontamination. This article provides insights into the application of antimicrobial nanomaterials for decontaminating contaminants of concern that have high affinity on the surfaces of inert media and discusses scientific perspectives regarding the limitations of this approach.

Surface contaminants are those that attach onto inert media or metal surfaces, causing changes in the physicochemical properties of the contaminants or the longevity of surfaces through interactions of contaminants with coating materials of metal oxides or metals. Bioinspired nanomaterials are versatile in fabrication and their applications. For synthesis, they can be fabricated from organic particles (e.g., fullerenes, graphene, and carbon-based quantum dots) and inorganic particles (e.g., gold, silver, silica, iron, zinc, titanium, and some metal oxides) using biodegradable coatings or through bio reduction via various eco-friendly extracts (e.g., plant extract; banana peel extract; and biocomponents such as fungi, bacteria, and yeast) [1-4].

Some nanomaterials have revealed promising antiviral and antimicrobial applications [4]. For instance, antimicrobial nanomaterials (e.g., antimicrobial silver and gold; ZnO-encapsulated with an alginate biopolymer) have shown superior treatment of recalcitrant bacteria including antibiotic resistant bacteria (e.g., E. coli, S. aureus, P. aeruginosa, etc.) [5-7]. Similarly, gold NPs (AuNPs), synthesized through bioreduction of chloroauric acid using Mentha piperita (plant extract), displayed the highest antibacterial activity against Escherichia coli [8].

Bioinspired ZnO nanoflowers (NFs) synthesized with Wathiana coagulants extract exhibited superior antibacterial properties, especially against Gram-positive bacteria Staphylococcus aureus, in addition to other benefits (e.g., enhanced harvesting efficiency of algae for producing bioethanol) [9]. Interestingly, a study revealed that antiadenoviral activity was dependent on the nanoparticle coating types, leading to a 15% difference in antiadenoviral activity at the highest nanoparticle concentration and a 35% difference in antiadenoviral activity at the lowest nanoparticle concentration, with lower antiadenoviral activity from using A-type coating (synthesized from the soil-gel transformation process) than from using B-type coating (synthesized by a polycondensation process) [4]. The use of antiviral polymer coatings and biobased nano sensor enabled detection devices requires further research, especially in controlling and identifying infectious pathogens.

Contaminants on plastic surfaces are of significant concern as some of the contaminants (e.g., antibiotic resistant bacteria) become increasingly resistant to degradation and are potentially affected by the natural degradation of plastic particles. From this perspective, antimicrobial nanomaterials could be effective alternatives to any other treatment methods. Several bioinspired nanomaterials have revealed promising results regarding effective treatment of plastic polymers including polyethylene (PE), high-density PE (HDPE), and low-density PE (LDPE) [10]. For instance, gold nanoparticles extracted from combined hydrogen tetrachloroaurate (III) with a plant extract (aqueous leaf extract of Ananas comosus) exhibited photocatalytic degradation of LDPE films [10]. Similarly, palladium nanoparticles produced via a green synthesis method using the leaf extract of Ananas comosus [11] revealed photo-induced degradation of LDPE, with a treatment efficacy of 40% in solar light.

Despite their superior performance and proven benefits, bioinspired nanomaterials contain several limitations. These limitations are discussed below, adopting scientific perspectives toward resolving such issues and making suggestions for further research.

A. Reusability: One of the most significant hurdles to be addressed regarding the applications of nanomaterials is the deterioration of nanomaterial effectiveness over time. Given the limited capacity in dealing with increasing antibiotic resistance over time, it is essential to investigate the longevity of nanomaterials for their continued reuse. One recent study exhibited the reuse of nanomaterials up to five times without any decrease in photocatalytic degradation efficiency of LDPE films [10]. Nonetheless, applications of nanomaterials including bioinspired nanomaterials have a limited capability for treating and detecting trace levels of residual contaminants. From the perspective of sustainability, such an issue is challenging considering the accumulation of residual contaminants. Other challenging issues of nanomaterials and their modified forms include the safe disposal of degradation byproducts and their utilization in a sustainable way.

B. Antimicrobial nanomaterials on plastic surfaces: While there has been extensive research on the applications of nanomaterials for addressing contaminants, relatively few studies have explored the use of bioinspired antimicrobial nanomaterials for surface decontamination despite the role of plastics as a vector for carrying surface contaminants. It is worth exploring antimicrobial bionanomaterials for surface contaminants on plastics, especially with photo-assisted degradation in different environmental media (e.g., freshwater, marine water, soil, etc.).

C. Bioinspired nanohybrids for surface decontamination: Recent studies have demonstrated the promising antimicrobial properties of nanohybrids (e.g., ZnO-GO, TiO_2-GO, ZnO-CNT, and TiO2-CNT) on Escherichia coli (DH5α, a multidrug-resistant coliform bacterium) [12]. Given the superior efficacy of nanohybrids regarding antimicrobial degradation, more research focused on bioinspired nanohybrids is needed to examine the transformation of recalcitrant surface contaminants, along with degradation mechanisms and application feasibility.

D. Bioinspired nanomaterial application for the upcycling of plastic waste: Biodegradable plastics are being widely investigated for their applications in replacement with chemical plastics. However, bioplastic applications contain numerous disadvantages, including poor properties (e.g., poor thermal and mechanical qualities). One way to overcome such drawbacks is to explore biodriven nanoparticles incorporating plastic polymers for better plastic degradation efficiency and cost effectiveness, along with the potential application of bioinspired nanomaterials for the valorization of plastic waste.

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