Small Materials, Big Problems: Using Nanotechnology to Detect Chemical Hazards

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Abstract

The detection of chemical contaminants in environmental and food samples remains a significant analytical challenge, particularly where rapid, sensitive and reliable screening is required. Advances in nanotechnology have enabled the development of innovative sensing platforms that exploit the unique optical and physicochemical properties of nanomaterials to improve analytical performance. In particular, plasmonic nanomaterials and surface-enhanced Raman spectroscopy (SERS) offer considerable potential for detecting trace contaminants while reducing reliance on conventional laboratory-based analytical techniques. The development of novel gold-based nanostructures has demonstrated the potential of engineered plasmonic materials for highly sensitive mercury detection in water, establishing a foundation for their application to a broader range of chemical hazards. Building on these advances, the integration of nanomaterial-enabled SERS with portable Raman spectroscopy has enabled progress towards rapid, on-site screening of pesticide residues in food, addressing important challenges associated with analytical sensitivity, portability and practical deployment. Further applications in mycotoxin detection have demonstrated the versatility of spectroscopic approaches, including SERS, combined with chemometric and machine-learning techniques for the detection and discrimination of contaminants in complex food matrices. Collectively, these developments highlight the potential of nanotechnology-enabled sensing to address diverse analytical challenges across environmental monitoring and food safety. Continued advances in nanomaterial engineering, synthetic biology and data-driven analysis offer opportunities to develop the next generation of intelligent, adaptable and deployable sensing technologies for chemical hazard detection.