ACS AGRICULTURAL SCIENCE & TECHNOLOGY

pubs.acs.org/acsagscitech

Editorial

Pioneering Nano-Enabled Solutions for Sustainable Food and Agriculture

Cite This: https://doi.org/10.1021/acsagscitech.5c00333

Read Online

ACCESS | Metrics & More | Article Recommendations

Nanotechnology is revolutionizing the way we approach food safety, crop protection, and agricultural sustainability. As global challenges such as food security, environmental stresses, and agricultural efficiency demand innovative solutions, nano-enabled technologies have emerged as powerful tools to address these pressing issues. This joint special issue, "Emerging Nano-Enabled Technologies for Sustainable Food and Agriculture", being published across *Journal of Agricultural and Food Chemistry*, *ACS Agricultural Science & Technology*, and *ACS Food Science & Technology*, aims to highlight nanotechnology's latest advancements and applications in sustainable food and agriculture, fostering interdisciplinary collaboration and accelerating the adoption of these cutting-edge innovations. The contributions in this issue span a diverse range of applications, highlighting how nanotechnology is redefining the agricultural and food sciences.

Among several notable contributions in this special issue, one highlight is the development of a CRISPR/Cas12a-based biosensor with fluorescence locking mechanisms for detecting *Salmonella typhimurium* (https://pubs.acs.org/doi/10.1021/acs.jafc.4c07681). This biosensor enhances pathogen detection sensitivity, offering a robust solution for food safety. Similarly, the use of a nanozyme−enzyme cascade reaction in a ratiometric fluorescence immunosensing platform significantly improves the detection of ractopamine, an illegal growth promoter in livestock, ensuring meat safety (https://pubs.acs.org/doi/10.1021/acs.jafc.4c08869). Another noteworthy study employs real-time, *in situ* surface-enhanced Raman spectroscopy (SERS) to track the penetration and uptake behavior of nanopesticides in tea plants (https://pubs.acs.org/doi/10.1021/acs.jafc.4c07914). These findings provide crucial insights for optimizing pesticide formulations to enhance efficacy while minimizing environmental concerns. In the field of food safety and environmental monitoring, SERS has been explored for nitrite detection, a crucial factor in food and water quality control (https://pubs.acs.org/doi/10.1021/acs.jafc.4c09391).

Advancements in metal−organic frameworks (MOFs) are also highlighted in this collection. A novel fluorescent enzym-linked immunosorbent assay utilizing MOFs demonstrates improved enzymatic stability for the detection of zearalenone, a toxic fungal metabolite found in maize (https://pubs.acs.org/doi/10.1021/acs.jafc.4c07146). The use of DNA nanowalker-assisted solid-phase microextraction further enhances the sensitivity of chloramphenicol residue analysis in animal-derived food products, ensuring compliance with stringent food safety regulations (https://pubs.acs.org/doi/10.1021/acs.jafc.4c07497). Additionally, research on nanosilica priming in *Brassica napus* (rapeseed) reveals how this treatment enhances plant tolerance to cadmium and arsenic stresses by regulating cellular metabolism and antioxidant defenses, offering a potential solution for agriculture in contaminated soils (https://pubs.acs.org/doi/10.1021/acs.jafc.4c08246).

Seed coating technologies have also seen remarkable progress. A study comparing layered double hydroxide-based micronutrient seed coatings with traditional soluble coatings finds that the former improves nutrient delivery while reducing toxicity risks, providing an efficient alternative for sustainable agriculture (https://pubs.acs.org/doi/10.1021/acs.jafc.4c08911). Additionally, developing a polymer-based nanocarrier for glyphosate aims to enhance herbicide efficiency while mitigating environmental contamination (https://pubs.acs.org/doi/10.1021/acs.jafc.4c08328). Meanwhile, a novel nanoformulation of fluxapyroxad fungicide has been developed for improved plant uptake, effectively controlling *Verticillium* wilt in potatoes while minimizing chemical waste (https://pubs.acs.org/doi/10.1021/acs.jafc.4c12450).

Sustainable fertilization strategies are another critical focus, as demonstrated by research on the release of phosphorus from nanohydroxyapatite derived from biowaste in the presence of phosphate-solubilizing bacteria (https://pubs.acs.org/doi/10.1021/acs.jafc.4c09325). This soil column experiment underscores the potential of nanobased fertilizers in sustainable agriculture. Likewise, studies on emerging iCVD nanocoatings highlight their applications in food preservation and packaging, offering new possibilities for extending shelf life (https://pubs.acs.org/doi/10.1021/acs.jafc.5c01820). Encapsulation technologies are also prominently featured in this collection. The controlled release of hexanal through multilayer electrospun nanofibers has been shown to extend the postharvest shelf life of mangoes, reducing food waste and preserving fruit quality (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00383). Additionally, nanosensors for detecting volatile compounds provide an innovative approach to pest management, promoting sustainable agricultural practices (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00531).

Received: April 27, 2025
Accepted: May 13, 2025

Precision agriculture benefits from the development of a valinomycin-decorated reduced graphene oxide-based potassium sensor, enabling real-time soil nutrient analysis (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00406). Furthermore, research on nanocellulose particles derived from agricultural waste demonstrates their potential to produce biodegradable takeaway food bowls, offering an eco-friendly alternative to plastic packaging (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00425). Another study enhances chitosan nanofilm with agricultural waste fillers to improve the mechanical properties of biodegradable food packaging (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00398). Advances in nanobased weed control strategies are also explored, with the encapsulation of thyme essential oil in silica nanoparticles enhancing its herbicidal properties (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00580). Similarly, the formulation of copper nanoparticles into an oil dispersion has shown promising results in combating bacterial blight in rice while minimizing environmental toxicity (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00643). Comparative studies on selenium nanoparticles (SeNPs) versus traditional selenite fertilizers for rice biofortification highlight the advantages of nanoparticle-based approaches in improving nutrient uptake (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00613).

Concerns regarding nanoparticle accumulation in the food chain are addressed in a study evaluating the ionomic profile alterations and silver accumulation in pigs fed silver nanoparticles, raising important questions about potential human exposure risks (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00624). Meanwhile, the development of a Janus mesoporous silica nanopesticide delivery system demonstrates enhanced foliar deposition and sustained-release behavior, improving pesticide utilization efficiency (https://pubs.acs.org/doi/10.1021/acsagscitech.4c00670).

Innovative utilization of nanotechnology in food science includes the use of Pickering emulsions in catalytic food processing to improve reaction efficiency while maintaining food safety (https://pubs.acs.org/doi/10.1021/acsfoodscitech.4c00839) and exploration of the potential hydroxyapatite-based fortifying agent in candy derived from chicken eggshell as a sustainable source of calcium while promoting waste valorization (https://pubs.acs.org/doi/10.1021/acsfoodscitech.4c00699). In addition, a novel cactus-like nickel oxide nanostructure-based parts per billion level trimethylamine gas sensor has been developed to effectively monitor the freshness of saltwater fish (https://pubs.acs.org/doi/10.1021/acsfoodscitech.4c00817). It is worth noting that nanotechnology-driven food packaging solutions have been addressed through the development of a UV-protective polymer with natural enhancements and nano-enhancements as a replacement for nondegradable plastics in the packaging industry to increase the shelf life of stored food products (https://pubs.acs.org/doi/10.1021/acsfoodscitech.4c00672). However, concerns regarding the migration of nanoparticles from packaging materials to food have been examined in a study in which silver migration from plastic packaging containing silver nanoparticles to solid foods was observed for all food types and indicated the need for further safety assessments (https://pubs.acs.org/doi/10.1021/acsfoodscitech.4c00813). A comprehensive review regarding nanobubbles as the next potential drive to advance technologies in the food industry covers the preparation methods, fundamental properties of nanobubbles, and their potential applications in the food industry (https://pubs.acs.org/doi/10.1021/acsfoodscitech.4c00810). Finally, a discussion of nanozymes as a sustainable alternative to traditional enzymes for food quality control demonstrated their potential for rapid and cost-effective food safety testing (https://pubs.acs.org/doi/10.1021/acsfoodscitech.4c01040).

These studies highlight nanotechnology's transformative potential in food safety, sustainable agriculture, and environmental management. By advancing detection methodologies, optimizing nutrient delivery, and developing eco-friendly alternatives, these research efforts contribute to a future in which agricultural and food systems are both highly efficient and environmentally sustainable.

The contributions also demonstrate scientific ingenuity and a commitment to environmentally responsible innovation by integrating advanced nanomaterials, intelligent delivery systems, precision diagnostics, and biodegradable platforms. From enhanced crop protection to safer food packaging and nutrient management, this collection underscores the versatility of nanotechnology in addressing complex agri-food challenges. The insights presented are poised to catalyze further research and interdisciplinary collaboration, supporting a new era of sustainable agricultural transformation.

The editors hope this special issue will serve as a stepping stone for further research and discussion on these cutting-edge topics. By bringing together experts in nanotechnology, food science, and agricultural innovation, we aim to inspire new ideas, collaborations, and technological breakthroughs that will shape the future of sustainable food and agriculture. We express our deepest appreciation to the authors who contributed their exceptional research, the reviewers who ensured the quality of these studies, and the scientific community that continues to drive innovation in this field. We hope this special issue serves as both a reference and an inspiration for future advancements in nano-enabled food and agricultural technologies.

Ramesh Raliya orcid.org/0000-0002-9534-4943
Leonardo Fernandes Fraceto orcid.org/0000-0002-2827-2038
Laura McConnell orcid.org/0000-0001-6142-0656
Qing X. Li
Yixiang Xu orcid.org/0000-0003-3122-6101

AUTHOR INFORMATION

Complete contact information is available at: https://pubs.acs.org/10.1021/acsagscitech.5c00333

Notes

Views expressed in this editorial are those of the authors and not necessarily the views of the ACS.

https://doi.org/10.1021/acsagscitech.5c00333
ACS Agric. Sci. Technol. XXXX, XXX, XXX−XXX