NANOTECHNOLOGY AT ITS PEAK: flexibility and efficacy of nanosensors in food safety

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1. INTRODUCTION

Food spoilage concerns from ethical, social, economic, and environmental points of view because of its direct link to food insecurity. At every stage of the value chain, food products are subject to spoilage due to the loss of freshness resulting from contamination caused by flaws in the traceability or adulteration events. The existing quality controls and detection methods are time-consuming, and need a significant amount of sample concentration, expertise, and expense. Nanotechnology, particularly nanosensors, could be a game-changer in identifying food contaminants such as **pathogens, allergens, or pesticides.** Nanosensors are a promising tool for food quality assessment, as they are selective, sensitive, and reliable devices capable of real-time monitoring.

Nevertheless, we must consider the uncertainties surrounding nanotechnology, including the unawareness of nanomaterials and their toxicity. Also, consumers' perspectives, the feasibility of implementation, and cost-effectiveness must be considered for the future applications of these devices. Yet, intensive evaluation and validation by regulatory organizations responsible for food safety control and monitoring are crucial for their continuous development and implementation. **This poster focuses on the most current research on the potential advantages of this cutting-edge technology of applying nanosensors to detect biological and chemical contaminants in food samples.**

2. ASSESSMENT OF BIOLOGICAL TARGET MOLECULES

2.1. Nanosensors against foodborne pathogens

The major cause of food infections/intoxications is attributed **to the presence of pathogenic bacteria in food.** In addition, many of these pathogens are transmissible to humans through direct contact with food and water. The methodology for detecting pathogenic bacteria in food usually involves the collection of significant amounts of samples, separation of the bacteria, and subsequent detection. Food samples are complex and sometimes have very small bacterial loads. Therefore, specific separation and efficient concentration of bacteria is one of the main targets in the development of sensitive and selective sensing devices.

Nanosensors based on metallic, biofunctionalized, composite NMs have shown considerable potential for improving the above-mentioned sensitivity and selectivity through tailored signal amplification. **Nanosensors would allow the identification of a whole bacterial cell or DNA after interaction between the bacteria and the recognition element.** Examples of pathogen detection are shown in **Figure 1.**

1A. General scheme version illustrating the SERS multiplex pathogen detection assay in milk samples

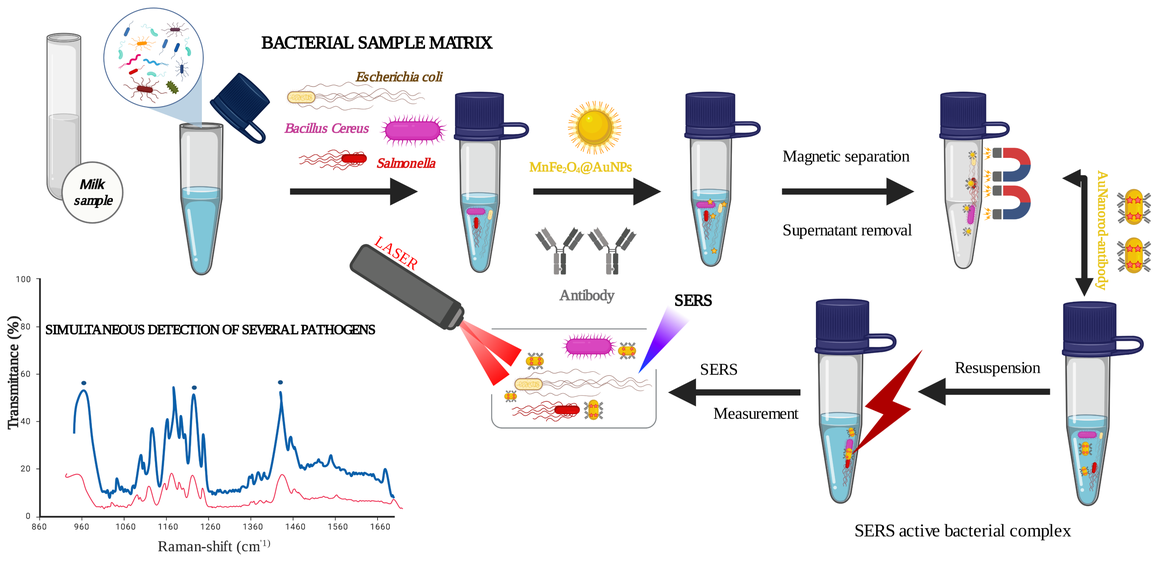

Figure 1A. A method for multiplex detection of food bacteria by SERS based on a nanosensor modified with MnFe2O4@A.

1B. Schematic description of a fluorescent nanosensor for pathogen screening based on AuNPs for food samples

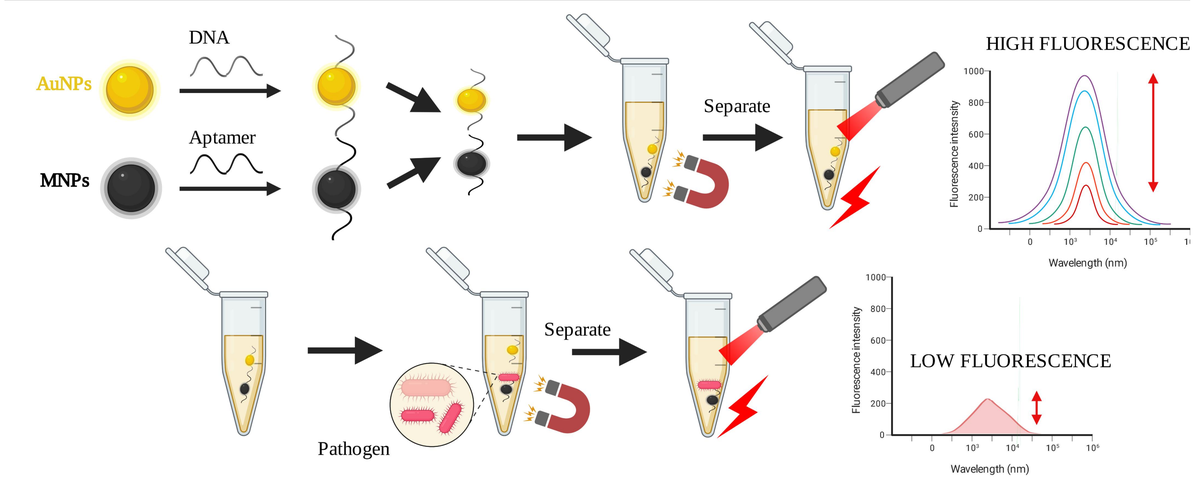

Figure 1B. Representative generic illustration of a fluorescence nanosensor for the screening of pathogens in food samples.

2.2. Nanosensors against foodborne allergens

Food allergies are an immunological reaction mechanism mediated by immunoglobulin E (IgE) and non-immunoglobulin E (non-IgE) after exposure to a certain food. Hypersensitivities are largely caused by protein allergens belonging to eight major foods: egg (ovomucoid, ovalbumin, ovotransferrin and lysozyme in egg white and α-livetin and vitellogenin-1 precursor in yolk), cow milk (α-lactoalbumin, β-lactoglobulin, immunoglobulin and caseins (αs1, αs2, β and κ)), wheat (gluten (glutenins and gliadins), globulin and albumin), nuts (arachin (Ara) h1 to Ara h13)), crustacean, shellfish and fish (arginine kinase, calcium binding protein, light chain myosin, sarcoplasmic triose phosphate isomerase, tropomyosin and troponin), and soybean.

Table 1. Recent studies on the application of nanosensors for detection of biological molecules in foodstuff.

S	Target	NMs	Method	Food matrix	DT (min)	LOD (cfu mL^{-1})	Lineal range (cfu mL^{-1})	Sensing	Ref.
				Allergens					
N	Ara (h1)	Nanosheet	BPNSs	Cookie	20	21.6[B]	50 – 1000[A]	Electrochemical (CV/DPV)	(H. Jiang et al., 2021)
BN	TM	MNPs	Label free – MNPs – Ap	Shellfish.	40	77[B]	0.4 – 5[C]	Fluorescence (Op)	(Youxiong Zhang et al., 2018)
BN	TM	AuNPs	TMBA – AuNPs	Shrimp	-	70[D]	10 – 200[D]	Colorimetric (Op)	(Pavase et al., 2021)

***Abbreviations*:** S: sensor; N: nanosensor; BN: bionanosensor; DT: detection time; NMs: nanomaterials; LOD: detection limit; MNPs: magnetic nanoparticles; Ap: aptamer; AuNPs: gold nanoparticle; Ara: *Arachis hypogaea*; TM: tropomyosin; TMBA: tropomyosin-binding aptamer; BPNSs: Black phosphorus nanosheets. * Dose expressed in: [A]pg/mL; [B]ng/mL; [C]µg/ml; [D]nmol/L.

Biosensors are a recently employed alternative for food allergen detection because they take advantage of the high specificity of various biological binding reactions such as antigen-antibody, enzyme-substrate, receptor-ligand, and other physical/chemical reactions in combination with a wide range of transducers. As shown in **Table 1**, Pavase et al., 2021, developed a label-free 275 colorimetric aptamer-nanosensor based on AuNPs for the detection of the shrimp allergenic protein TM in water samples obtaining a linear range of 10-200 nmol L^{-1} and a low LOD= 40 nmol L^{-1}. The assay was also carried out on shrimp, tofu, and eggs, with a LOD of 70, 90 and 80 nmol L^{-1}, respectively.

Despite the establishment of **mandatory food labeling laws**, which consumers consciously use to identify allergens, at times mislabeling, mix-up of ingredients in the supply chain, adulteration or hidden allergens caused **by cross-contamination in shared production equipment can trigger severe allergic reactions.**

Contamination, taste, and adulteration in food are indistinguishable from consumers. **Fast, reliable detection** of characteristic compounds in food products is essential to assess the quality and ensure **safety**

3. ASSESSMENT OF CHEMICAL TARGET MOLECULES

2.1. Nanosensors against pesticides in food matrices

The use of pesticides on crops has exceptionally increased the production and accessibility of nutrient-rich foods. At the same time, this aspect has led to excessive use of these substances that have determining drawbacks such as toxicity, they are not biodegradable, and they contaminate crops by releasing their residues into the environment, which are then consumed by soil and water mass spectroscopy in that they have a large surface area/volume relation, carry mainly more antibodies/enzymes (high sensitivity interface), have lower recognition limits, exceptional selectivity with small size and quick response. Nanosensors in pesticide detection have assets over other techniques such as gas/liquid chromatography and mass spectroscopy in that they have a **large surface area/volume relation**, carry mainly more antibodies/enzymes (high sensitivity interface), have lower recognition limits, exceptional selectivity with small size and quick response.

The use **of NMs enhances the indication or signals from the sensitive transducer.** **Table 2** provides a comparative overview of the various techniques for the nanosensing of pesticides in food samples. One of these experiments is schematized in **Figure 2** as an example of the procedure of pesticide detection using nanosensors.

3. Electrochemical determination of the pesticide physostigmine in juice samples using a Cu- SWCNT-Pc 3D/GCE nanosensor

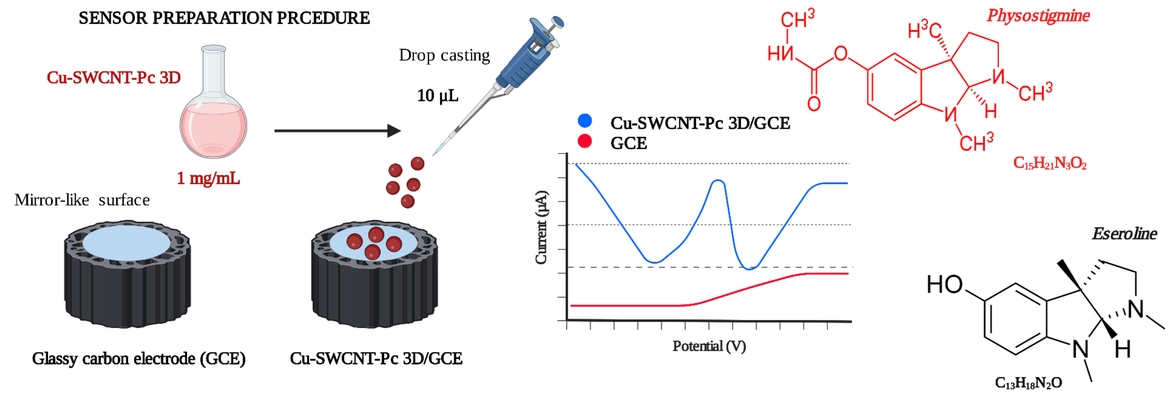

Figure 3. Schematic illustration of organophosphate pesticide detection by an electrochemical nanosensor in juice samples.

Fluorescent nanosensors have aroused great interest in pesticide detection due to their accuracy and sensitivity compared to other methods. As it can be ibserved in **Table 2**, Fu et al., 2022, developed an on-off-on fluorescent signal nanosensor based on AuNPs and biomass-derived nitrogen-doped carbon NPs (N-CDs) for accurate qualification and quantification of dithiocarbamate; thiram. The result obtained showed high selectivity as well as excellent sensitivity with an ultra-low LOD= 4.7 ng mL^{-1} and wide detection range of 10-200 ng mL^{-1}.

Table 2. Recent studies on the application of nanosensors for detection of chemical molecules in food matrix.

S	Target	Type	Food matrix	LOD (cfu kg^{-1})	NMs	Method	Lineal range (M)	Sensing	Ref.
				Pesticides					
N	Difenoconazole ($C_{19}H_{17}Cl_2N_3O_3$)	DMI	Grapes	48	Au@Ag NPS	Core – shell – Au@AgNAs	1×10^{-4} – 5×10^{-9}	SERS (Op)	(K. Wang, Sun, Pu, & Wei, 2019)
N	Methyl parathion ($C_8H_{10}NO_5PS$)	OPPs	Orange and cherry juice	1.78[D]	CNT	GCE – SWCNT – SubPc – Pc	2.5 and 3.75×10^{-8}[C]	Electrochemical (DPV)	(Köksoy, Akyüz, Şenocak, Durmuş, & Demirbaş, 2021)
N	Thiram ($C_6H_{12}N_2S_4$)	DHC	Orange peel	4.7[B]	AuNPs	N-CDs – AuNps	10 – 200[A]	Fluorescence (Op)	(Lizhu Fu et al., 2022)
BN	Atrazine ($C_8H_{14}ClN_5$)	OCP	Vegetables	1.00[B]	QDs	ZnS/QDs/DMSNs/peptide	0.007 – 0.24[B]	Fluorescence (Op)	(S. Li et al., 2022)
N	Carbofuran ($C_{12}H_{15}NO_3$)	CBM	Grain samples	4.9×10^{-8}[F]	CB	CB – SPE	1×10^{-7} – 1×10^{-4}[D]	Electrochemical (DPV)	(Della Pelle et al., 2018)

Abbreviations: S:sensor; NMs: nanomaterials; LOD: detection limit; OCP: organochlorine; DHC: dithiocarbamate; Op: optical; SERS: surface-enhanced Raman scattering; ; DMI: demethylation inhibidor; GCE: glassy carbon electrode; OPPs: organophosphophate; SWCNT-SubPc-Pc: novel hybrid carbon nano-material; DPV: differential pulse voltammetry; AuNP: gold nanoparticle; N-CDs: Nitrogen-doped carbon nanoparticles; Thiram: tetramethylthiuram disulfide; Mn-doped ZnS/QDs: glutathione-doped bimetallic quantum dots; DMSNs; QDs: quantum dots; CBM: carbamate; CB: nano carbon black; SPE: screen printed sensor. *Dose expressed in:; [A]ng/mL; [B]µg/mL; [C]nM; [D]mol/L.

4. CONCLUSION AND FUTUR PERSPECTIVES

- Nanosensors help to provide a convenient**, high-speed, and ultra-sensitive evaluation of food products.**
- Features such as **sensitivity or selectivity**, as well as the range of available NMs are some of the properties that make this technology stand out from more traditional ones.
- Different classes of nanosensors share **a basic workflow** and are applied to the efficient detection of analytes.
- The main challenge associated with nanosensors in food is **determining their limitations.** As well as the lack of knowledge and mistrust of stakeholders.
- To mitigate the potential long-term risk and associated hurdles, **ongoing research is the most critical aspect** of relying on a field that has proven successful against food spoilage.