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Applications of Noble Nanomaterials in Ensuring Food Safety: A Review of Recent Developments

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ABSTRACT

Compounds derived from natural sources, as well as industrial and agricultural waste, are examples of food contaminants. Food contaminants found naturally are mostly of microbiological origin, including pathogenic organisms and some other fungal and bacterial toxins. Food is among the most significant priorities for public security because it is one of the most basic components of living organisms. As a result, precautions are needed to make sure that foods are exempt from contaminants that enter the food supply via food handling, manufacturing, and dispersion. At the moment, people are increasingly concerned with the accuracy, convenience, and efficiency of food quality and safety testing. On the other hand, many traditional detection methods have drawbacks such as inconvenient operation, interference factors, and long detection times. Nanomaterials can also be used to monitor the lifespan of preserved foods. These can be developed to fluoresce when exposed to food pathogens, chemicals, or contaminants, acting as a sensor for detecting small traces of contaminants. As a result, functionalized nanomaterials with higher selectivity and sensitivity, such as pesticides, veterinary drugs, heavy metals, additives, and synthetic pigments, pathogenic bacteria, and mycotoxins, are widely used in food detection. This paper looks into how noble nanomaterials that can be placed precisely can be used to check the quality and safety of food.

Keywords: *Food Contaminant; Pathogens; Noble Nanomaterial; Food Safety*

INTRODUCTION

Numerous nanoparticles exist, including metallic NPs, polymeric NPs, and magnetic NPs. NPs can also have multiple functionalities, including hydrophobicity or hydrophilicity, and that has a significant impact on their implementations. Noble metal NPs (NMNPS) have a high multifunctionality due to their physical–chemical properties (Fratoddi *et al.*, 2018). Nanoparticles of noble metals, such as AgNPs, AuNPs, and PtNPs, have a high level of stability, are simple to synthesise, and can have their surface functionalization tuned (Neuschmelting *et al.*, 2018). NPs have two significant applications in food control: assessing toxic compounds (like mycotoxins, pesticides, and so on) and biologically active compounds (nutrients, antioxidant substances, proteins, etc.).

Recently, the application of noble metal nanoparticles as a substitute for traditional methods of assessment was proposed. NPs might be able to improve analytical precision, high accuracy, detection limits, and sample size, which would make a wider range of food applications possible.

Contaminants are biological or chemical components that are not deliberately added to food and could be noticeable as a result of different phases of production, manufacturing, or shipping. They are also capable of causing environmental pollution. Synthetic pollutants and xenobiotics that enter the environment, water and land can contaminate food. This, however, at low concentrations, has negative consequences for living creatures (Chen *et al.*, 2018). Food safety legislation has emerged as a top priority to impose strict control on the production of food, manufacturing, stockpiling, and xenobiotic tolerance to avoid the onset of toxic chemicals.

Traditional methods, for example, spectrophotometric or chromatographic methods, are typically used to determine such species as food sources. As food manufacture and supply become more globalised, food pollution poses a number of threats from both natural and human activities (Akrami-Mohajeri *et al.*, 2018). This includes biological and chemical pollutants, drugs, external hazards, and microbial organisms. Foodborne organisms have emerged as a leading issue within the food industry. In spite of the progress in advanced analytics and the implementation of food laws, the prevalence of foodborne illnesses has not decreased.

Food nano packaging, nano sensing, nanostructured food ingredients, and nutrient delivery are just a few of the applications for nanomaterials in food manufacturing, as well as in nutritional science. Uncertainties and health issues, however, are emerging as a result of their probable cytotoxicity and hazards to the environment and health. Even successful nanotechnology applications in food are still rare. To overcome this barrier, novel nanomaterials with high effectiveness and security must be developed.

There has already been significant progress in nanotechnology in current years, including the creation of specifically designed nanostructures for analytical techniques. For food safety control, the viability of employing a wide range of inorganic nanomaterials like silver, gold, and Pt was investigated (Lukman *et al.*, 2018). A few of the most significant advancements with this field in recent years are described and analyzed in this review. The goal is to concentrate on effective applications of noble nanomaterials using modern techniques with a specific focus on detection of food additives and contaminants. Specifically, Au, Ag NPs delivering excellent results in order to detect food contaminants and pollutant is outlined here.

RESULTS AND DISCUSSION

Determination of Contaminants

Even after food handlers' endeavours, pathogen adaptation technologies enable foodborne pathogens to survive and thrive. Microbial contaminants seem to be the most commonly notified foodborne causative factors (Sugrue *et al.*, 2019). Innumerable foodborne epidemics have emphasized the threats of foodborne diseases, prompting the design and technology for execution of schemes (e.g., HACCP systems) to sharply and delicately identify biotoxins and food pathogens.

There are two types of food-borne biotoxins: intrinsic and extrinsic foodborne biotoxins. Bacterial endotoxins can be produced through epithelial autolysis, peripheral lysis, or cytolytic digestion. But bacterial exotoxins like mycotoxins, enterotoxins, and hemolysins are ejected from the interstitial spaces directly.

Mycotoxin Toxins generated by mould as well as other microscopic organisms that induce toxicity, both acute and chronic, are known as mycotoxins (trichothecenes, aflatoxins, fumonisins, and so on). Depending on the mode of activity, mycotoxins are categorized into four types: poisons that are cytotoxic, neurotoxins, and gastrointestinal allergens, and toxins that produce symptoms whenever ethyl alcohol is consumed (Ünüsan, 2019). Secondary metabolites of the genera Penicillium, Aspergillus, and Fusarium accumulate as mycotoxins, which are commonly observed in food.

Alternariol monomethyl ether (AME), a carcinogenic and mutagenic substance, is available in a diverse selection of fruits and vegetables, as well as cereals. In a recent article (Man *et al.*, 2018), a method for determining AME was developed. The colorimetric approach for immunosensor relies on AuNP aggregation and a monoclonal antibody was used to modify the properties that unify AME molecules in specimens competitively.

The use of gold nanorods with platinum coating (AuNR@Pt) for the quick and precise identification of staphylococcal enterotoxin B was observed. It was supported by immobilization of a toxin aptamer via a complementary DNA (cDNA) fragment. Ochratoxin A was detected using a hypersensitive surface-enhanced Raman scattering (SERS) aptasensor based on Au(core)@Au-Ag(shell) nanogapped nanostructures (Shao *et al.*, 2018). Different types of mycotoxin detection are summarised in the Table 1.

Table 1: Detection of Mycotoxin in Food stuffs.

Nanomaterial	**Food**	**Type of detection**	**Procedure**	**References**
AuNCs	Maize	AflatoxinB(1)	Fluorescence resonance energy transfer	(Khan *et al.*, 2019)
AuNRs	Maize	Aflatoxins and Zearalenones	Immunochromatographic assay	(Chen *et al.*, 2020a)
PtNPs		Zearalenone	Chronoamperometry	(Ji *et al.*, 2019)
AuNps		T-2 toxin	Chronoamperometry	(Zhong *et al.*, 2019)
AgNps	Redwine	Ochratoxin A	Electrochemical determination	(Zhang, Yang & Chen, 2019)
AuNps	Grapejuice	Ochratoxin A	Multicolor colorimetric detection	(Tian *et al.*, 2020)
AuNps	Maize	Deoxynivalenol	SERS	(Li *et al.*, 2019)
AgNPs	Red yeast rice	Citrinin	SPCC immunoassay	(Jiang *et al.*, 2020)

Carcinogenic Commponents

Carcinogenic compounds are indeed substances that have the potential to cause cancer in humans. A colorimetric method based on the aggregation of gold nanoparticles (AuNPs) by glutathione (GSH) was also created for detecting azodicarbonamide (ADA) in flour commodities. Melamine and nitrites are commonly found in food as a result of food preservation methods. Rajput (2018) recently established a melamine detection assay using AgNPs that is based on melamine's interaction with Ag^+ ions. A gold nanoparticle/poly (methylene blue) (GNP/PMB)-modified pencil graphite electrode (PGE) was used to detect nitrites. This methodology was employed on samples of mineral water and commercial sausage.

Table 2: Detection of carcinogenic compound in Food stuff

Nanomaterial	**Food**	**Type of detection**	**Procedure**	**References**
AgNps	Flour	Azodicarbanamide	UV–vis spectrometry	(Chen *et al.*, 2021)
Ag NPs	Apricot	Cyanide detection	Voltammetric and Amperometric techniques	(Zhang *et al.*, 2020)
AuNps	Milk	Melamine	SERS	(Sun *et al.*, 2021)
AuNps	Apple juice	Thiram	SERS	(Sun *et al.*, 2021)
AuNps	Milk	Melamine	Optical absorbance	(Siddiquee *et al.*, 2021)

Pesticide

Pesticide residues on vegetables and fruits are among the most serious consumer concerns about food safety. For detection of atrazine present in apple juice. Surface enhanced Raman spectroscopy (SERS) in conjunction with AuNPs and for difenoconazole present in grape nanoparticle aggregates of core-shell Au@Ag (Ma *et al.*, 2018) has been used to detect two pesticides. In this research, a potential use of AgNPs/GO (Graphene Oxide) for the detection of pesticides in food was explored in this research, with promising results by Ma *et al*., 2018.

Table 3: Detection of Pesticide in Food stuff

Nanomaterial	Food	Type of detection	Procedure	References
AgNps	Grapes Tomato	Chlorpyrifos	Surface-enhanced Raman scattering	(Subramaniam & Kesavan, 2022)
AuNps	Fruits and vegetable	Chlorpyrifos	Electrochemical Immuno - Sensing	(Talan *et al*., 2018)
AuNps	Apple skin	Thiram, Malathion, Acetamiprid, Phosmet	Surface enhanced Raman spectroscopy	(Kabashin, Dubowski, & Geohegan, 2019)

Allergens and Drugs

Veterinary drugs employed in livestock for food production may end up with some residues in commonly consumed animal products like milk, meat, honey and eggs. As a result, numerous AuNPs applications for detection in food samples have been discovered (Rath *et al.*, 2019). Unauthorized veterinary drug use is now a major issue. To regulate the illegal use of unfamiliar drugs and drug residue mixtures in farm animals, new detection methods like metabolomics have now been established. This method works by monitoring metabolite changes in body tissues. This intriguing paper discusses the prospect of enhancing the designed immunoassay's signal. The reaction boosted assay responsivity and resulted in a visible colour shift from bright red to deep purple which can be seen also with bare eyes. This immunoassay has the potential to be used for simple detection on-site detection in ensuring food safety.

Some techniques also have been devised for antibiotic detection that are being exploited in the animal husbandry and may be discovered as remnants in food derived from animals. These AuNP-based techniques were designed to detect aminoglycoside antibiotics (Yan, Lai, Du & Xiang, 2018) and ceftriaxone in foods derived from animals for example eggs, milk, and meat. A voltammetry biosensor comprised of a carbon electrode with AuNP-coating was developed. It was used in conjunction with a sandwich immunoassay to recognize Peanut allergens in food products.

Table 4: Detection of Allergens and Veterinary Drug residue

Nanomaterial	Food	Type of detection	Procedure	References
AuNp	Kidney beans,	Lectins	Voltammetric immunosensor	(Sun *et al*., 2019)
AuNP	Milk Shrimp	β-lactoglobulin Tropomyosin	Microfluidic paper-assisted analytical device (PAD)	(Tah *et al*., 2018)
AuNp	Shellfish	Tropomyosin	Surface plasmon resonance (SPR)	(Zhou *et al*., 2020)
AuNp	Fish	Parvalbumin	Enzyme-linked immunosorbent assay	(Wang *et al*., 2020)
AuNp	Soybean and Sesame	Gly m Bd 28K 2S albumin	Hybridization chain reaction	(Yuan *et al*., 2019)
AuNPs	Fish	Sulfadimethoxine	Fluorescence	(Chen *et al*., 2020b)

Bacteria

Certain bacteria must be absent from food for safe consumption since some strains of bacteria are harmful to human health. They are capable of causing diarrhoea, fever, typhoid, hemorrhagic colitis and haemolytic uraemic syndrome. Method based on AuNP used lateral flow immunoassay to detect bacteria like Salmonella and E. coli in milk and water (Lukman *et al.*, 2018).

Table 5: Detection of Pesticide in Food stuff

Nanomaterial	Food	Type of detection	Procedure	References
AgNps	-----	*Salmonella*	SERS	(Wei, Li & Zhao, 2018)
AgNCs	Milk	*Staphylococcal enterotoxin A*	Fluorescence aptasensor detection	(Zhang, Sun & Cao, 2020)
AuNPs	Milk	*Salmonella Enterica*	Colorimetric ELISA	(Gao *et al.*, 2019)
AuNPs	Orange juice	*Staphylococcus Aureus*	SERS	(Wang *et al.*, 2021)

Bioactive Compound

Gluten A protein complex Gluten is found in several cereals that are made up of glutenin and gliadin, two proteins. It is indeed the main protein responsible for allergic reactions, and the majority of applications of nanoparticles are dependent on it. Numerous immunosensors using modified AuNPs have recently been designed in order to measure gliadin in samples of foodstuffs (Manfredi *et al*., 2016). These are also entirely focused on the recognition of DNA.

Amino Acid In amperometric immunosensor monosodium glutamate (MSG) detection, the anti-glutamate antibody was encapsulated on the surface of the sensor, which was made with a carbon electrode decorated with gold nanoparticles and a nanocomposite of molybdenum disulfide/chitosan (Au@MoS_2/Ch). Li *et al*. used sensitive nanoprobes made of gold nanoparticles on graphene oxide to detect L-cysteine easily by the optical absorption method. A smartphone-based system was used in this method that performs analysis of multiple modes of hue-saturation-value and lightness, as well as red-green-blue (RGB), and cyan-magenta-yellow-black (CMYK) values (Li *et al.*, 2018).

Antioxidants Metabolic byproducts of several plants Antioxidants, widely present, particularly in vegetables, are also among the most essential natural compound groups. These have anticarcinogenic, antimicrobial, and antioxidant properties, which have been illustrated in vivo and in vitro experimental studies. Furthermore, their potential anti-cardiovascular and neurodegenerative consequences have recently been explored. Della Pelle *et al.* provided a colorimetric assay for phenolic compound identification. The said technique relies on the formation of gold nanoparticles by phenolic content found in endogenous fat. The intensity of phenolic compounds was associated with the formation of AuNP, which was governed by surface plasmon resonance (Della Pelle *et al.*, 2015). Functionalized AuNPs were also used to retrieve phenolic compounds derived from olive oil. This quick and sustainable method was improved by employing a response surface analysis and building a central composite design (CCD) of some parameters, among which was the amount of AuNPs or the time spent stirring NPs in oil. The agglomeration or morphological characteristics of AuNPs and AgNPs were also responsible for the development of antioxidant activity in beverages, including tea and lemon juice.

Table 6: Detection of Bioactive Compounds

Nanomaterial	Food	Type of detection	Procedure	References
AuNPs AgNPs	Lemon juice Tea	Flavonoids and polyalcohols.	Colorimetric sensor array	(Bordbar *et al.*, 2018)
Au@Ag nanobox	Green tea	Polyphenols	Localized surface plasmon resonance	(Wang *et al.*, 2018)
Ag NPs	Corn flour	Gliadin	Enzyme-linked immunosorbent assay	(Mercadal *et al.*, 2018)

CONCLUSION

Deeper insights exploration on material stability, physicochemical properties is indeed required in the coming years. Bulk manufacturing activities and growing quite automated techniques regarding application also to be realized. Greener and more ecofriendly materials should be designed and developed. Pollution from heavy metal ions in the eco system has become much pervasive as industry develops. Since these contaminants enter food sources, aquatic animals and plants, started to accrue in the food web, they have a negative impact on human health. As a result, detection of heavy metal is an essential aspect of food quality and safety sensing. Several agricultural productions are conveniently affected by various fungal pathogens resulting in food material adulterated with mycotoxins. The significance of mycotoxin is that it causes drastic physical problems also at trace levels. Analytical methods that are more responsive, sophisticated, productive, and cost-effective need to be developed in the future to ensure food safety, reliability, and greater transparency without jeopardising dietary, functional, or sensory properties in accordance with relevant legislation and customer expectations.

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