Int. J. Bio-Inorg. Hybr. Nanomater., 9(3): 149-177, Autumn 2020

Aptamer-based hybrid nanomaterials for food safety assay

N. Dorosti[1], *P. Gill*[1,2,4] *and A. Rafati*[*1,3,4]

[1] *Department of Medical Nanotechnology, Faculty of Advanced Technologies in Medicine,*
Mazandaran University of Medical Sciences, Sari, Iran
[2] *Immunogenetics Research Center, Mazandaran University of Medical Sciences, Sari, Iran*
[3] *Diabetes Research Center, Mazandaran University of Medical Sciences, Sari, Iran*
[4] *The Health of Plant and Livestock Products Research Center, Mazandaran University of*
Medical Sciences, Sari, Iran

Received: 7 June 2020; Accepted: 10 August 2020

ABSTRACT: Given the high prevalence of acute and chronic diseases caused by unhealthy food consumption, design and development of accurate and sensitive sensors for the detection of food contaminates is importance. The appearance of nanotechnology and nanomolecular detection mathods based on aptamer-conjugated nanoparticles has made it possible to identify the lowest concentration of risk factors in food at point. In this study we described an over review on the different types of nanostructures used in the design of detection biosensors in the field of food safety assay. Nanostructures and nanomaterials are the most important candidates for improving the sensitivity and LOD (Limit of Detection) properties of biosensors due to their unique characteristics such as high surface-to-volume ratio and physicochemical and optical properties. Nanomaterials with high surface-to-volume ratio will provide a large surface area for the loading of specific recognition element and will also have good molecular interaction with target molecules. Also, by using the optical and physicochemical properties of nanomaterials, these structures can amplify the optical and electrochemical signals generated in biosensors that result from the interaction between the target molecule and its specific recognition element. Given that the design and development of high-precision and sensitive diagnostic biosensors is crucial for identifying biomarkers, and various studies have shown that the use of nanostructures due to their structural and physical properties can play an important role in improving the biosensor properties.

Keywords: *Aptasensors, Food Safety, Hybrid Nanomaterials, Point of Care, Smartphone*

INTRODUCTION

Foodborne disease or food poisoning is caused by eating food that is contaminated with bacteria, toxins, viruses, antibiotics or parasites. These contaminations usually occur due to improper transportation, supply or storage of food. Foodborne illnesses can be caused by the presence of a pesticide or drug in the food or toxic substances such as fungi toxic [1]. The World Health Organization defines foodborne disease as: "Diseases that are infectious or poisonous and that enter the body through food. Everyone is exposed to such diseases. The World Health Organization (WHO) are estimates

---

(*) Corresponding Author - e-mail: Rafati.adele@gmail.com annually 600 million people fall in disease after eating contaminated food from diarrhea to cancer in worldwide. As well as, The Centers for Disease Control and Prevention (CDC) are estimated annual 128000 hospitalizations due to foodborne illness thet A quarter of that number leading to death [1]. More than 200 types of foodborne illnesses have been identified that threats the health of the community. The most common of these threatening agents include bacterial pathogens, fungi, viruses and parasites. Viral agents are very widespreade, but bacteria and fungi are most cause of death. The most common of these diseases is diarrhea, which can be very dangerous, especially in children [2, 3]. In the study by Farahi and coworkers, critical issue in water and food safety was divided into two broad categories of biological and chemical agents. Reviews on this show diversity of molecular species such as Campylobacter, Salmonella, Listeria monocytogenes, and Escherichia coli (E. coli O157: H7) were the most biologic contaminants in food in the United States. Water-borne pathogens also include Vibrio cholerae O139, enterohemorrhagic E. coli O157: H, chlorineresistant Cryptosporidiumare, and multi-drug-resistant Pseudomonas aeruginosa that are expanding daily driven by forces such as population growth, translocation, and socio-economic all over the worldwide [2]. Occasionally, an epidemic of infectious diseases can be caused by a common source of contaminated water and food, but sometimes but it can be a global bioterrorist factor too in a particular person or population. Unfortunately, in addition to the factors of bioterrorism [6] even financial profits have led to fraud [7] in the food industry that have made vital the need for regular and rapid on-site monitoring. Therefore, from the start of the production and processing process to the point of use, regular and rapid monitoring should be done with easy and high accessible and good cost effectiveness methods and accessories [4]. Traditional water and food analysis techniques include chromatography, spectroscopy, electrochemical, and Molecular techniques such as Polymerase Chain Reaction (PCR) and ELISA Enzyme-Linked Immuno-Assay (ELISA) that require expensive equipment and expert operators. Although the sensitivity, specificity, precision and accuracy of these devices are important that is also dependent on appropriate laboratory conditions for accurate results [5-7]. Due to importance of early detection of food contamination for prevent of foodborne illness epidemic, the need for designing simple and point of care diagnostic methods with quickly and accurately analysis of food has been a matter of great concern to food industry regulators. Now, Conventional analysis methods such as GC-MASS and HPLC for assessment of food in terms of the present of toxins, antibiotics and pathogens in food is very time-consuming and costly, while immunuassay are presented as accurate analytical methods, lowest cost and fastest diagnostics kit for assessing food quality and safety. Immunoassay as a new techniques by necessary and sufficient specificity and sensitivity, are used broadly in the food industry to the detection of natural compounds, antibiotics, pesticide residues and microorganisms. ELISA is an immunological technique involving an enzyme to detect the presence of an antibody or antigen in a sample. The advances in ELISA technology have led to the rapid development of a variety of commercial kits for use in the food industry. With all the specificity that the antibodies have in targeting the molecule, but due to the complex process and high cost of production and the detection function depend on the buffering conditions, antibodies based immunoassay has many challenges.

Today, aptamers have been used broadly as a candidate for antibody replacement in recognition element role with high sensitivity and specificity and low production cost. However, it has good chemical and thermal stability compared to antibodies and is extremely unsensitive to buffering and environmental conditions [8-10]. The design and fabrication of hybrid nanomaterials resulting from the nanoparticles and aptamers conjugation has become a technology in the design of nanobiosensors today. The use of nanomaterials in the design of nanobiosensors has been aimed at increasing the sensitivity and improving the detection limit in the sensors. Because nanostructures, due to their high surface-to-volume ratios as well as their specific physical and chemical properties, can play an important role in loading increasing of the recognition elements such as aptamers, creating and enhancing the detection signal.

One of the main commonalities among fast and accurate methods is the use of nanoparticles of various sizes and shapes. In biosensors, these nanoparticles must be functionalized by a specific recognition element and after identifying the target molecule, they will either produce light or change color and then detected by a detector either quantitatively or semi-quantitatively or qualitatively with any types of spectrophotometers [11]. With the advent of the electronics industry in the field of smart phone design and programming of any applications, this device can replace a variety of spectrometers that we can detect and measure with smartphones to quickly perform the necessary measurements at any location [11-13]. On the other hand, Smartphones are rapidly expanding their imaging and processing capabilities and optimum computing capabilities, which can be a good opportunity for regular and rapid monitoring of harmful factors in the food chain from production to consumption. The integration of these technologies can guarantee food and water safety [11].

Technology of Apta-sensors

The aptamer is derived from the Latin word "aptus", meaning appropriate, and the Greek suffix "mer" means unit or particle. Aptamers are single-stranded sequences of DNA or RNA with a specific three-dimensional structure less than 25 kDa that can bind to any target molecules from ions to proteins with high affinity and specificity. Because of their high specificity, aptamers can be used as recognition element in biosensor design. The small size, fast and inexpensive manufacturing process, low immunogenicity and high chemical and thermal stability make them attractive molecules in the design and manufacture of new specialized, rapid and inexpensive diagnostic and therapeutic sensors. Acid nucleic aptamers have been produced against various targets such as organic dyes, metal ions, drugs, amino acids, co-factors, nucleotides, peptides, a variety of proteins and cell surface receptors. Apart from all this, aptamers have also been produced against viruses, pathogenic bacteria and cancer cells [14]. Aptamers are typically divided into two classes of RNA and DNA and usually observed in three-dimensional spatial structure in the form of series hairpins, bulges, pseudoknots, bulge loop, and G-quartet, and G-quadruplexes formed by the hydrogen bond, Van Der Waals Force, hydrophobic interaction, and other molecular interactions [15-17]. The biosensor in which the aptamer plays the role of recognition element is called an aptosensor. Not only the high affinity and specificity but also the wide range of target molecule detection, laboratory synthesis and chemical stability are the main advantages of aptamers over other biosensors. Due to the high potential of aptamers in the design and production of specific biosensors in the field of pathogen identification and hazardous food Contaminants, in recent years various methods such as fluorescent, colorimetric, electrochemical, photo-electrochemical, electrochemical methods have been used [8].

Aptamers are identified and selected during a in vitro process named as SELEX (systematic evolution of ligands by exponential enrichment) [17]. The random library contains approximately 10^{15} sequences with a length of 20-220 nt. The aptamers can identified small target molecules that means enter target in the cave-like specific space, be interacted with it by noncovalent junctions such as hydrogen bonding, van der Waals and hydrophobic bonding with supermolecules. The aptamers easily modified and are suitable candidate for functionalization of all types of nanostructures for any applications. Also, the biophysical and chemical properties of the nucleic acid structure are known, and are tailored to suit a variety of web-based modeling and structure prediction applications that can determine the possible second structure of the aptamer in the face of its target molecule. The biochemical properties of nucleic acids have enabled them to play a special role in the analysis and detection of toxins and harmful substances [8, 18, 19]. Despite all of the advantages, laboratory process (SELEX) for selection and identification of aptamer aginst desired target is generally time consuming and costly [20].

Nowadays, many web-based applications are designed and programmed to predict and modelling the secondary structure of aptamers in the face of the target molecule such as RNAstructure (https://rna.urmc.rochester.edu/RNAstructure.html) and mfold (http://unafold.rna.albany.edu/?q=mfold). Until now, aptamer-biosensores (aptasensores) have been designed broadly against inorganic compounds, biotoxins, Pharmaceutical Residues (includes drugs, antibiotics, antiparasitics, steroidal hormones, and other residues), organic dyes, agonists, and micro-organisms. Aptam-

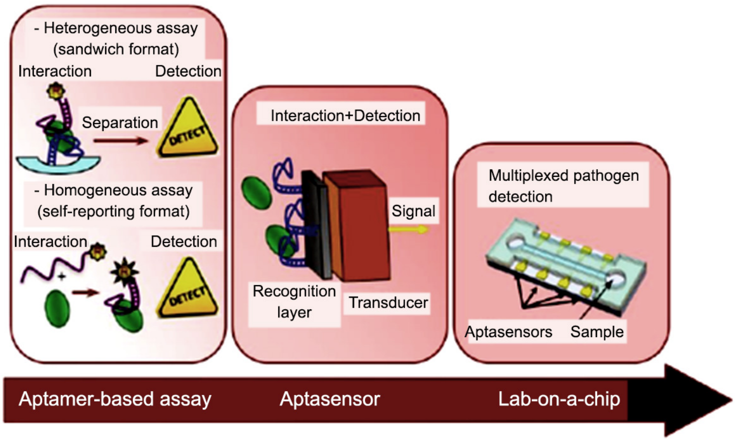

Fig. 1. Schematic overview of the different approaches for aptasensing according to their level of integration [23].

ers that have been designed against heavy metals such as potassium (K^+), lead (Pb^{2+}), mercury (Hg^{2+}), zinc (Zn^{2+}), nickel (Ni^{2+}), cadmium (Cd^{2+}) and arsenic (As^{3+}) have been used in the food industry. Biotoxins, including mycotoxins and exotoxins, can be extremely dangerous even at very low concentrations in foods. Including aflatoxin B_1(AFB_1), Ochratoxins (OTA), Fumonisins, Trichothecenes, Zeralenone (ZEA) which are often highly mutagenic and carcinogenic and must be monitored with great accuracy and regularly [17, 21]. For this reasons, it has attracted the remarkable attention of many scientists for research in this field for design and fabrication of aptasensores to intend for use in the food industry to detectin of food toxin which are reviewed below (Fig. 1). Ronald and his colleagues have succeeded in designing a tool that can detect and detoxify aflatoxin B using the aptamer nucleotide sequence of inactivating mycotoxins, transformants, and antioxidants [22]. In designing biosensors, aptamers are generally conjugated with nanostructured carriers to enhance diagnostic sensitivity.

Nanomaterials are conjugated to aptamers by electrostatic interaction, covalent and non-covalent bonds, and specific linkers such as streptavidin-biotin. Functionalization of nanomaterials with aptamer leads to the creation of hybrid nanomaterials can be used in design of nanobiosensors. This hybrid nanomaterial due to its high aspect ratio can be used as a platform for loading larger amounts of the identifier unit which will increase the sensitivity of the sensor. On the other hand, these hybrid nanomaterials play the role of transducer due to their optical and electrochemical properties, which will produce a stronger recognition signal [23-26].

Nanostructures based sensors for point of care detection (Hybrid Nanomaterials)

The remarkable properties of nanomaterials, such as unique shapes, high aspect ratio and size, physicochemical properties and catalytic activity, play an important role in improvement of biosensors function in detection and enhancement of signal generation. As a result, even the smallest amount of target molecule can be detected and the likelihood of a false response will be minimal [8]. Designing of biosensor based on hybrid nanomaterials to produce detectable signals has become a potential opportunity for improved food safety [26]. In this study, we divided hybrid nanomaterials based on aptamer-nanoparticle hybrid, into four general categories of metal nanoparticles, carbon based nanomaterials, polymeric nanomaterials, and biological nanomaterials and we explained the importance of their role in rapid and accurate identification of food risk factors.

Metal and metal oxide NPs

Metallic materials in three dimensions of length, width and thickness can be designed and manufactured on a nanoscale (1-100 nm) for diagnostic and therapeutic purposes. Metal nanoparticles are modified with functional groups for conjuction of them with aptamer/antibody so act as recognition elements to target identification and generate the detectable signal. The main reason for the popularity of metal nanoparticles is their uniformity and sharp distribution in nanometer size. Unique characteristics such as surface Plasmon resonance and optical properties of metal nanoparticles have been widely used in design and fabrication of diverce types of biosensors. Some metal nanoparticle, because of their free electrons, can resonate in the presence of light that this phenomena called Localized Surface Plasmon Resonance (LSPR) [27]. Gold (AuNP), Silver (AgNP), and Copper nanoparticles exhibit this phenomenon in Visible (vis) light, while Lead (pb), Indium (In), Mercury (Hg), Tin (Sn) and Cadmium (Cd) exhibit in the presence of ultraviolet (UV) wavelengths [28]. Silver has anti-bacterial and antiseptic properties. The unique properties of metals are due to the presence of free electrons in their capacitance layer and due to their cumulative state, the free electrons are increased at the metal surface which can dramatically increase the rate of chemical reaction affected by the reactant surface [27]. The physicochemical properties of noble metals largely rely on their size [29]. The presence of free electrons on the surface of the metals gives them good electrical conductivity. On the other hand, by decreasing the size of the particles, their aspect ratio increases, resulting in unique optical properties [25]. Such properties make it possible for these nanoparticles to act as aptamer coupling substrates that following the target's recognition by the aptamer, the surface properties of these nanoparticles changed, such as the optical and chemical properties and this binding lead to the detecting signal.

AuNPs (Gold nanoparticles)

Most nanotechnology-based measurement approaches use noble metal nanoparticles such as gold and silver [25]. Among the metallic nanoparticles, the spherical colloidal gold nanoparticles are 20 nm in red ruby colour while the same nanoparticles are 200 nm has bluish colour. Due to their unique properties, such as good biocompatibility, excellent conductivity, effective catalysis, high density and high aspect ratios, gold nanoparticles (AuNPs) are widely used in the field of quality and quantity sensing [10]. These nanoparticles are also one of the most stable metal nanoparticles and readily interact with biomolecules such as DNA and proteins by modified thiol and amine bands without disturbing the activity of the biomolecules [10].

Optical Biosensors –Based on GNP

Various nanomaterials including metal nanoparticles, quantum dots (QDs), graphene oxide (GO), carbon nanotubes (CNTs), polymers, carbon dots (CDs), and metal organic frameworks (MOFs) have been widely used in development of point-of-care (POC) devices such as optical biosensors for rapid and accurate detection of pathogenic contaminants (e.g., bacteria, fungi, viruses, and parasites) in water resources. These devices have special advantages such as portability, stability, easy-to-use, on-site detection, and shortened detection. Metal nanoparticles, especially gold NP because of their excellent plasmonic properties, can easily detect microbial agents in the naked eye [30]. The literature review on optical nanobiosensors can be divided into several general categories, including: Colorimetric sensors, Surface plasmon resonance (SPR) sensors, evanescent field or evanescent wave based fiberoptic biosensors, Long period grating (LPG) based biosensors, Raman spectroscopy- based biosensor such as SERS (Surface-enhanced Raman spectroscopy), Fluorescent and chemiluminescent biosensors [29].

Among the wide range of optical biosensors, colorimetric sensors have become more widely used and commercialized because they are portable, simple interpretation of results gives the user and is economically appropriate. Numerous studies have been performed the design gold nanoparticles based optical colorimetric sensors.

In this section, we have reviewed the properties and potential of gold nanoparticles in colorimetric based biosensors for food safety screening. The design of colorimetric biosensors is mainly based on several unique features of AuNP, including SPR behavior [31, 32]. These biosensors are very useful in measuring water and nutrient contaminants from heavy metals (Hg^{2+}, Pb^{2+}, Cu^{2+}, Co^{2+}, Pt^{2+}) [33] to bacterial and fungal toxins [mycotoxins such as AFB1, OTA and etc] [34] and even pesticide [35-37] and antibiotics [38, 39] residues [25, 29]. The role of gold nanoparticles in optical biosensors is usually defined as individual fluorescence quenchers, catalysts, immobilization platform and colorimetric agent, based on SPR and SERS

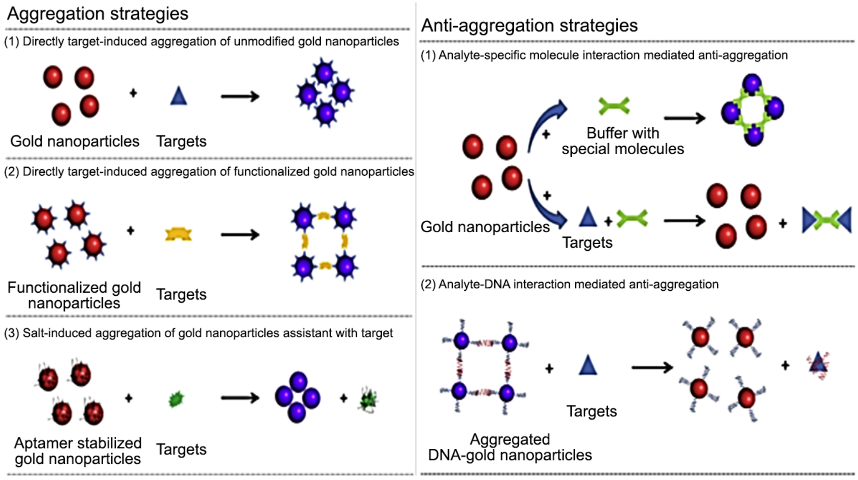

Fig. 2. Typical strategies of colorimetric detection mechanism with gold nanoparticles. (For interpretation of the references to color in this Figure legend, the reader is referred to the Web version of this article.) [25].

phenolmena that can increase the sensitivity of nanobiosensors [10]. Gold nanoparticles have strong optical properties and electrical conductivity that can be used in the design of biosensors based on colorimetric, surface plasmon resonance (SPR) and electrochemical signal generation [25]. Common strategies include gold nanoparticle colorimetric detection mechanism: aggregation (blue-shift) and anti-aggrigation [40]. Various colorimetric and electrochemical assays based on AuNPs have been reported for the identification of chemical contaminants such as alkali and alkali earth metal ions, heavy metal ions and for the evaluation of microbiological food contamination such as bacteria (Fig. 2) [41]. But two important points should be considered when gold nanoparticles based colorimetric biosensors are designing. First they are sensitive to food matrix, so preparation techniques should be used to reduce matrix interference and second, gold nanoparticles should be Modified by functional group to prevent of cross-linking or aggregation occure [32].

Non-Optical Biosensors

Because of the community's need for cheap and affordable biosensors, expensive instruments such as fluorescent spectrometers, SPR / SERS Instruments, although they are accurate enough to detection but they are very expensive and cpmplex for use in field. Recent advances in the use of gold nanoparticles in non-optical bioassays, including piezoelectric biosensor, electrochemical biosensor, and inductively coupled plasma mass spectrometry (ICP-MS) bio-detection have been seen in the literature indicating the scope of this area [10].

Piezoelectric Biosensor:

Gold nanoparticles with their high density properties are used in piezoelectric biosensors as a label for mass modifications and thus to increase diagnostic sensitivity. The most common of these biosensors are quartz crystal microbalances (QCM) which have been highly sensitive. When a mechanical force is applied to the quartz crystal, the crystal creates an electric potential in the direction of the applied force, and vice versa [10].

Electrochemical biosensor:

Gold nanoparticles play a role in electrochemical biosensors as immobilization platform, electrocatalyst or electron migration, which can increase the sensitivity, specificity and stability of the detection. By modifying the surface, increasing conductivity, enhancing conductivity, increasing the immobilization of biomolecules and catalyzing the electrochemical reactions were accoured [10, 42].

Inductively Coupled Plasma Mass Spectrometry (ICP-MS):

In this technology, high-temperature ionization properties combine inductive plasma with rapid and sensitive scanning mass spectrometry that is a highly sensitive method for elemental, isotopical and morphological analysis. This technique does not require the use of toxic reagents such as HCl and nitric acid to digest, for this reason; it is safe and eco-friendly. But unfortunately it requires mass spectroscopic equipment that is expensive and complex that makes it a bit difficult to interpret the results [10].

- Application of gold nanoparticles in food contaminant detection

Chen et al reviewed the use of gold nanoparticles in colorimetric biosensors for food screening tests in 2018. The distinct optical characteristic of GNP in the aggregated/non aggregated state, provides the design of simple sensors with desirable features including high selectivity, sensitivity, simplicity, celerity, and portability [25]. Heavy metals enter the food chains as a result of human activities such as industrial processing, combustion of fossil fuels and the use of special fertilizers, resulting in numerous problems. For example, excessive lead (Pb) ingestion can lead to neurological problems, renal failure, hematologic effects, hypertension, and cancer. Colorimetric Apta-nanosensors based on AuNPs have been widespread employed in the measure of metallic ions. Najafzadeh et al was designed a promising strategy with Anti-aggregation of gold nanoparticles in colorimetric sensor arrays for detection of metallic ions. Several case are handling of colorimetric sensors of Hg^{2+} by GNP with aggregation sterategy [43, 44]. High affinity of Proteins and oligopeptides for capturing of specific targets through their functional groups at the inner or outer surface provides a great opportunity to design dedicated biosensors. Cysteine-rich protein or peptide sequences tend to combine with heavy metals because there is a strong affinity of heavy metal to thiols groups of cysteine in peptides. Guo et al were loaded papain with seven cysteine residues onto GNP substarte as recognition element that could simultaneously detect the presence of Hg^{2+}, Pb^{2+} and Cu^{2+} in water and food. The detection limit of this sensor is 200 nM [45, 46]. Zhu et al designed cysteine-modified simultaneously Au-Ag core-shell nanorods based biosensor with the etching process by using aggregation effect that detect the Hg (II) with high sensitivity and LOD equal to 25 nM [47]. Also, Gan et al in 2019 was designed the GNP-based apta-nanosensor to quantitative measurement of the concentration of cadmium ions using a smartphone. Based on the anti-aggregation strategy of gold nanoparticles, this tool is red in the presence of the target molecule trapped in the specific aptamer trap. The change in color intensity has been a sign of the change in cadmium concentration in the target water sample, which can be measured by shooting with the iPhone 4s and analyzing with the application of the smartphone-based colorimetric system (SBCS). limit of detection for this sensor is claimed 1.12 μg/L [48]. Veterinary drug residues detection was also observed with highly efficient GNP-induced aggregation methods. The LOD of these types of sensors for clenbuterol (one of the type of β-agonists) can reach nanomolar concentration (0.7 μM can be obtained within a few Minutes) by naked eyes [49].

Liu's group developed fluorescence sensor based on Fluorescence resonance energy transfer (FRET) between long-strand aptamers functionalized upconversion nanoparticles (UCNPs) and short-strand aptamers functionalized gold nanoparticles (GNPs) for mercury detection. In the absence of mercury in the sample, FRET occurred between the UCNPs and the GNP due to specific matching between the two aptamers, leading to the fluorescence quenching of the UCNPs. In the presence of Hg^{2+}, long filamentous aptamers into the hairpin structure due to the stable bonding interaction between Hg^{2+} and thymine lead to the release of GNPs from UCNPs, resulting in silent fluorescence repair. The linear detection range is 0.2 to 20 μM and the sensitivity (LOD) is 60 nM [50]. Cheng's team was made an ultrasensitive luminescence aptasensor based on luminescence energy transfer (LET) for quantitative evaluation of Salmonella typhimurium. Mn^{2+} -doped $NaYF_4$: Yb, Tm UCNPs as donor and Gold nanorods as acceptor were used. The linear assay range of S. typhimurium was estimated 12 to 5×10^5 cfu/ ml with reproducibility %0.99 (R2) and LOD 11 cfu/ml in an aqueous buffer [51]. Also, Zhao et al was developed an electrochemiluminesence (ECL) aptasensor with Au@nano-C60 electrodes for measure kanamycin with a sensitivity of 45 pM [52].

Yuan and his colleagues designed a piezoelectric aptasensor to detect arsenite using a self assembeled monolayer (SAM) of mercaptoethylamine as an immobilizeer on the surface of a quartz crystal microbalance (QCM) and modified GNPs with arsenite aptamer as amplifier signal in apta-nanosensor. The sensitivity of this sensor is evaluated in the linear range of 8 to 1000 nmol.L^{-1}, 4.4 nmol.L^{-1} [53]. Similarly, an apta-nanosensor using silica-coated magnetic nanoparticles (Fe_3O_4@SiO_2@p(Polyethyleneglycol dimethacrylate (PEG-MA)-Glycidyl methacrylate (GMA)) has been used to detect Brucella melitensis in milk and dairy products with linear range 1.02–1.07 CFU mL^{-1} [54]. Mousavi et al Electrochemical aptasensor using nanocomposite of graphene oxide and gold nanowires for AFB1 with LOD 1.4 pM and linear range was 5.0–750.0 Pm [55]. Also, developed an electrochemical aptasensor for the detection of staphylococcal enterotoxin B (SEB) as a bacterial toxin causing severe food poisoning with reduced graphene oxide (rGO) and gold nano-urchins (AuNUs). The sensitivity of this sensor was calculated as 0.21 fM [56]. Xing et al designed a sensor using a DNA-modified single gold nanoparticle, a T-Hg (II) -T interaction, and a single-particle ICP-MS that could measure twice the positive mercury ion concentration in water. Coupled plasma mass spectrometry [ICP-MS] is one of the techniques proposed to measure the concentration of water pollutants [57, 58]. Single particle (SP) ICPMS is used to determine the aggregation by reducing the total number of AuNPs or NP aggregates detected. Compared to most other Hg^{2+} assays using the same scattering principle with DNA-modified AuNPs, this method has a much lower limit of detection (0.031 ng.L^{-1}, 155 fM) and a wider linear range (10 A thousand fold) (up to 1 microgram L^{-1}). This method also had good practical potential due to the minimal interference in the water sample matrix [59].

AgNPs (Silver nanoparticles)

The prominent optical, electronic, and antibacterial Features of silver nanoparticles have also made it widely used in biosensors. These nanoparticles are mostly used for therapeutic applications and infection control, but their entry into the human body can also be toxic and dangerous. The the silver nanostructures shape and its functionalization have a significant effect on the physicochemical properties and consequently their application in biosensore design. Silver salts turned into black on exposure to light while silver nanoparticles, like gold in the visible light, exhibit the properties of Localized Surface Plasmon Resonance (LSPR) [60]. Several sensing systems based on the optical properties of silver nanoparticles have been reported based on color changing between aggregate and non-aggregated state of Ag nanoparticles from yellow to brown, which can be associated with a change in the concentration of a target molecule. Based on this principle, various AgNP-based methods have been developed for the detection of metal ions, proteins, melamine and pesticides. Compared to AuNPs, AgNPs maintain a higher extinction coefficient and cost less (Fig. 3).

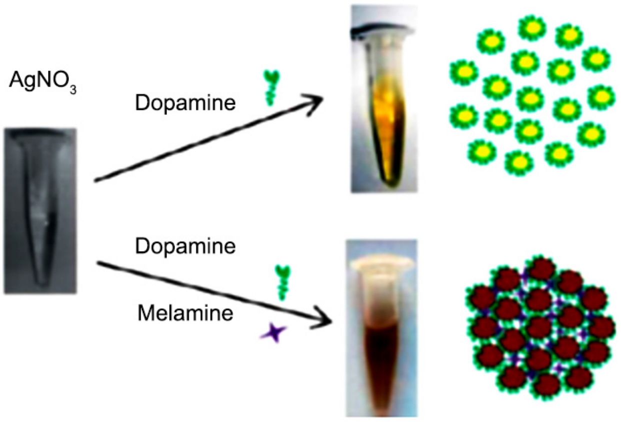

Fig. 3. Schematic illustration of colorimetric method with AgNPs/dopamine system for the detection of melamine (reproduced from with permission of The Royal Society of Chemistry) [41].

However, due to the following limitations, there has been less focus on Ag NP-based assays:

[1] The functionalization effects on AgNPs that can chemically degrade nanoparticles to silver ions

[2] The surface of AgNPs is easily oxidized exposed to biological environment [41].

However, in most nanobiosensors, silver and gold nanoparticles simultaneously are used as optical signal transducers and LSPR [61-63].

- Application of Silver nanoparticles in food contaminant detection

Ratnarathorn et al designed a silver nanoparticle-based paper colorimetric sensor that can measure copper concentration with a limit of naked-eye detection is 7.8 nM or 0.5 μg L^{-1} with accuracy and reproduc-

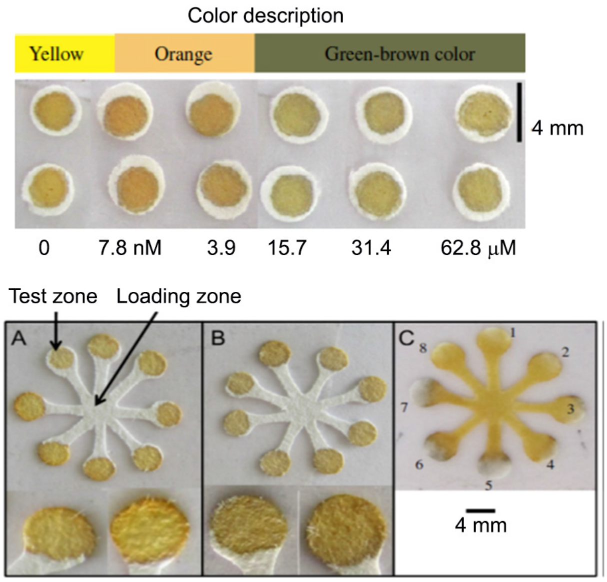

Fig. 4. mPAD forthesemi-quantitativeanalysisofCu2þ after spotting AgNPs modified with Hcyand DTT into the test zone and then (A) dropping buffer solution and (B) 15.7 mM of Cu2þ solution into the loading zone. (C) m PAD forthesemi-quantitative analysisof Cu2þ after spotting [8]0[2]7.8nM [3]780nM [4]7.8 mM [5]15.7 mM [6] 31.4 mM [7] 62.8 mM ofCu2þ solution and then dropping AgNPs modified with HcyandDTT intoloading zone [64].

ibility of R^2= 0.992. WHO has set the maximum permissible level of copper in drinking water at 1.3 mgL^{-1} or 20.5 µM. So this simple and fast sensor can be very efficient (Fig. 4) [64].

Amirjani et al designed a colorimetric sensor that could measure the concentration of ammonium in the water by formation of silver-ammonia complex $[Ag(NH_3)_2^+]$ in the present of ammunia as a target that can be detect based on the localized surface plasmon resonance phenomenon with the help of the OSnap app on the smartphone. Calculated for the detection of ammonia (10–1000 mgL^{-1}) with a sensitivity (LOD) of 180 mg L^{-1} (ppm) with 0.98% repeatability [65]. He et al developed a simple, facile, and highly sensitive Chemiluminescent sensor, based on silver nanoparticles, that can measure five organophosphate and carbamate pesticides, including dimethoate, dipterex, carbaryl, chlorpyrifos, and carbofuran Simultaneously. In this study, 20 unknown pesticide samples were analyzed with this diagnostic system. This measurement system has 95% accurate with 24 µg/mL LOD [66]. Bala et al development an ultrasensitive, rapid and low cost colorimetric apta-nanosensor with AgNPs for measurement of malathion residues in water and food. Malathion is an organophosphate insecticide. The presence of different concentrations of melamine in the water and food samples with this indicator is seen as red intensities. This means that the tool also uses a silver nanoparticle anti-accumulation strategy. limit of detection this sensor 0.5 pM was achieved [67].

Magnetic NPs

Magnetic nanoparticles have been shown to be maghemite (γ-Fe_2O_3) and magnetite (Fe_2O_3) due to their supermagenetic properties, and have been highly for the design of biosensors [26]. These nanoparticles can also be used to isolate contaminants and detoxify by surface modification and conjugate with a specific recognition element such as antibody, aptamer and so on. They also appear to improve electron conductivity because they are chemical metal oxides [68]. Based on these features, MNPs are widely used in diagnostic field [69]. Li et al designed a nanomolecular system that could detect and isolate the general Escherichia coli bacterium in food using magnetic nanoparticles coupled with upconversion of a specific aptamer (Fig. 5) [41, 70]. These nanomaterials along with gold nanoparticles have also been used to identify and isolate Staphylococcus aureus with its specific aptamer [71]. In this study, they play roles such as MNP in isolation agnet and AuNP in colorimetric agent.

- Application of Magnetic nanoparticles in food contaminant detection

To date, several devices developmented with Aptananosensors functionalized Magnetic nanomaterials for extraction, detection and detoxification of mycotoxins including MNP-ELISA, MNP-HPLC, Immunomagnetic nanoparticle-based assay, Magnetic micromotors, Magnetic nanoparticles-based Aptasensor, Magnetic molecularly imprinted polymers (MMIPs). Through them MNP-based Aptananosensors are simple, high sensitive and cost-effectivness for public healthcare special in food safety assessment [72-75]. Major roles of MNPs are played in biosensors including enzyme immobilization support or capture probe. unique physical, magnetic and chemical properties

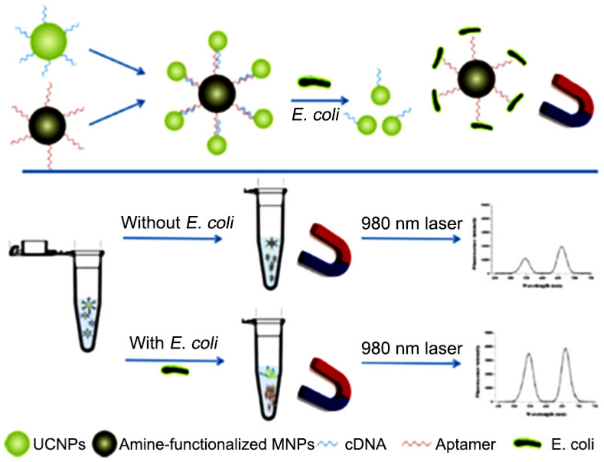

Fig. 5. Sensing method for detection and isolation of the general Escherichia coli bacterium in food using magnetic nanoparticles coupled with upconversion of a specific aptamer.

caused design and development of analytical platforms for food analysis by MNP-based biosensoes [76]. Li et al designed a fluorescence apta-nanosensor conjugated with MNP and UCNP for screening Escherichia coli in food. Specific binding between two aptamers functionalized magnetic nanoparticles and a cDNA-upconversion nanoparticle is principle for this detection. The fluorescence emission intensity of the MNPs-aptamer-cDNA-UCNPs complex piecemeal decreased upon rise in the E coli levels. The linear range for this sensor is 58–58×10^6 cfu.mL^{-1} and sensitivity is 10 cfu mL^{-1} [77]. Liu et al designed a Colorimetric immunoassay with aptamer functionalized MNPs for detection of Listeria monocytogenes in food samples. In this device core gold nanoparticles, silver nanoclusters as oxidase mimetics are used. Presence of L. monocytogenes in sample caused dispersion of AuNPs and finally red shift observed. Sensitivity of the Apta-nanosensor is 10 cfu.mL^{-1} [78].

Silica NPs (SiNPs)

The stable, robust, and adjustable shell of silica nanoparticles has made them ideal for functionalization, simple manipulation, and immobilization of chemical or biological species, either through covalent linking or physical adsorption. Because of the stability of these nanoparticles, the biological safety of other nanoparticles can be enhanced as shell-core structures, such as QDs@SiO_2 and Fe_3O_4@SiO_2 [26].

Silica nanoparticles in addition to good stability and dispersibility in different media, biocompatibility and low cost can act as fluorescent enhancers for fluorophores. One of the biosensore for detection of aflatoxin based on the silica nanoparticles conjugated with aflatoxin B1-specific aptamer was designed to detect this mycotoxin by amplifying the fluorescent signal [79]. Now, These nanoparticles are also used in food packaging widly [80].

- Application of Silica nanoparticles in food contaminant detection

Recently mesoporous silica particles [MSPs] employed as inorganic scaffolds for the encapsulation organic molecules due to their high stability, biocompatibility, homogeneous porosity, high inertness, and large load capacity [81]. Taghdisi et al designed fluorescent aptasensor with silica nanoparticles for detection of aflatoxin B1. linear range and a limit of detection [LOD] of the sensor is calculated 30–900 pg/mL and 8 pg/mL respectively [79].

Cerium Oxide NPs (Nanoceria)

Oxidized cerium nanoparticles have the potential to alter redox states and surface properties due to their dual oxidation properties of Ce (III)/Ce (IV) on the NP surface. Peroxidase-, superoxide-, and oxidase-like activities have also been demonstrated in these nanoparticles that can be used as surrogates for the development of biosensors. Depending on the optical activity of these nanoparticles and their specific interactions at surfaces, they can produce a unique color pattern that can be useful in colorimetric biosensors if conjugated to specific recognition element such as aptamer or antibodies [41]. The sensors are designed to detect dietary antioxidants and glucose, based on ceria nanoparticles [82-84].

- Application of Nanoceria in food contaminant detection

Sharpe et al are development a colorimetric Portable ceria nanoparticle-based assay for rapid detection of food antioxidants. This nanosensor with detection limits ranging from 20 to 400 mM depending on the antioxidant involved. This assay includes the steps to providing a colorimetric reagent (the reagent containing a multiplicity of ceria nanoparticles immobilized to a support, contacting the colorimetric reagent with the food sample, and sensing an optical property of the colorimetric reagent, where a change in the optical property). The presence of antioxidant in the food sample coresponding change in the optical property colorimetric reagent. The concentration of the antioxidant in the food sample has a significant relationship with its concentration in the sample which is optimized during testing of standard and sample concentrations [85]. Zhou et al make a Ce-MOF@COF hybrid nanostructure for detection of oxytetracycline (OTC) residues in aqueous solution environments. This aptasensor is electrochemical. Nanohybrids Porous organic framework (COF) and Ce-based metal organic framework (Ce-MOF) employed as label-free bioplatforms for a sensitive aptasensor to detect OTC. limit of detection is reported 17.4 fg mL^{-1} [86].

Platinum NPs (PtNPs)

Platinum nanoparticles increase the catalytic surface area, but are more likely to aggregate, using soluble polymer matrix or encapsulation in dendrimers to stabilize these nanoparticles [87]. Platinum nanoparticles can be used to modify biosensor electrodes.

- Application of Platinum nanoparticles in food contaminant detection

Wulandari and his colleagues used platinum coatings to detect acrylamide in foods. Other commonly found in high-fat foods such as potato chips and biscuits with various thermally processed, sensitive, rapid and simple detection is essential [88]. Madianos et al developmented ultrasensitive impedimetric aptasensor based on microwires formed by platinum nanoparticles which could detect acetamiprid and atrazine with a linear range of response in the range of (10 pM-100 nM), (100 pM^{-1} µM) and with a limit of detection (LoD) at 1 pM, 10 pM respectively [89].

Titanium dioxide NPs (TiNPs)

Titanium dioxide (TiO_2) is used as a food additive in a variety of food products that is used to enhance white, luminosity and sometimes taste. This compound has been widely used commercially in pigment and in sunscreens, paints, ointments, toothpaste in the present century. The observation of the photocatalytic cleavage phenomenon on the TiO_2 electrode under ultraviolet (UV) light prompted the researchers to further experiment on the optical and electrical properties of the nanoparticles, especially in the design of biosensors [90]. The attractive optical, electrical, chemical, and catalytic properties of titanium oxide nanoparticles have made it widely used to modify electrode coatings in electrochemical sensors. Its synthesis by sol-gel method retains its desirable properties [91]. Gan and his colleagues designed an electrochemical sensor that can detect and analyze commercial additive dyes simultaneously with the help of graphene and mesoporous TiO_2 hybrid nanomaterials [92].

- Application of TiNPs in food contaminant detection

One of the optical sensors based on hybrid nanoparticles with titanium dioxide can be Bragg Fiber Grating (FBG) combined with titanium dioxide coated long period fiber grating (LPFG) for monitoring organic solvents. This device is sensing concentration of n-hexane ($CH_3(CH_2)_4CH_3$). Poly (methyl methacrylate) (PMMA) flow cell Used in this device including with two channels and six openings, four to pass the fibers and two to fill and drain liquid samples. Sample movement in this substrate has led to the identification and identification of N-hexane, which is very important for the health of edible oils. LoD For this sensor 0.07 dB/%V/V and a resolution better than 0.16%V/V were claimed [93].

Copper NPs and Related NMs (CuNPs)

The attractive physicochemical properties of copper metal nanoparticles are the unique catalytic property and high electrical conductivity. If the copper nanoparticles become smaller and crystalline, the photoluminescence characteristic indicates that it can be used as a fluorescent tag in the design and development of fluorescence-based sensors with excellent catalytic properties. These nanoparticles can improve amperometric performance in electrochemical transducers.

- Application of CuNPs in food contaminant detection

For example, Gao et al copper nanocrystals (CuNCs) were used to measure the concentration of kojic acid in foods. It is one of the metabolites of Aspergillus sepsis that are used in the food industry as antioxidant,

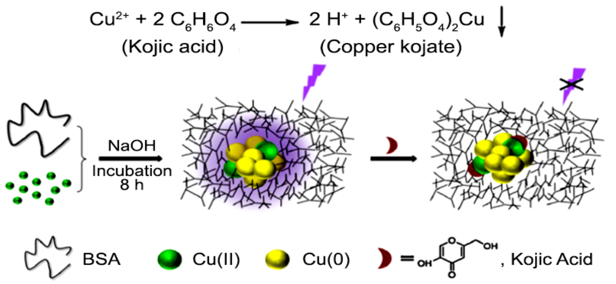

Fig. 6. Schematic illustration of the BSA-capped CuNCs for KA sensing [94].

preservative, and antimicrobial activity in the food proccess. While it has undesirable carcinogenicity, it also has ambrotoxicity. The sensor is designed with CuNCs to increase the concentration of the target molecule, reducing the fluorescent intensity. linear range of 0.2–50 µM and limit of detection for these biosensor is 0.07 µM at a signal-to-noise ratio of 3 [94]. He et al designed A fluorescent aptasensor for detection of ochratoxin A based on enzymatically generated copper nanoparticles with a polythymine scaffold with LOD 2.0 nM (Fig. 6] [95].

Fluorescent Nanomaterials

The fluorescence phenomenon is a type of luminescence that some chemical materials can emit visible light after absorption of light or other electromagnetic radiation that is not normally visible, such as ultraviolet light. Fluorescent materials stop radiation almost immediately after the radiation source stops, unlike phosphorescent materials, which emit after some time [96]. Nanostructures can also enhance fluorescence due to increasing surface area ratios. Well-known fluorescent nanomaterials often include quantum dots and Up-Conversion Nanoparticles (UCNPs). They are often referred to as fluorophores or quenchers, labels in the biosensor identifier probe. They can be either electron or energy donors in the phenomenon of either electron transfer or Fcrster resonance energy transfer (FRET) processes to distinguish the presence or absence of the target factor in the biosensor [97].

Quantum Dots (QD)

Quantum dots are Semiconductor nanocrystals approximately spherical in shape and 1–10 nm in diameter that exhibit quantum behavior and emit different colored wavelengths, depending on the size of the particle, by absorbing a specific wavelength. The nanosize of QDs leads to unique optical properties that by controlling the size of quantum nanoparticles, several target molecules of food contaminant pathogens can be simultaneously identified and quantified based on their radiation intensity. Various research findings have shown that quantum dots are more sensitive and stable than other fluorophores. Their smaller size lead to needed to excite greater amount of energy, and therefore, the blue fluorescence light emitted changes [blue-shift]. Elements used in the preparation of quantum dots include II – VI materials (e.g. CdSe, CdTe), III – V materials (e.g. InP, InAs), IV – VI materials (e.g. PbS, PbSe) and group IV materials (e.g. Si) [98]. Commonly used elements include Cd, Zn, Se, and Te, In, P or as. The quantum dot composition is often composed of CdSe/ZnS (core/shell). Quantum dots are widely used in labeling which can be used in real time PCR Quantitative-Polymer Chain Reaction (q-PCR) techniques. Food-borne pathogens identified with quantum dots including Cryptosporidium parvum, E. coli, Giardia lamblia, Listeria monocytogenes, Salmonella Typhimurium, Shigella flexneri, Bacillus anthracis, Campylobacter jejuni, Staphylococcus aureus and Yersinia enterocolitica and enteric viruses have been reported in literature [98, 99].

The use of QD for the identification of pathogens, pesticides, antibiotics and Genetically Modified Organisms (GMOs) has been widely reported. Applicable QDs that are expected to lead to future commercial products include photovoltaics, solid-state lighting and biomedical technologies [98]. The challenge of QDs is solved by the lack of water solubility and biocompatibility usually encapsulated with functional polymers to maintain their unique optical properties [11]. QDs can be combined with aptamers while maintaining aptamer specificity intact and quantum dot emission features [68]. As a result, several specific risk factors in water and food materials can be identified and quantified in a concurrent, efficient and safe manner. By combining quantum dots with other nanoparticles such as graphene oxide with the help of FRET (Forster Resonance Energy Transfer) on microfluidic chips, they identified the allergens well with the desired sensitivity [100]. Recently, encapsulating QDs into silica spheres has been used to improve chemical stability and reduce the leaching and potential toxicity of the QDs. The results of these studies have demonstrated that the quantum dot confinement in silica nanoparticles reduces photobleaching without affecting the photophysical properties of the QDs. On the other hand, the abundance of the silica element can dramatically reduce the cost of mass production of these biosensors. Also chemically inert and optically transparent silica nanoparticles have made them suitable for fluorescence sensing applications in various chemical media. Modification of the silica matrix surface enables the specific identification of such nanoparticles by identifiable elements such as aptamers [101].

- Application of QDs in food contaminant detection

Nsibande and Forbes reviewed Fluorescence detection of pesticides using quantum dot materials. QD modification strategies for pesticide detection including Doped QD, SiNPs, with macrocyclic/supramolecular host molecules, with molecularly imprinted polymers (MIPs), Enzyme-modified, Carbon quantum dots, QD films (Table 1). Coupling them to recognition elements like enzymes, aptamers, MIPs, or specially crafted supramolecules which offer selectivity detection towards targeted pesticides that can be improved performance of QD. For example, sensitivity of DNA-Aptamer functionalized CdTe-AuNPs of Acetamiprid is 7.29 nM [101].

Up-Conversion NPs (UCNP)

Upconversion nanoparticles (UCNPs) are an anti-Stokes process that, in a single or multi-photon mechanism, converts a low-energy photon with a higher

Table 1. Comparison of selected QD based pesticide sensor limits of detection (LOD) with regulatory guideline limit values and typical concentrations found in samples (nd = not detected) [101].

Particle	Matrix	Occurrence			Guideline limit		Sensing with QDs	
		Country	Concentration Range ($\mu g.L^{-1}$)	Study	$\mu g.L^{-1}$	($mol.L^{-1}$)	Reponted Lod ($mol.L^{-1}$)	Study
Paraquat	Water	Thailand	1.5-87.0	[37]	10[a]	38.89×10^{-9}	6.39×10^{-9}	[38]
							11.7×10^{-12}	[39]
							2×10^{-8}	[40]
Parathion	Water	India	0-2.12	[41]	50[a]	0.172×10^{-6}	4.82×10^{-12}	[42]
							4.47×10^{-12}	[43]
							32.5×10^{-9}	[44]
							2.47×10^{-12}	[45]
							34.3×10^{-9}	[46]
Pentachiorophenol	Water	China	nd-103.70	[47]	60[a]	0.225×10^{-6}	86×10^{-9}	[48]
							11.3×10^{-12}	[49]
Carbaryl	Water	bangladesh	nd-0.163	[50]	90[a]	0.447×10^{-6}	12.4×10^{-9}	[51]
Chlorpyrifos	Water	bangladesh	nd-1.189	[50]	90[a]	0.257×10^{-6}	17×10^{-9}	[52]
Dissinon	Water	USA	nd-0.09	[53]	20[a]	65.7×10^{-9}	0.164×10^{-6}	[54]
Glyphosate	Water	Mexico	nd-36.7	[55]	280[a]	1.66×10^{-6}	0.0725×10^{-9}	[56]
Carbaryl	Apples	China	0-10 $\mu g.g^{-1}$	[57]	15000[b]	74.5×10^{-3}	26.8×10^{-12}	[58]
Paraquat	Rice				50[b]	0.198×10^{-6}	6.39×10^{-9}	[38]
Parathion-methyl	rice				1000[b]	3.8×10^{-6}	61.8×10^{-9}	[59]

Notes:

[a] Guidelines for Canadian drinking water quality [60].

[b] Tolerances and exemptions for pesticide chemical residues in food in the USA [61].

[c] Values that were not reported in $mol.L^{-1}$ were converted for comparison.

wavelength to a more energetic photon with a lower wavelength. Low energy photons are usually infrared or near infrared, while higher wavelengths are usually visible or ultraviolet. The main advantage of upconversion nanoparticles over other fluorescent nanomaterials is the ability to emit visible light under near-infrared radiation. This radiation with low autofluorescence, less scattering and absorption can lead to deep penetration into biological samples [102, 103]. Because these nanoparticles are excited at 980 nm, which is very high for other fluorescent materials, they reduce the background effect well and, on the other hand, their broad absorption spectrum, thus increasing the sensitivity of detection with these nanoparticles. These nanoparticles doped with lanthanide ions in the 4F layer contain many transfer electrons. To achieve high efficiency, it is necessary to co-dope the sensitizer ions alongside the activator ions which have a close intermediate excitation state [104]. Upconversion nanoparticles with different compositions can produce different colors. Thus, by controlling their constituents that produce different fluorescent colors, and modifying their surface by specific markers such as aptamers, they Identified simultaneously target several target molecules such as mercury toxic ions in drinking water to toxic pesticides [105] and bacterial pathogens in crop and food samples [106]. Turn-On Fluoresence Sensor for Hg2+ in Food Based on FRET between Aptamers-Functionalized Upconversion Nanoparticles and Gold Nanoparticles.

- Application of UCNPs in food contaminant detection

Jin et al designed fluorescent aptasensor on multiplex lateral flow assay for Simultaneous detection of Hg^{2+}, Ochratoxin A and Salmonella with UCNPs in tap water. Limit of detection 10^{-4} ppb for Hg^{2+}, 0.01–50 μg/mL for OTA and 150–2000 CFU/mL for SE claimed. Finally, fluorescent intensity by smartphone measured and determinate concentration of target [106].

Carbon-Based NMs

The most common inorganic nanoparticles in designing biosensor are carbon-based nanomaterials. Due to the excellent chemical, mechanical, electrical and thermal properties of carbon nanostructures (i.e., thermal and electrical conductivity, high mechanical strength, and optical properties) with single entity and various forms, they have been widely used in industry and medicine. The presence of four single electrons in the carbon atom's capacitance layer has shown high electrical and thermal conductivity and has the potential to form bonds with other atoms. Therefore, the heterocyclic state of the C-C bonds in carbon-based nanomaterials causes remarkable chemical and electronic proportions [107-109]. Depending on their spatial dimensions, carbon-based nanomaterials can be roughly subdivided into fullerenes (zero-dimensional), carbon nanotubes (one-dimensional), graphene (two-dimensional), graphene (multidimensional) coils, and so on [108, 110]. Carbon-based nanomaterials used in diagnostic sensors for water and food safety that most carbon nanostructures used include mesoporous carbon, single- or multi-walled carbon nanotubes (SWCNT and MWCNT), graphene and carbon quantum dots [111]. The prominent features and advantages of using these nanostructures in the development of high-performance sensing devices for food and water safety engineering include small-size, interface, surface, dielectric confinement, macroscopic quantum tunneling efects followed by ease of preparation, stability and high heat and electronic conductivity. Mesoporous carbon Matrixes are newly introduced carbon nanostructures with diameters between 2-50 nanometers of silica. The synthesis of these materials are optimized and controlled and has extremely large surface area to volume ratio because of pore-liked structures. These nanostructures have been applaied to amplify electrochemical aptasensors to detect Hg^{+} ions [111]. Carbon dots or graphene oxides with quantum dot are used for the FRET phenomenon in many electrochemical and fluorescence-quenching biosensors [112].

- Application of CBNs in food contaminant detection

Pan et al compared the characteristics of typical carbon-based nanomaterials. Mesoporous carbon materials have several excellent features, such as high specific surface area and porosity, adjustable pore size, controllable pore wall composition and structure, simple synthesis and a lock of physiological toxicity and stability. Cui et al make an apta-nanosensor for detection of mercury which with using sulfur nitrogen codoped Ordered Mesoporous Carbon (SN-OMC)

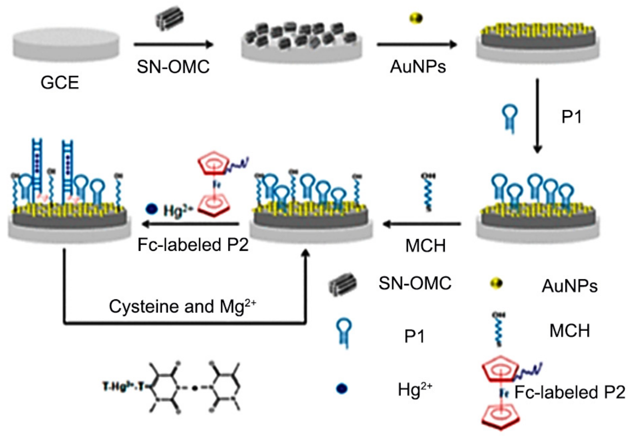

Fig. 7. Assembly diagram of electrochemical aptasensor based on the OMC nanomaterials for Hg2+ detection. Reproduced with permission from referenc [114].

and thymine-Hg^{2+}-thymine mismatch structure. These sensors have a fine linear range (0.001–1000 nM) with sensitivity 0.45 pM (Fig. 7).

Yari et al fabrication an electrochemical aptasensor with molybdenum disulfide nanosheet [MoS_2] coating of the multi wall carbon nano tube (MWCNT) surface for voltammetric determination of sulfamethoxazole. The MoS_2@MWCNT- modified electrode in this biosensor was responsed linear range from 0.08 to 1392 µM and sensitivity was 0.01502 Mm [113].

Wang et al designed a fluorescent apta-nanosensor using iron-doped porous carbon and aptamer-functionalized nitrogen-doped Grophen oxide-Quantum Dots as the probe for measurement of ochratoxin A, which can detect OTA with LOD of 2.28 nM [115]. Shi et al reviewed on applications of carbon dots in assessment of Metal ions and anions, Pesticide residues, Antibiotics and other veterinary drug residues, Bacteria. The mechanism of target detection is increasing fluorescent intensity of Carbon Dots due to adsorbtion onto the surfaces of bacteria, accordingly with increasing bacteria concentration in most cases. Wang et al designed an apta-nanosensor with aptamer conjugated quantum dots for recognition of specific membrane protein on the surface of salmonella typhimurium. The concentration of target could be quantified with measurement of the fluorescent intensity of solution after buffer elution process. Escherichia coli were detected using CDs modified with mannose, colistin, and amikacin. Zhong's team reported that the CDs modified with vancomycin can be aggregate on the surface of Staphylococcus aureus, leading in a decrease in fluorescent intensity. Similarly, Bacillus subtilis and Listeria monocytogenes. Recently, the similar strategy is used to sensing of Escherichia coli by introduction of Mag-CDs (Fig. 8) [116].

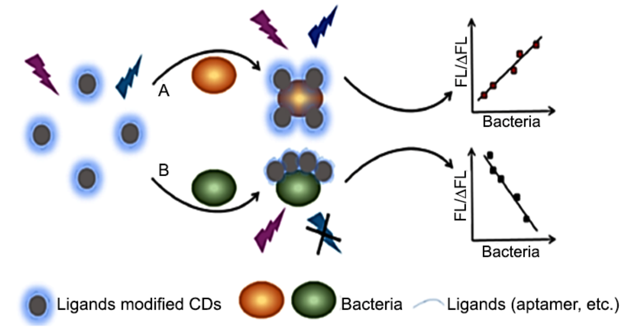

Fig. 8. Schematic illustration of CDs-based nanosensors for detecting bacteria. (A) Fluorescence increasing strategies with the increasing of bacteria concentration. (B) Fluorescence quenching strategies due to too close among individual CDs [117].

Wang's group reported fluorescent apta-nanosensor with CDs for quantification of kanamycin in milk. linear range of 0.04–0.24 µM, with a limit of detection (LOD) as low as 18 nM obtained [118]. Umrao's team

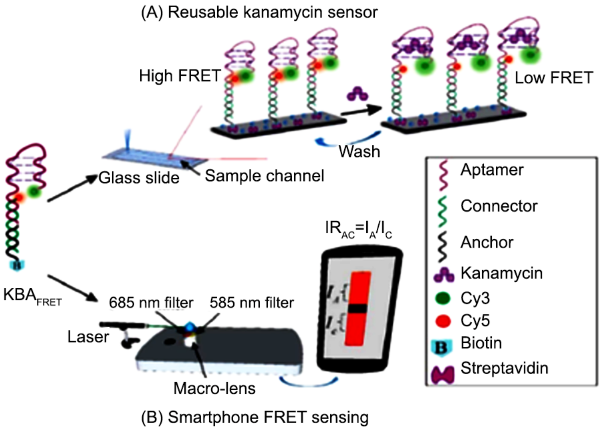

Fig. 9. Schematic for FRET-based kanamycin binding aptasensor. The top half [purple strand] of the aptasensor is the kanamycin binding aptamer and the bottom double-stranded DNA region [green and black strands] is used for surface mobilization when required. (A) Surface immobilization of the KBAFRET aptasensor using biotin–avidin chemistry allows repeated kanamycin detection and aptasensor regeneration by washing. (B) Kanamycin detection using KBAFRET is demonstrated with a smartphone-based two-color fluorescence reader [120].

demonstrated a Smartphone-based fluorescence aptasensor with Forster resonance energy transfer (FRET) between dye pairs on DNA aptamers can detect kanamycin rapidly and sensitively. Sensitivity of this aptasensor is 0.18 nM (Fig. 9) [119]. Weng's group demonstrated an aptamer functionalized QDs using graphen oxide based on FRET phenomenon on a microfluidic system could be quantified peanut allergen (Ara h_1) [100].

Polymer NMs

Polymeric and composite nanoparticles have been extensively studied and commercialized to prevent microbial contamination in the food packaging. Smart or Intelligent packaging is capable of sensing, detecting and recording external or internal changes in the presence of contaminants and assessing the safety and quality of food products under various environmental conditions. These changes are usually designed to be easily visible and user friendly [121, 122]. The safest commercialized nanocomposites authorized in the PLGA-chitosan food industry for antimicrobials applications have been introduced [123, 124]. During evolution, nature has provided the catalytic power and identification of selective molecules of biopolymers. This feature has been exploited for over 50 years in clinical analysis, environmental analysis, food control, and pharmaceutical analysis. Nanobiosensors with integrated receptor-transducer device have been able to overcome the difficulties of traditional food analysis techniques such as chromatography, mass spectrometry, spectrophotometry, and fluorimetry, which were costly and difficult to identify and specifically target molecules. "Minienzymes," synzymes, aptamers, and molecularly imprinted polymers (MIPs) have been introduced as biosensors for specific identification of the target molecule. MIPs were designed to mimic the active site of biopolymers. For the preparation of MIPs, functional monomers and crosslinkers (if crosslinking is not required for electrolymerization) are polymerized in the presence of the target analyte, the so-called pattern [125, 126]. Biosensors that use Molecularly Imprinted Polymer for identification include antibiotics [127] and chloramphenicol [128] detection in milk and honey. They also use Hybrid Aptamer/Conjugated Polymer Complexes for sensor detection [129, 130].

- Application of Polymer NMs (Polymer nanocomposites (PNC)) in food contaminant detection

The potential of nano-based sensors is in the detection of pathogens, deterioration, chemical contaminants, or manipulation of products or tracking of materials or products through the world-wide processing chain. Nowadays, intelligent and active food packaging forecasts are clear for food safety [131]. Aghaei and colleagues designed alizarin-containing cellulose acetate nanofibers, which is used as a holochrome sensor for qualitative evaluation of rainbow trout fish spoilage. The color of this on-packaging sensor changes with the amount of total volatile basic nitrogen (TVB-N) and pH increase in Rainbow trout fillets [132]. Pola's group reported development and optimization of pH-responsive nanoparticle based on poly (D, L-lactide-coglycolide) (PLGA) and chitosan (CHIT) for delivery of natural antimicrobial using trans-cinnamaldehyde (TCIN) as a model compound. Finally, the physicochemical properties of the nanoparticles and their antimicrobial activity were optimized against Salmonella typhimurium and Staphylococcus aureus. Showed a satisfactory encapsulation of TCIN (0.85 ± 0.35 33 33.20), spherical shape, pH-responsive release, faster release in the presence of CHIT at low pH, and increased antimicrobial activity against both pathogens [123]. Sergeyeva's team quantified AFB1 using molecularly imprinted polymer membranes and smartphone-based optical biomimetic sensor. The developed system enables simultaneous detection of aflatoxin B1 in 96 channels. Ultraviolet irradiation of aflatoxin B1, selectively bound by the MIP membranes of the analyzed samples, initiated fluorescence of aflatoxin B1 with direct intensity proportional to its concentration. The composition of the MIP membranes used as a detection element is optimized by considering computational modeling data. Two functional monomers (2-acrylamido-2-methyl-1-propansulfonic acid and acrylamide) were identified as desirable for the formation of selective aflatoxin B1 binding sites in the structure of MIP membranes. The storage stability of these sensors is estimated to be one year if stored at 22 °C [133].

Biological NMs

Biological nanomaterials are mostly used as a recognition element or carrier of low soluble drugs or targeted drugs such as antibodies [134], enzymes [135] and aptamers [8] and bacteriophages [136, 137] that specifically identify pathogens and toxins. As carriers like phospholipid structures [138] such as liposomes [139, 140] and niosomes [141], DNA nanostructures [142, 143] such as DNA nanotube [144, 145] that are used to increase the solubility and absorption of foods and drugs. Farooq et al the applications of phage-based biosensors in the detection of infectious diseases, food safety and environmental monitoring are reviewed. Bacteriophage has been used to identify pathogenic bacteria as a biological probe in different transmission platforms, which are grouped into three general categories, including Phage-optical biosensors (Phage-SPR-based sensors, Phage-bioluminescence sensors, Phage-SERS-based sensors, Phage-fluorescent sensor, Phage-colorimetric sensors), Phage-based micromechanical sensors (Phage-QCM-based sensors, Phage magnetoelastic sensors), Phage based electrochemical biosensors (Phage amperometric biosensors, Phage impedimetric sensors). Recently, advanced phage-based colorimetric techniques have been reported to integrate with new technologies such as surface plasmon, macroscope and smartphone and lateral flow sensing [136].

- Application of Biological NMs in food contaminant detection

Phages as bio-probes can be conjugated with Quartz crystal microbalance (QCM) sensors for selective screening of bacterial cells. Physical absorption bacteriophages at about 3× 10^{10} PFU/cm^{-2} on the surface of the piezoelectric transducer provided a very fast and sensitive substrate for the detection of Salmonella typhimurium. This immobilized bacteriophage in the QCM biosensor has a sensitivity of 10^2 CFU/ml with a wide linear range of 10^0–10^7 CFU/ml and a rapid reaction and rapid detection time of less than 3 min [136, 146]. Chen et al reported a DNA origami-based fluorescent aptasensors. This sensor is based on a DNA pyramid nanostructure [DPN] and PicoGreen [PG] dye for the determination of ochratoxin A (OTA). Its sensitivity is estimated to be 0.135 nM with a linear range of 0.3–10 nM [147]. Lipid-based nanomaterials in control food-borne bacteria act as delivery of antimicrobials [148].

Nano Structures for capturing enhancement of target in nanobiosensors. Among the known structures of nanorods, nanofibers, nanotubes, sheet [plate], such as graphene, provide more surface area and can, besides signal generation, target the molecule as well, especially with other conjugated nanoparticles, with dramatically increasing factors such as aptamers [149].

Technology of Smartphone

In 2019, approximately 4.68 billion of the population worldwide already owns a smartphone. Useful properties of smartphones such as digital cameras, surface plasmone resonance (SPR) [61] and image processing, operating systems, internal memory, computing, and machine learning, wireless connectivity with other devices can be used in hea;th care system. Moreover, high availability, user-friendly, easy operation for everyone resulted in more researchers focus on the smartphones foe designing portable biosensing devices for in field applications [11].

Smartphone is being developed as Instrumentation, a new approach to improving health care by preventing, regularly diagnosing and monitoring the symptoms and risk factors in public health. Most of these programs are related to the measurement of direct biological specimens initially deployed with simple colorimetric and microscopic manifestations. With the advancement of the mobile Complementary metal-oxide semiconductor (CMOS) camera, integrated optical processing capabilities and availability, more advanced metrics such as spectroscopy analysis by smartphones are now being implemented. The literature review on smartphone-based instrumentation has divided applications of this simple and accessible device into several major categories including colorimetry, microscopy, intensity-based fluorimetry, spectroscopy, and surface plasmon-based sensing. These applications have seen a major breakthrough in the field of "lab-in-a-phone" technology in healthcare [12]. This technology integrates and integrates with a variety of biosensors including optical, physical, and electrochemical [150].

Recently, several colorimetric devices have been designed and developed of smartphone-based biosensors for variety platforms such as lateral flow assay [151-

153], microfluidic [18] systems [61, 154-157].

Smartphone-based biosensors have also been used repeatedly to evaluate portable food. A wide range of food contaminants in the complex matrix of water and food crops and livestock have been rapidly identified and quantified with this technology [13, 158-160]. With the help of this emerging and publicly available technology, can be rapidly and accurately assessed water and food safety for the presence of contaminant agents, and the prevention and incidence of many water and foodborne illnesses can be prevented by providing appropriate, well-prepared measures.

- Application of Smartphone in food contaminant detection

Color-based sensing allows you to use simple diagnostic systems such as spectrophotometers or even smartphones, both of which are relatively common and practical [154]. Zheng's group reported a microfluidic colorimetric biosensor for rapid detection of Escherichia coli O157:H7 using gold nanoparticle aggregation and smart phone imaging. The red shift of the conjugated gold nanoparticles with the specific antibody resulting from the presence of the target bacterium in the injected sample is quantified in this system. The sensitivity of this system is 50 CFU / mL [161]. Recently, various electrochemical techniques, such as potentiometric [32], amperometric [33, 34], and impedimetric method [35], have been achieved on smartphone. Mishra et al made a wearable biosensor which flexible and stretchable glove that could quantify organophosphorus chemical threats in the hazardous area based on a smartphone. Identification of nerve constituents of organophosphate (OP) on suspicious surfaces and crops will be done after their swipe on the thumb. The new wireless glove-based biosensor system holds significant promise for rapid screening of OP nerve agents and pesticides in defense and food safety programs, with significant speed and benefits. Such "laboratory glove" demonstrations open the field for flexible wearable sensors for future chemical detection in multiple fields in the future (Fig. 10) [162]. Similarly, Li et al Electrogenerated chemiluminescence biosensor electrodes with graphen quantum dots nanocomposites modified so as to measure the concentration range of 10 cfu / mL to 107 cfu / mL of Escherichia coli [163].

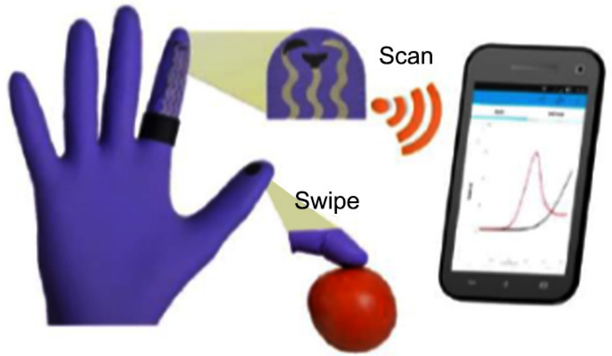

Fig. 10. Wearable flexible and stretchable glove biosensor for on-site detection of organophosphorus chemical threats [162].

CONCLUSIONS

(Convergence Technology of Aptasensors, Hybrid NMs and Smartphone)

Water [164] and food are a prerequisite for human life to contaminate a variety of pollutants, including heavy metals [33, 165], pathogenic bacteria [166-168], antibiotics [169], agricultural pesticides [170] and mycotoxins [171-173] and even allergen [174] in food. Numerous studies have investigated the use of nanosized sensors in the detection of food risk factors, which are reviewed in this article. Today, various technologies of point of care detection of water and food poisons and microbial agents have been designed and built that are being commercialized in the near future due to their availability. One of the most powerful tools available to the general public is the smartphone [12, 13, 150, 154], microfluidic [175], lateral flow assay [176, 177], wearable sensor [178-181]. The main components of biosensors include bioreceptor, transducer and detector. The main advantage of using aptamers at the bioreceptor role is to establish specificity and reduce the likelihood of false positive response. These three-dimensional structures in the SELEX process obtain the desired specificity against their target molecule [182]. Therefore, the simultaneous use of aptamers as spesific recognition element, nanostructures as capturing elements or transducers or signal amplifiers which increasing contact surface area for target molecule and smartphone capabilities, can be a major shift in the management and engineering of food and water safe-

Table 2. brief review on the Smartphone-Based Apta-nanosensors

Nanoparticle	Nanomaterial Role	Principle, Transducer, Method	Target, Sample	Platform	Sensitivity	Time response	Ref.
UCNP	Fluorescence quencher	Optical, Fluorescent	multi-target (SE,OTA, Hg2+) in Water	LFA	5 ppb, 3 ng/mL and 85 CFU/mL	about 30 min	[106]
quantum dots nanobeads and gold nanostars	fluorophore-quencher nano-pair	Optical, Fluorescent	of multi-pesticides (chlorpyrifos, diazinon, and malathion)	LFA	0.73 ng/mL, 6.7 ng/mL, and 0.74 ng/mL	about 30 min	[183]
aptamer	Recognition element	electrochemical	Antibiotic (streptomycin) in milk and Chicken	Tris-HCl buffer solution (pH 7.5)	94 nM	scanning speed of 300 nm/min	[184]
silver nanoparticle-decorated graphene oxide	luminol-functionalized	Visual electrochemiluminescence	aflatoxin M1	PBS and milk	0.05 ng mL^{-1}	-	[155]
AuNPs	controllable aggregation	Optical, colorimetric	multiplex antibiotic (TET and CAP)	Chicken and milk samples	32.9 and 7.0 nM	5 min	[185]
AuNPs	aggregation	Optical, colorimetric	Antibiotics (Streptomycin (STR))	STR in honey, milk and tap water	12.3 Nm (8.97 mg kg^{-1})	-	[158]
lanthanum ion –assisted gold nanoparticle	aggregation	Optical, colorimetric	Antibiotics (chloramphenicol)	acetate buffer (pH = 4.8) milk and chicken samples	5.88 nM	-	[158]

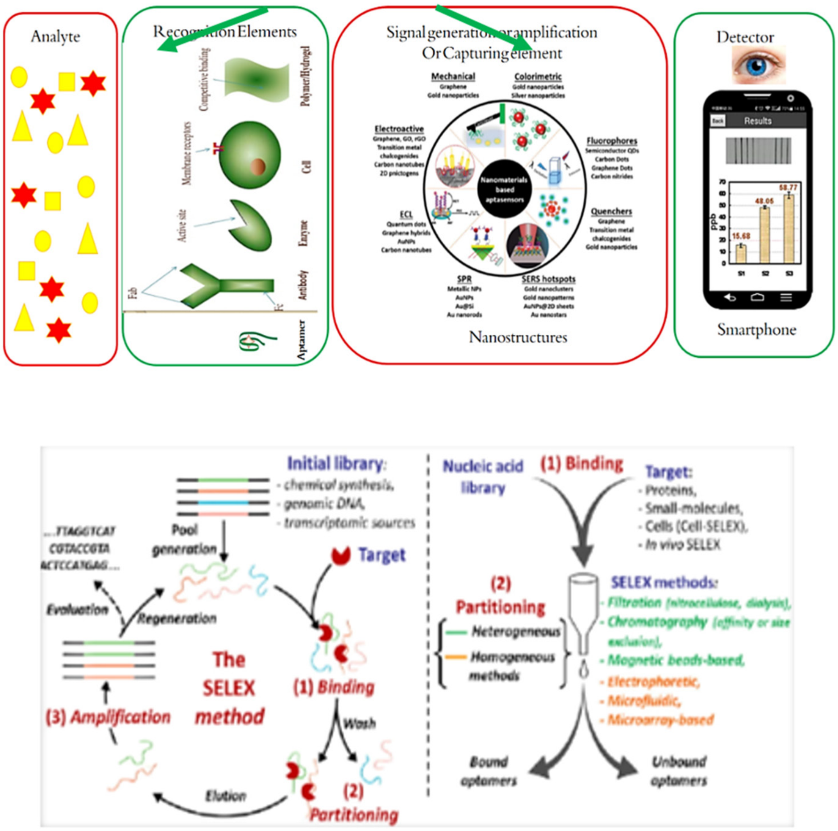

Fig. 11. Convergence Technology of Aptasensors, Hybrid NMs and Smartphone for development food safety by rapid and sensitive monitoring from farm to Forks.

ty with regular and simple and rapid monitoring and screening, Fast and accessible to the public [18, 68]. Hybrid nanomaterials fabricated from aptamer conjugated nanomaterials open new avenue in diagnostics and health care fields (Table 2) (Fig. 11).

REFERENCES

[1] Lytton TD. (2019). Outbreak: Foodborne Illness and the Struggle for Food Safety: University of Chicago Press.

[2] Farahi RH, Passian A, Tetard L, Thundat T. (2012). Critical issues in sensor science to aid food and water safety. Acs Nano., 6 (6), 4548-56.

[3] Kirk MD, Pires SM, Black RE, Caipo M, Crump JA, Devleesschauwer B. (2015). World Health Organization estimates of the global and regional disease burden of 22 foodborne bacterial, protozoal, and viral diseases, 2010: a data synthesis. PLoS Medicine. 12(12), e1001940.

[4] Wu MY-C, Hsu M-Y, Chen S-J, Hwang D-K, Yen T-H, Cheng C-M. (2017). Point-of-care detection devices for food safety monitoring: proactive disease prevention. Trends in Biotechnology, 35 (4), 288-300.

[5] Kaur H, Bhagwat SR, Sharma TK, Kumar A. (2018). Analytical techniques for characterization of biological molecules–proteins and aptamers/oligonucleotides. Bioanalysis, 11 (02), 103-17.

[6] Ferreira SL, Junior MMS, Felix CS, da Silva DL, Santos AS, Neto JHS, (2019). Multivariate optimization techniques in food analysis–a review. Food Chemistry, 273, 3-8.

[7] Barbosa IdS, Brito GB, dos Santos GL, Santos LN, Teixeira LS, Araujo RG. (2019). Multivariate data analysis of trace elements in bivalve molluscs: Characterization and food safety evaluation. Food Chemistry, 273, 64-70.

[8] Song S-H, Gao Z-F, Guo X, Chen G-H. (2019). Aptamer-Based Detection Methodology Studies in Food Safety. Food Analytical Methods, 12 (4), 966-90.

[9] Xia X, He Q, Dong Y, Deng R, Li J. (2018). Aptamer-based homogeneous analysis for food control. Curr Anal Chem., 14, 1-9

[10] Jiang P, Wang Y, Zhao L, Ji C, Chen D, Nie L. (2018). Applications of gold nanoparticles in non-optical biosensors. Nanomaterials, 8 (12), 977.

[11] Aydindogan E, Guler Celik E, Timur S. (2018). Based Analytical Methods for Smartphone Sensing with Functional Nanoparticles: Bridges from Smart Surfaces to Global Health. ACS Publications.

[12] Jamalipour A, Hossain MA. (2019). Smartphone Instrumentations for Public Health Safety: Springer.

[13] Rateni G, Dario P, Cavallo F. (2017). Smartphone-based food diagnostic technologies: A review. Sensors, 17 (6), 1453.

[14] Liu X, Zhang X. (2015). Aptamer-based technology for food analysis. Applied biochemistry and biotechnology, 175 (1), 603-24.

[15] Cho YJ, Kim CJ, Kim NS, Kim CT, Maeng JS, Kim TE. (2014). Slide chip for detection sensor of food-borne pathogens and preparation method thereof. Google Patents.

[16] Cai S, Yan J, Xiong H, Liu Y, Peng D, Liu Z. (2018). Investigations on the interface of nucleic acid aptamers and binding targets. Analyst, 143 (22), 5317-5338.

[17] Dun-Ming X, Min W, Yuan Z, ZHANG Q, Cui-Chen W, Yu Z, (2011). Application of aptamers in food safety. Chinese Journal of Analytical Chemistry, 39 (6), 925-33.

[18] Lu X. (2017). Sensing Techniques for Food Safety and Quality Control: Sensing Techniques for Food Safety and Quality Control: Royal Society of Chemistry.

[19] Lehotay SJ. Xiaonan Lu (Ed.). (2018). Sensing techniques for food safety and quality control, 410 (9), 2271-2

[20] Zhang Y, Lai BS, Juhas M. (2019). Recent advances in aptamer discovery and applications. Molecules, 24 (5), 941.

[21] Rai VR, Bai JA. (2017). Selection and Characterization of Aptamers for Food Contaminant Monitoring. Food Safety and Protection CRC Press.

[22] Madhyastha RRM. (2015). Inventor; Mycotox Solutions Inc, assignee. Aptamers for mycotoxin detoxification.

[23] Amaya-González S, De-los-Santos-Álvarez

N, Miranda-Ordieres AJ, Lobo-Castañón MJ. (2013). Aptamer-based analysis: a promising alternative for food safety control. Sensors, 13 (12), 16292–16311.

[24] Yang L, Zhang X, Ye M, Jiang J, Yang R, Fu T, (2011). Aptamer-conjugated nanomaterials and their applications. Advanced drug delivery reviews, 63 (14-15), 1361-70.

[25] Chen H, Zhou K, Zhao G. (2018). Gold nanoparticles: From synthesis, properties to their potential application as colorimetric sensors in food safety screening. Trends in food science & technology, 78, 83-94.

[26] Hassanpour S, Mokhtarzadeh A, Hasanzadeh M, Hejazi M, Baradaran B. (2019). Nanomaterials for Use in Apta-Assays. Handbook of Smart Materials in Analytical Chemistry, Chapter 8, 243-271.

[27] Kumar H, Venkatesh N, Bhowmik H, Kuila A. (2018). Metallic Nanoparticle: A Review. Biomedical Journal of Scientific & Technical Research, 4 (2), 3765-75.

[28] Hutter E, Fendler JH. (2004). Exploitation of localized surface plasmon resonance. Advanced materials, 16 (19), 1685-706.

[29] Bhardwaj N, Bhardwaj SK, Bhatt D, Lim DK, Kim K-H, Deep A. (2019). Optical detection of waterborne pathogens using nanomaterials. TrAC Trends in Analytical Chemistry, 02, 22.

[30] Saber , R., Shakoori, Z., Gill, P. (2013).Spectroscopic and microscopic analyses of rod-shaped gold nanoparticles interacting with single-stranded DNA oligonucleotides. IET Nanobiotechnology, 7 (2), 42-9.

[31] Sun J, Lu Y, He L, Pang J, Yang F, Liu Y. (2019). Colorimetric sensor array based on gold nanoparticles: design principles and recent advances. TrAC Trends in Analytical Chemistry, 115754.

[32] Liu G, Lu M, Huang X, Li T, Xu D. (2018). Application of gold-nanoparticle colorimetric sensing to rapid food safety screening. Sensors, 18 (12), 4166.

[33] Li M, Gou H, Al-Ogaidi I, Wu N. (2013). Nanostructured sensors for detection of heavy metals: a review. ACS Publications.

[34] Nabok A, Al-Rubaye A, Al-Jawdah A, Tsargorodska A, Marty J-L, Catanante G. (2019). Novel optical biosensing technologies for detection of mycotoxins. Optics & Laser Technology, 109, 212-21.

[35] Bai W, Zhu C, Liu J, Yan M, Yang S, Chen A. (2015). Gold nanoparticle based colorimetric aptasensor for rapid detection of six organophosphorous pesticides. Environmental Toxicology and Chemistry, 34 (10), 2244-9.

[36] Verdian A. (2018). Apta-nanosensors for detection and quantitative determination of acetamiprid–A pesticide residue in food and environment. Talanta, 176, 456-64.

[37] Liang M, Fan K, Pan Y, Jiang H, Wang F, Yang D. (2012). Fe3O4 magnetic nanoparticle peroxidase mimetic-based colorimetric assay for the rapid detection of organophosphorus pesticide and nerve agent. Analytical Chemistry, 85 (1), 308-12.

[38] Vu VP, Tran QT, Pham DT, Tran PD, Thierry B, Chu TX. (2019). Possible detection of antibiotic residue using molecularly imprinted polyaniline-based sensor. Vietnam J. Chemistry, 57 (3), 328-33.

[39] Youn H, Lee K, Her J, Jeon J, Mok J, So J-i, (2019). Aptasensor for multiplex detection of antibiotics based on FRET strategy combined with aptamer/graphene oxide complex. Scientific Reports, 9 (1), 7659.

[40] Castro CE, Kilchherr F, Kim D-N, Shiao EL, Wauer T, Wortmann P. (2011). A primer to scaffolded DNA origami. Nature Methods, 8, 221.

[41] Bulbul G, Hayat A, Andreescu S. (2015). Portable nanoparticle-based sensors for food safety assessment. Sensors, 15 (12), 30736-58.

[42] Zhang Y, Wei Q. (2016). The role of nanomaterials in electroanalytical biosensors: A mini review. Journal of Electroanalytical Chemistry, 781, 401-9.

[43] Chen G-H, Chen W-Y, Yen Y-C, Wang C-W, Chang H-T, Chen C-F. (2014). Detection of mercury [II] ions using colorimetric gold nanoparticles on paper-based analytical devices. Analytical Chemistry, 86 (14), 6843-9.

[44] Chen Y, Yao L, Deng Y, Pan D, Ogabiela E, Cao J. (2015). Rapid and ultrasensitive colorimetric

detection of mercury [II] by chemically initiated aggregation of gold nanoparticles. Microchimica Acta, 182 (13-14), 2147-54.

[45] Guo Y, Wang Z, Qu W, Shao H, Jiang X. (2011). Colorimetric detection of mercury, lead and copper ions simultaneously using protein-functionalized gold nanoparticles. Biosensors and Bioelectronics, 26 (10), 4064-9.

[46] Huang D, Liu X, Lai C, Qin L, Zhang C, Yi H. (2019). Colorimetric determination of mercury [II] using gold nanoparticles and double ligand exchange. Microchimica Acta, 186 (1), 31.

[47] Zhu J, Zhao B-z, Qi Y, Li J-J, Li X, Zhao J-W. (2018). Colorimetric determination of Hg [II] by combining the etching and aggregation effect of cysteine-modified Au-Ag core-shell nanorods. Sensors and Actuators B: Chemical, 255, 2927-35.

[48] Gan Y, Liang T, Hu Q, Zhong L, Wang X, Wan H. (2020). In-situ detection of cadmium with aptamer functionalized gold nanoparticles based on smartphone-based colorimetric system. Talanta, 208, 120231.

[49] He P, Shen L, Liu R, Luo Z, Li Z. (2011). Direct detection of β-agonists by use of gold nanoparticle-based colorimetric assays. Analytical Chemistry, 83 (18), 6988-95.

[50] Liu Y, Ouyang Q, Li H, Chen M, Zhang Z, Chen Q. (2018). Turn on Fluoresence Sensor for Hg2+ in Food Based on FRET between Aptamers-Functionalized Upconversion Nanoparticles and Gold Nanoparticles. Journal of agricultural and food Chemistry, 66 (24), 6188-95.

[51] Cheng K, Zhang J, Zhang L, Wang L, Chen H. (2017). Aptamer biosensor for Salmonella typhimurium detection based on luminescence energy transfer from Mn2+-doped NaYF4: Yb, Tm upconverting nanoparticles to gold nanorods. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 171, 168-73.

[52] Zhao M, Zhuo Y, Chai Y-Q, Yuan R. (2015). Au nanoparticles decorated C60 nanoparticle-based label-free electrochemiluminesence aptasensor via a novel “on-off-on” switch system. Biomaterials, 52, 476-83.

[53] Yuan M, Zhang Q, Song Z, Ye T, Yu J, Cao H. (2019). Piezoelectric arsenite aptasensor based on the use of a self-assembled mercaptoethylamine monolayer and gold nanoparticles. Microchimica Acta, 186 (5), 268.

[54] Bayramoglu G, Ozalp VC, Oztekin M, Arica MY. (2019). Rapid and label-free detection of Brucella melitensis in milk and milk products using an aptasensor. Talanta, 200, 263-271.

[55] Nodoushan SM, Nasirizadeh N, Kachuei R, Fooladi AAI. (2019). Electrochemical detection of aflatoxin B1: an aptasensor prepared using graphene oxide and gold nanowires. Analytical Methods, 11, 6033-6042.

[56] Nodoushan SM, Nasirizadeh N, Amani J, Halabian R, Fooladi AAI. (2019). An electrochemical aptasensor for staphylococcal enterotoxin B detection based on reduced graphene oxide and gold nano-urchins. Biosensors and Bioelectronics, 127, 221-8.

[57] Pooja D, Kumar P, Singh P, Patil S. (2020). Sensors in Water Pollutants Monitoring: Role of Material. Springer.

[58] Jia M, Lu Y, Wang R, Ren N, Zhang J, Changhua X. (2020). Extended GR-5 DNAzyme-based Autonomous isothermal Cascade machine: An efficient and sensitive one-tube colorimetric platform for Pb2+ detection. Sensors and Actuators B: Chemical, 304, 127366.

[59] Xing Y, Han J, Wu X, Pierce DT, Zhao JX. (2020). Aggregation-based determination of mercury [II] using DNA-modified single gold nanoparticle, T-Hg [II]-T interaction, and single-particle ICP-MS. Microchimica Acta, 187 (1), 56.

[60] Wei L, Lu J, Xu H, Patel A, Chen Z-S, Chen G. (2015). Silver nanoparticles: synthesis, properties, and therapeutic applications. Drug Discovery Today, 20 (5), 595-601.

[61] Li X, Yang F, Wong JX, Yu H-Z. (2017). Integrated smartphone-app-chip system for on-site parts-per-billion-level colorimetric quantitation of aflatoxins. Analytical Chemistry, 89 (17), 8908-16.

[62] Daniel JR, McCarthy LA, Ringe E, Boudreau D. (2019). Enhanced control of plasmonic properties of silver–gold hollow nanoparticles via a reduction-assisted galvanic replacement approach. RSC Advances, 9 (1), 389-96.

[63] e Asl SD, Sadrnezhaad SK. (2019). Gold@ Silver@ Gold Core Double-Shell Nanoparticles: Synthesis and Aggregation-Enhanced Two-Photon Photoluminescence Evaluation. Plasmonics, 15, 409-416.

[64] Ratnarathorn N, Chailapakul O, Henry CS, Dungchai W. (2012). Simple silver nanoparticle colorimetric sensing for copper by paper-based devices. Talanta, 99, 552-7.

[65] Amirjani A, Fatmehsari DH. (2018). Colorimetric detection of ammonia using smartphones based on localized surface plasmon resonance of silver nanoparticles. Talanta, 176, 242-6.

[66] He Y, Xu B, Li W, Yu H. (2015). Silver nanoparticle-based chemiluminescent sensor array for pesticide discrimination. Journal of agricultural and food Chemistry, 63 (11), 2930-4.

[67] Rajni Bala SM, Rohit K. Sharma, NishimaWangoo. (2018). A supersensitive silver nanoprobe based aptasensor for low cost detection of malathion residues in water and food samples. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 196, 268-273.

[68] Sharma R, Raghavarao K. (2019). Nanoparticle-Based Aptasensors for Food Contaminant Detection. Nanomaterials for Food Applications: Elsevier,123-45.

[69] Ramzannezhad A, Bahar A, Gill P. (2017). Fabrication of magnetic nanorods and their applications in medicine. BioNanoMaterials, 18 (3-4).

[70] Li H, Ahmad W, Rong Y, Chen Q, Zuo M, Ouyang Q. (2020). Designing an aptamer based magnetic and upconversion nanoparticles conjugated fluorescence sensor for screening Escherichia coli in food. Food Control, 107, 106761.

[71] Chang Y-C, Yang C-Y, Sun R-L, Cheng Y-F, Kao W-C, Yang P-C. (2013). Rapid single cell detection of Staphylococcus aureus by aptamer-conjugated gold nanoparticles. Scientific Reports, 3, 1863.

[72] Mohamed M. Ramadan MAM, Hassan Almoammar, Kamel A. Abd-Elsalam. (2018). Magnetic nanomaterials for purification, detection, and control of mycotoxins. Nanomycotoxicology: Elsevier Inc; 2018.

[73] Harshvardhan Modh TSaJ-G. (2018). Aptamer-Modified Magnetic Beads in Biosensing. Sensors, 18, 1041.

[74] Nafiseh Dorosti AR, Pooria Gill, (2020). inventor NANOMOLECULAR DETECTION OF AFLATOXIN B1, Publication Number: WO/2020/141498

[75] Musa Razzaghi AR, Pooria Gill, (2020). InventorKit for Molecular Detection of Pork Adulteration.

[76] Reem Khan AR, Akhtar Hayat , and Silvana Andreescu. (2019). Magnetic Particles-Based Analytical Platforms for Food Safety Monitoring. Magnetochemistry.

[77] Huanhuan Li WA, Yawen Rong, Quansheng Chen, Min Zuo, Qin Ouyang, Zhiming Guo. (2019). Designing an aptamer based magnetic and upconversion nanoparticles conjugated fluorescence sensor for screening Escherichia coli in food. Food Control, 107, 106761.

[78] Yushen Liu JW, Xiuling Song, Kun Xu, Huisi Chen, Chao Zhao, Juan Li. (2018). Colorimetric immunoassay for Listeria monocytogenes by using core gold nanoparticles, silver nanoclusters as oxidase mimetics, and aptamer-conjugated magnetic nanoparticles. Microchimica Acta, 185 (360).

[79] Taghdisi SM, Danesh NM, Ramezani M, Abnous K. (2018). A new amplified fluorescent aptasensor based on hairpin structure of G-quadruplex oligonucleotide-Aptamer chimera and silica nanoparticles for sensitive detection of aflatoxin B1 in the grape juice. Food Chemistry, 268, 342-6.

[80] Wu C, Zhu Y, Wu T, Wang L, Yuan Y, Chen J. (2019). Enhanced functional properties of biopolymer film incorporated with curcurmin-loaded mesoporous silica nanoparticles for food packaging. Food Chemistry, 288, 139-45.

[81] Jose V. Ros-Lis AB, Edgar Perez, Jose M. Barat, Ramon Martinez-Manez. (2018). Functionalized Silica Nanomaterials as a New Tool for New Industrial Applications. Impact of Nanoscience in the Food Industry, 165-196.

[82] Ornatska M, Sharpe E, Andreescu D, Andreescu S. (2011). Paper bioassay based on ceria nanoparticles as colorimetric probes. Analytical Chemis-

try, 83 (11), 4273-80.

[83] Sharpe E, Frasco T, Andreescu D, Andreescu S. (2013). Portable ceria nanoparticle-based assay for rapid detection of food antioxidants (NanoCerac). Analyst, 138 (1), 249-62.

[84] Saha B, Evers TH, Prins MW. (2014). How antibody surface coverage on nanoparticles determines the activity and kinetics of antigen capturing for biosensing. Analytical Chemistry, 86 (16), 8158-66.

[85] Erica Sharpe TF, Daniel Andreescu and Silvana Andreescu. (2013). Portable ceria nanoparticle-based assay for rapid detection of food antioxidants (NanoCerac). The Royal Society of Chemistry, 138, 249-262.

[86] Nan Zhou YM, Bin Hu, Linghao He, Shijun Wang, Zhihong Zhang, Siyu Lu. (2018), Construction of Ce-MOF@COF hybrid nanostructure: Label-free aptasensor for the ultrasensitive detection of oxytetracycline residues in aqueous solution environments. Biosensors and Bioelectronics, 127, 92-100

[87] Eklund SE, Cliffel DE. (2004). Synthesis and catalytic properties of soluble platinum nanoparticles protected by a thiol monolayer. Langmuir, 20 (14), 6012-8.

[88] Wulandari R, Ivandini T, Saefudin E, editors. (2019). A boron-doped diamond electrode decorated with hemoglobin-modified platinum nanoparticles as a biosensor for acrylamide detection. IOP Conference Series: Materials Science and Engineering, IOP Publishing.

[89] Madianos, L, Tsekenis, G, Skotadis, E, Patsiouras, L, Tsoukalas, D. (2018). A highly sensitive impedimetric aptasensor for the selective detection of acetamiprid and atrazine based on microwires formed by platinum nanoparticles. Biosensors and Bioelectronics, 101, 268-274.

[90] Chen X, Mao SS. (2007). Titanium dioxide nanomaterials: Synthesis, properties, modifications, and applications. Chemical Reviews, 107 (7), 2891-959.

[91] Lunsford SK, Choi H, Stinson J, Yeary A, Dionysiou DD. (2007). Voltammetric determination of catechol using a sonogel carbon electrode modified with nanostructured titanium dioxide. Talanta, 73 (1), 172-177.

[92] Gan T, Sun J, Meng W, Song L, Zhang Y. (2013). Electrochemical sensor based on graphene and mesoporous TiO2 for the simultaneous determination of trace colourants in food. Food chemistry, 141 (4), 3731-7.

[93] Coelho L, Viegas D, Santos JL, de Almeida JMMM. (2016). Optical sensor based on hybrid FBG/titanium dioxide coated LPFG for monitoring organic solvents in edible oils. Talanta, 148, 170-6.

[94] Gao Z, Su R, Qi W, Wang L, He Z. (2014). Copper nanocluster-based fluorescent sensors for sensitive and selective detection of kojic acid in food stuff. Sensors & Actuators: B Chemical, (195), 359-64.

[95] He Y, Tian F, Zhou J, Jiao B. (2019). A fluorescent aptasensor for ochratoxin A detection based on enzymatically generated copper nanoparticles with a polythymine scaffold. Microchimica Acta.186 (3), 199.

[96] Chang H-C, Hsiao WW-W, Su M-C. (2018). Fluorescent Nanodiamonds: Wiley.

[97] Zheng P, Wu N. (2017). Fluorescence and sensing applications of graphene oxide and graphene quantum dots: a review. Chemistry–An Asian J., 12 (18), 2343-53.

[98] Wegner KD, Tran MV, Massey M, Algar WR. (2017). Quantum dots in the analysis of food safety and quality. Sensing Techniques for Food Safety and Quality Control, 17-60.

[99] Burris KP, Stewart Jr CN. (2012). Fluorescent nanoparticles: Sensing pathogens and toxins in foods and crops. Trends in food science & technology, 28 (2), 143-52.

[100] Weng X, Neethirajan S. (2016). A microfluidic biosensor using graphene oxide and aptamer-functionalized quantum dots for peanut allergen detection. Biosensors and Bioelectronics, 85, 649-56.

[101] Nsibande S, Forbes P. (2016). Fluorescence detection of pesticides using quantum dot materials–a review. Analytica Chimica Acta, 945, 9-22.

[102] Chen J, Zhao JX. (2012). Upconversion nanomaterials: synthesis, mechanism, and applica-

tions in sensing. Sensors, 12 (3), 2414-35.

[103] Altavilla C. (2016). Upconverting nanomaterials: perspectives, synthesis, and applications: CRC Press.

[104] Wen S, Zhou J, Zheng K, Bednarkiewicz A, Liu X, Jin D. (2018). Advances in highly doped upconversion nanoparticles. Nature communications, 9 (1), 1-12.

[105] Yin M, Wu C, Li H, Jia Z, Deng Q, Wang S. (2019). Simultaneous Sensing of Seven Pathogenic Bacteria by Guanidine-Functionalized Upconversion Fluorescent Nanoparticles. ACS Omega, 4 (5), 8953–895.

[106] Jin B, Yang Y, He R, Park YI, Lee A, Bai D. (2018). Lateral flow aptamer assay integrated smartphone-based portable device for simultaneous detection of multiple targets using upconversion nanoparticles. Sensors and Actuators B: Chemical, 276, 48-56.

[107] Fecht HJ, Brühne K. (2016). Carbon-based nanomaterials and hybrids: synthesis, properties, and commercial applications: Pan Stanford.

[108] Nasir S, Hussein MZ, Zainal Z, Yusof NA. (2018). Carbon-based nanomaterials/allotropes: A glimpse of their synthesis, properties and some applications. Materials. 11 (2), 295.

[109] Cha C, Shin SR, Annabi N, Dokmeci MR, Khademhosseini A. (2013). Carbon-based nanomaterials: multifunctional materials for biomedical engineering. ACS Nano., 7 (4), 2891-7.

[110] Loos M. (2015). Allotropes of Carbon and Carbon Nanotubes. Carbon Nanotube Reinforced Composites; Elsevier: Amsterdam, The Netherlands, 73-101.

[111] Pan M, Yin Z, Liu K, Du X, Liu H, Wang S. (2019). Carbon-Based Nanomaterials in Sensors for Food Safety. Nanomaterials, 9 (9), 1330.

[112] Qu J-H, Wei Q, Sun D-W. (2018). Carbon dots: Principles and their applications in food quality and safety detection. Critical reviews in food science and nutrition, 58 (14), 2466-75.

[113] Yari AS, A. (2018). Silver-filledMWCNT nanocomposite as a sensing element for voltammetric determination of sulfamethoxazole. Anal Chim Acta, 1039, 51–58.

[114] Lai C, Liu S, Zhang C, Zeng G, Huang D, Qin L. (2018). Electrochemical aptasensor based on sulfur–nitrogen codoped ordered mesoporous carbon and thymine–Hg2+–thymine mismatch structure for Hg2+ detection. ACS Sensors, 3 (12), 2566-73.

[115] Wang CKT, R.; Li, J.Y.; Zhang, Z.X. (2019). Exonuclease I-assisted fluorescent method for ochratoxin A detection using iron-doped porous carbon, nitrogen-doped graphene quantum dots, and double magnetic separation. Anal Bioanal Chem., 411 (11), 2405-2414.

[116] Xingbo Shia WW, Zhaodi Fu, Wenli Gao, Chunyan Zhang, Qian Zhao, Fangming Deng, Xiangyang Lu. (2019). Review on carbon dots in food safety applications. Talanta, 194.

[117] Shi X, Wei W, Fu Z, Gao W, Zhang C, Zhao Q. (2019). Review on carbon dots in food safety applications. Talanta, 194, 809-21.

[118] Jinlong Wang TL, Yang Hu, XueliWang, YuangenWu. (2019). A label-free and carbon dots based fluorescent aptasensor for the detection of kanamycin in milk. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,226.

[119] Saurabh Umrao AS, Vasundhara Jain, Banani Chakraborty and Rahul Roy. (2019). Smartphone-based kanamycin sensing with ratiometric FRET. RSC Advances.

[120] Umrao S, Anusha S, Jain V, Chakraborty B, Roy R. (2019). Smartphone-based kanamycin sensing with ratiometric FRET. RSC Advances, 9 (11), 6143-51.

[121] Vasile C. (2018). Polymeric nanocomposites and nanocoatings for food packaging: A review. Materials, 11 (10), 1834.

[122] Shivakumar N, Madhusudan P, Daniel SK. (2018). Nanomaterials for Smart Food Packaging. Handbook of Nanomaterials for Industrial Applications: Elsevier, 260-70.

[123] Pola CC, Moraes AR, Medeiros EA, Teófilo RF, Soares NF, Gomes CL. (2019). Development and optimization of pH-responsive PLGA-chitosan nanoparticles for triggered release of antimicrobials. Food Chemistry, 295, 671-9.

[124] Shi Y, Jia L, Du Q, Niu J, Zhang D. (2018). Surface-modified PLGA nanoparticles with chitosan for oral delivery of tolbutamide. Colloids

and Surfaces B: Biointerfaces, 161, 67-72.

[125] Kurbanoglu S, Yarman A, Scheller FW, Ozkan SA. (2019). Molecularly Imprinted Polymer-Based Nanosensors for Pharmaceutical Analysis. New Developments in Nanosensors for Pharmaceutical Analysis: Elsevier, 231-71.

[126] Saylan Y, Akgonullu S, Yavuz H, Unal S, Denizli A. (2019). Molecularly imprinted polymer based sensors for medical applications. Sensors, 19 (6), 1279.

[127] Zhou T, Halder A, Sun Y. (2018). Fluorescent nanosensor based on molecularly imprinted polymers coated on graphene quantum dots for fast detection of antibiotics. Biosensors, 8 (3), 82.

[128] Gao F, Feng S, Chen Z, Li-Chan EC, Grant E, Lu X. (2014). Detection and quantification of chloramphenicol in milk and honey using molecularly imprinted polymers: Canadian penny-based SERS nano-biosensor. J. Food Science, 79 (12), N2542-N9.

[129] Ho H-A, Leclerc M. (2004). Optical sensors based on hybrid aptamer/conjugated polymer complexes. Journal of the American Chemical Society, 126 (5), 1384-7.

[130] Leclerc M, Ho H-A, Boissinot M. (2013). Optical sensors based on hybrid aptamer/conjugated polymer complexes. Google Patents.

[131] Idumah C, Zurina M, Ogbu J, Ndem J, Igba E. (2019). A review on innovations in polymeric nanocomposite packaging materials and electrical sensors for food and agriculture. Composite Interfaces, 1-72.

[132] Aghaei Z, Emadzadeh B, Ghorani B, Kadkhodaee R. (2018). Cellulose acetate nanofibres containing alizarin as a halochromic sensor for the qualitative assessment of rainbow trout fish spoilage. Food and bioprocess technology, 11 (5), 1087-95.

[133] Sergeyeva T, Yarynka D, Piletska E, Linnik R, Zaporozhets O, Brovko O. (2019). Development of a smartphone-based biomimetic sensor for aflatoxin B1 detection using molecularly imprinted polymer membranes. Talanta, 201, 204-10.

[134] Yamabhai M, Rangnoi K, Sompunga P, O'Kennedy R. (2019). Novel Recombinant Antibody and Protein-based Approaches for Analysis of Food and Food Contaminants with Particular Relevance to Asia. Rapid Antibody-based Technologies in Food Analysis, 195-222.

[135] Gutiérrez TJ. (2019). Antibiofilm Enzymes as an Emerging Technology for Food Quality and Safety. Enzymes in Food Biotechnology: Elsevier, 321-42.

[136] Wang S, Farooq U, Ullah MW, Yang Q. (2019). Applications of Phage-Based Biosensors in the Diagnosis of Infectious Diseases, Food Safety, and Environmental Monitoring. Chapters.

[137] Farooq F, Ali U, Shoukat S, Paray AR, Ali M. (2019). Bacteriophages as biocontrol agents for foodborne diseases.

[138] Assadpour E, Jafari SM. (2019). An overview of lipid-based nanostructures for encapsulation of food ingredients. Lipid-Based Nanostructures for Food Encapsulation Purposes: Elsevier,1-34.

[139] Rigg R. (2019). Liposome Containing Compositions and Their Use in Personal Care and Food Products. Google Patents.

[140] Lopez-Polo J, Silva-Weiss A, Zamorano M, Osorio FA. (2019). Humectability and physical properties of hydroxypropyl methylcellulose coatings with liposome-cellulose nanofibers: Food application. Carbohydrate Polymers, 115702.

[141] Assadpour E, Jafari SM. (2019). Nanoencapsulation: Techniques and Developments for Food Applications. Nanomaterials for Food Applications: Elsevier, 35-61.

[142] Praetorius F, Kick B, Behler KL, Honemann MN, Weuster-Botz D, Dietz H. (2017). Biotechnological mass production of DNA origami. Nature, 552 (7683), 84.

[143] Tang MS, Shiu SC-C, Godonoga M, Cheung Y-W, Liang S, Dirkzwager RM, (2018). An aptamer-enabled DNA nanobox for protein sensing. Nanomedicine: Nanotechnology, Biology and Medicine, 14 (4), 1161-8.

[144] Ramaswamy R, Ahn J, Balasubramaniam V, Saona LR, Yousef AE. (2019). Food safety engineering. Handbook of farm, dairy and food machinery engineering: Elsevier, 91-113.

[145] Daems D, Pfeifer W, Rutten I, Saccà B, Spasic

D, Lammertyn J. (2018). Three-Dimensional DNA Origami as Programmable Anchoring Points for Bioreceptors in Fiber Optic Surface Plasmon Resonance Biosensing. ACS applied materials & interfaces, 10 (28), 23539-47.

[146] Smartt AE, Ripp S. (2011). Bacteriophage reporter technology for sensing and detecting microbial targets. Analytical and Bioanalytical Chemistry, 400 (4), 991-1007.

[147] Sameiyan E, Bagheri E, Ramezani M, Alibolandi M, Abnous K, Taghdisi SM. (2019). DNA origami-based aptasensors. Biosensors and Bioelectronics, 111662.

[148] Yousefi M, Ehsani A, Jafari SM. (2019). Lipid-based nano delivery of antimicrobials to control food-borne bacteria. Advances in Colloid and Interface Science.

[149] Kalita D, Baruah S. (2019). The Impact of Nanotechnology on Food. Nanomaterials Applications for Environmental Matrices: Elsevier, 369-79.

[150] Seo SE, Tabei F, Park SJ, Askarian B, Kim KH, Moallem G. (2019). Smartphone with optical, physical, and electrochemical nanobiosensors. Journal of Industrial and Engineering Chemistry.

[151] Lee S, Kim G, Moon J. (2013). Performance improvement of the one-dot lateral flow immunoassay for aflatoxin B1 by using a smartphone-based reading system. Sensors, 13 (4), 5109-16.

[152] Song S, Liu N, Zhao Z, Njumbe Ediage E, Wu S, Sun C. (2014). Multiplex lateral flow immunoassay for mycotoxin determination. Analytical Chemistry, 86 (10), 4995-5001.

[153] Kim G, Lim J, Mo C. (2015). A review on lateral flow test strip for food safety. J. Biosystems Engineering, 40 (3), 277-83.

[154] Lu Y, Shi Z, Liu Q. (2019). Smartphone-based Biosensors for Portable Food Evaluation. Current Opinion in Food Science.

[155] Khoshfetrat SM, Bagheri H, Mehrgardi MA. (2018). Visual electrochemiluminescence biosensing of aflatoxin M1 based on luminol-functionalized, silver nanoparticle-decorated graphene oxide. Biosensors and Bioelectronics, 100, 382-8.

[156] Oplatowska-Stachowiak M, Sajic N, Xu Y, Haughey SA, Mooney MH, Gong YY. (2016). Fast and sensitive aflatoxin B1 and total aflatoxins ELISAs for analysis of peanuts, maize and feed ingredients. Food Control, 63, 239-45.

[157] Vashist SK, Schneider EM, Luong JH. (2014). Commercial smartphone-based devices and smart applications for personalized healthcare monitoring and management. Diagnostics, 4 (3), 104-28.

[158] Liu Z, Zhang Y, Xu S, Zhang H, Tan Y, Ma C. (2017). A 3D printed smartphone optosensing platform for point-of-need food safety inspection. Analytica Chimica acta, 966, 81-9.

[159] Cao Y, Liu Y, Li F, Guo S, Shui Y, Xue H. (2019). Portable colorimetric detection of copper ion in drinking water via red beet pigment and smartphone. Microchemical J., 150, 104176.

[160] Kartakoullis A, Comaposada J, Cruz-Carrión A, Serra X, Gou P. (2019). Feasibility study of smartphone-based Near Infrared Spectroscopy (NIRS) for salted minced meat composition diagnostics at different temperatures. Food Chemistry, 278, 314-21.

[161] Zheng L, Cai G, Wang S, Liao M, Li Y, Lin J. (2019). A microfluidic colorimetric biosensor for rapid detection of Escherichia coli O157: H7 using gold nanoparticle aggregation and smart phone imaging. Biosensors and Bioelectronics, 124, 143-9.

[162] Mishra RK, Hubble LJ, Martín A, Kumar R, Barfidokht A, Kim J. (2017). Wearable flexible and stretchable glove biosensor for on-site detection of organophosphorus chemical threats. ACS Sensors, 2 (4), 553-61.

[163] Li S, Liu J, Chen Z, Lu Y, Low SS, Zhu L. (2019). Electrogenerated chemiluminescence on smartphone with graphene quantum dots nanocomposites for Escherichia Coli detection. Sensors and Actuators B: Chemical, 297, 126811.

[164] Noronha VT, Aquino YM, Maia MT, Freire RM. (2019). Sensing of Water Contaminants: From Traditional to Modern Strategies Based on Nanotechnology. Nanomaterials Applications for Environmental Matrices: Elsevier, 109-50.

[165] Gumpu MB, Sethuraman S, Krishnan UM, Ray-

appan JBB. (2015). A review on detection of heavy metal ions in water–an electrochemical approach. Sensors and actuators B: chemical, 213, 515-33.

[166] Chen J, Andler SM, Goddard JM, Nugen SR, Rotello VM. (2017). Integrating recognition elements with nanomaterials for bacteria sensing. Chemical Society Reviews, 46 (5), 1272-83.

[167] Sharifi S, Vahed SZ, Ahmadian E, Dizaj SM, Eftekhari A, Khalilov R. (2019). Detection of pathogenic bacteria via nanomaterials-modified aptasensors. Biosensors and Bioelectronics, 111933.

[168] Gopinath SC, Tang T-H, Chen Y, Citartan M, Lakshmipriya T. (2014). Bacterial detection: From microscope to smartphone. Biosensors and Bioelectronics, 60, 332-42.

[169] Lan L, Yao Y, Ping J, Ying Y. (2017). Recent advances in nanomaterial-based biosensors for antibiotics detection. Biosensors and Bioelectronics, 91, 504-14.

[170] Capoferri D, Della Pelle F, Del Carlo M, Compagnone D. (2018). Affinity sensing strategies for the detection of pesticides in food. Foods, 7 (9), 148.

[171] Rhouati A, Bulbul G, Latif U, Hayat A, Li Z-H, Marty JL. (2017). Nano-aptasensing in mycotoxin analysis: Recent updates and progress. Toxins, 9 (11), 349.

[172] Goud KY, Reddy KK, Satyanarayana M, Kummari S, Gobi KV. (2020). A review on recent developments in optical and electrochemical aptamer-based assays for mycotoxins using advanced nanomaterials. Microchimica Acta, 187 (1), 29.

[173] Kahrarian Z, Horriat M, Shahbazi Y. (2019). A Review Application Method of Detecting Toxins in Food by Nanoaptamr. Asian Research Journal of Current Science, 9-11.

[174] Khedri M, Ramezani M, Rafatpanah H, Abnous K. (2018). Detection of food-born allergens with aptamer-based biosensors. TrAC Trends in Analytical Chemistry, 103, 126-36.

[175] Weng X, Neethirajan S. (2018). Paper-based microfluidic aptasensor for food safety. J. Food Safety, 38 (1), e12412.

[176] Jung Y, Heo Y, Deering A, Bae E, editors. (2019). Smartphone-based quantitative reader for detection of food-borne bacteria by lateral flow assay. Optics and Biophotonics in Low-Resource Settings V, International Society for Optics and Photonics.

[177] Carrell C, Kava A, Nguyen M, Menger R, Munshi Z, Call Z. (2019). Beyond the lateral flow assay: A review of paper-based microfluidics. Microelectronic Engineering, 206, 45-54.

[178] Kim J, Campbell AS, de Ávila BE-F, Wang J. (2019). Wearable biosensors for healthcare monitoring. Nature Biotechnology, 37 (4), 389-406.

[179] Haghi M, Thurow K, Stoll R. (2017). Wearable devices in medical internet of things: scientific research and commercially available devices. Healthcare Informatics Research, 23 (1), 4-15.

[180] Chan M, EstèVe D, Fourniols J-Y, Escriba C, Campo E. (2012). Smart wearable systems: Current status and future challenges. Artificial Intelligence in Medicine, 56 (3), 137-56.

[181] Chuah SH-W, Rauschnabel PA, Krey N, Nguyen B, Ramayah T, Lade S. (2016). Wearable technologies: The role of usefulness and visibility in smartwatch adoption. Computers in Human Behavior, 65, 276-84.

[182] Teng J, Yuan F, Ye Y, Zheng L, Yao L, Xue F. (2016). Aptamer-based technologies in foodborne pathogen detection. Frontiers in Microbiology, 7, 1426.

[183] Cheng N, Song Y, Fu Q, Du D, Luo Y, Wang Y. (2018). Aptasensor based on fluorophore-quencher nano-pair and smartphone spectrum reader for on-site quantification of multi-pesticides. Biosensors and Bioelectronics, 117, 75-83.

[184] Lin B, Yu Y, Cao Y, Guo M, Zhu D, Dai J. (2018). oint-of-care testing for streptomycin based on aptamer recognizing and digital image colorimetry by smartphone. Biosensors and Bioelectronics, 100, 482-9.

[185] Wu Y-Y, Huang P, Wu F-Y. (2020). A label-free colorimetric aptasensor based on controllable aggregation of AuNPs for the detection of multiplex antibiotics. Food Chemistry, 304, 125377.

AUTHOR (S) BIOSKETCHES

AUTHOR (S) BIOSKETCHES

Nafise Dorosti, MSc., Department of Medical Nanotechnology, Faculty of Advanced Technologies in Medicine, Mazandaran University of Medical Sciences, Sari, Iran

Pooria Gill, Assossiate Professor, Department of Medical Nanotechnology, Faculty of Advanced Technologies in Medicine, Mazandaran University of Medical Sciences, Sari, Iran & Immunogenetics Research Center, Mazandaran University of Medical Sciences, Sari, Iran & The Health of Plant and Livestock Products Research Center, Mazandaran University of Medical Sciences, Sari, Iran

Adele Rafati, Assistant Professor, Department of Medical Nanotechnology, Faculty of Advanced Technologies in Medicine, Mazandaran University of Medical Sciences, Sari, Iran & Diabetes Research Center, Mazandaran University of Medical Sciences, Sari, Iran & The Health of Plant and Livestock Products Research Center, Mazandaran University of Medical Sciences, Sari, Iran, *Email: Rafati.adele@gmail.com*