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REVIEW ARTICLE

Using nanobiosensors in the determination of food safety and quality

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HIGHLIGHTS

> The unique properties of nanomaterials expand the application possibilities of nanobiosensors in the food industry.
> Nanobiosensors enable the rapid detection of contaminants and nutrient content in foods.
> A growing number of publications and patents demonstrate the outstanding development of nanobiosensors in the food industry.

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ABSTRACT

Today, there is a growing demand for fast, reliable, and cost-effective systems for the detection, monitoring and diagnosis of food ingredients and contaminants. Quantitative/qualitative analysis of foods is carried out using traditional analytical methods, such as chromatographic and spectroscopic techniques. Despite their sensitivity and accuracy, these methods are challenging because of the multi-stage and complex sample preparation procedures, requiring specialized personnel and expensive instrumentation for analysis. In addition, their labor-intensive and time-consuming nature eliminates the possibility of on-site and high-frequency monitoring of the analytes. A wide variety of nanotechnology-based new nanobiosensors are being developed in order to eliminate the difficulties posed by these techniques. In this context, in the present study, nanomaterials used in the development of nanobiosensors for use in foods, their working principles and their use in foods were examined.

1. Introduction

In recent years, with the change in consumer preferences and awareness, interest in quality and safety issues in food has increased. For this reason, all parties operating in the food industry are under pressure to pay maximum attention to the supply of products in terms of quality and safety. These grounds are accurate, real-time, selective, cost-effective, free from interaction with other contaminants, etc. making it necessary to develop new methods [1]. Based on this need, biosensors have been defined by the International Union of Basic and Applied Chemistry as "a device that uses specific biochemical reactions generated by isolated enzymes, immune systems, tissues, organelles or whole cells to detect chemical compounds, usually with electrical, thermal or optical signals" [2]. Biosensors tend to interfere with signal generation due to the influence of the sensing matrix and co-existing molecules. In this context, metallic nanomaterials, polymers, carbon nanomaterials, quantum dots, etc. Today, nanomaterials with different sizes, shapes, and properties, such as nanomaterials, are widely used both in the scientific world and commercially to increase the efficiency of biosensors and reduce interference from the sensing matrix [3].

Basically, biosensors comprise three units, a biological recognition element (BRE), a transducer, and an amplifier and processor [4]. Biosensors have been developed for the sensitive detection of the analyte via BREs on a functionalized supporting matrix (sensor matrix). For this purpose, carbon paste, paper, graphite, and screen-printed electrodes (SPE) are some of the most widely used sensor matrices. BREs (enzymes, aptamer, antibody, nucleic acid, cell and tissue, etc.) are immobilized on the transducer surface so that the biological recognition event occurs with analyte molecules more effectively and selectively. On the other hand, the transducer (optical, electrochemical, thermal,

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and acoustic) transforms the biological recognition event into a measurable signal and enables it to be detected [5,6].

In light of current knowledge, various applications of biosensors, including quality and safety control in foods, have been revealed in many studies. Currently, biosensors are actively applied in foods for different purposes (pathogen, toxin, heavy metal, nutritional component, detection of prohibited substances, etc.). Moreover, these biosensors have been integrated into nanomolecules for the development of nanobiosensors to improve the performance of the detection system [7]. In this context, the development and application of nanobiosensors, which have a wide place both academically and commercially in the determination of food safety and quality, increase the interest in these materials. In the present review, the materials used in the development of nanobiosensors, their working principles and their applications in food are discussed.

2. Materials needed to build a biosensor

2.1. Nanomaterials

2.1.1. Metal and Metal Oxide Nanoparticles

Metal nanoparticles (MNPs) have many advantageous properties that make biosensors useful as a component of nanobiosensors. Many metals and metal-organic nanoparticles (NPs) are used in the development of nanobiosensors. Of these, gold, silver and platinum nanoparticles are the most popular. While these noble metals are chemically inert in bulk, they exhibit unique physicochemical properties at the nanoscale. It is possible to classify MNPs according to the physical/electrochemical changes that occur as a result of the binding of the analyte to be analyzed and the receptor target immobilized on the surface of the MNPs. MNPs contribute to the development of nanobiosensors by playing roles such as immobilization platform, accelerating electron transfer, catalyzing the reactions of chemical luminescence with their substrates, amplifying mass changes and improving refractive index (RI) changes [8].

Currently, among these MNPs, gold NPs (AuNPs) are widely used for biosensor applications due to their biocompatibility, unique opto-electronic properties, and relatively simple fabrication and modification techniques. AuNPs, which typically have a size between 1-100 nm, have a high surface-to-volume ratio. This property of AuNPs allows them to be used to immobilize a wide variety of biomolecules. Its superiority over other MNPs is that it supports quick and direct electron transfer, has excellent conductivity, and is a good stimulator for signal amplification with light scattering properties. All these features have allowed using AuNPs to improve the performance of optical, Electrochemical, and piezoelectric biosensors. On the other hand, they also provide the opportunity to adjust the light absorptions in the entire visible spectrum through their size, surrounding environment, and capping material [9]. Silver nanoparticles (AgNP), another important MNP, have a size of less than 2 nm and have attracted attention due to their photoluminescence in the ultraviolet (UV) region, just like AuNPs. Again, its molecule-like properties have allowed its use in biosensor applications. AuNPs have unique optical, catalytic, and electronic properties, which have enabled their use in the production of various biosensor platforms [10]. Their ultra-small size, strong fluorescence, good stability, low toxicity, good biocompatibility, and being cheaper than precious metal nanomaterials and having the same properties as precious MNPs have made copper nanomaterials (CuNP) preferable for the use of biosensors [11]. Among other materials included in MNPs, NPs based on iron oxide (Fe_2O_3) and manganese oxide (MnO_2) are considered the best-known magnetic nanomaterials due to their higher electron transfer rates. These are also components that are widely used in the construction of nanobiosensors in bioanalytical applications [12]. Cobalt oxide-based nanoparticles (Co_3O_4 NP) are of great interest in nanobiosensor applications due to their physical, chemical, magnetic, optical and electronic properties. It is especially used commercially for gas and chemical sensors [13]. As a bulk material, titanium dioxide (TiO_2) powder is applied in personal care products and paints as well as giving white color to some food products and increasing the brightness of food. In their different forms, TiO_2 NPs show features such as photocatalysis, n-type semiconductor, non-toxic, biocompatible, low cost, high stability and environmentally friendly. These features provide a good use of transforming materials in the development of biosensors for food safety and quality [14].

2.1.2. Semiconductor Quantum Dots

Semiconductor Quantum Dots (QD) are one of the most preferred nanoparticles for researchers as fluorescent labels in recent years. They play an important role in the development of different platforms for the detection of many analytes using their semiconductor-like electrical properties and narrow and size-tunable emissions. QDs with different compositions and emissions, such as CdS, Pbs, and ZnS, are widely used today to detect antibiotic residues by labeling them with complementary strands of aptamer specific to antibiotic residues [15].

2.2. Bioreceptors (Biological recognition element)

Biological materials such as antibodies, aptamers, cells, enzymes, receptors, or neurons are used as recognition/sensing elements in biosensors. BREs are known for their high specificity and selectivity towards the target molecule compared to their counterparts. These properties allow for ease of functionalization and amplification against any antigen in animal and microbial models. On the other hand, the unstable structure of BREs, which is one of the most important problems encountered in biosensor applications, is a problem that needs to be solved. Therefore, they must be immobilized [16].

Enzymes are common biocatalysts that are effective in increasing the rate of biological reactions. The working principle of enzyme-based biosensors can be explained by the following possible mechanisms: (a) The analyte is metabolized by the enzyme and thus the enzyme concentration is estimated by measuring the catalytic conversion of the analyte by the enzyme, (b) the enzymatic product formation as a result of an enzymatic reaction inhibited or activated by the analyte, and (c) changes in enzyme characteristics are monitored. Antibodies, also known as immunoglobulins, are preferred biorecognition elements in the development of biosensors for the detection of food contaminants, as they have good selectivity against their antigens [17].

Recognition of DNA sequences is necessary to control and detect molecular structures. Using single DNA/RNA strands or synthetic oligonucleotides called aptamers as BRE is a rather new and interesting approach. DNA-based biosensors use DNA probes for BRE, which are then converted into a signal using the transducer. Aptamers are small chain synthetic oligonucleotides that can bind specifically to toxins, peptides, ions, whole cells or proteins. Aptamer-based detection methods have attracted important attention in biosensor applications due to their high selectivity and affinity for bio-recognition elements [18].

2.3. Transducer

According to their working principles, transducers are generally classified as electrochemical, optical, thermal, electronic and gravimetric. Electrochemical transduction, which is among the available sensing modes, provides high sensitivity and specificity and portable analyzers, allowing the necessary instrumentation to be miniaturized [19]. Especially with advances in nanotechnology, these transducers allow simultaneous parallel monitoring of multiple chemicals or biological parameters or monitoring of a single parameter in several samples.

Fluorescence is another physical process used to develop sensors. Surface plasmon resonance (SPR), which is one of the optical techniques for pathogen detection, has widespread use. Techniques based on optical-based sensors monitor optical signal changes that occur between a functionalized nanomaterial and a toxin or bacteria. Used in this sense, SPR is the basis of many standard tools for measuring the adsorption of material onto planar metal surfaces or the surface of metal NPs. An SPR sensor can be used to measure the amount of analyte captured as it records the shift of the resonant wavelength as a function of time. In this context, fluorescent approaches are used in numerous biosensing applications [20].

Another type of transducer, piezoelectric sensors, consists of a piezoelectric material (usually a crystal) whose surface undergoes mechanical deformation and displacement of electric charge when pressure is applied, or vice versa when pressure is reduced. The quartz crystal microbalance (QCM) developed for this purpose is the most popular piezoelectric detector today. It works based on sending an electrical signal through a gold-plated quartz crystal with a biological recognition element on its surface. When bonding occurs, the mass change produces vibrations in the crystal, and the oscillation frequency in the crystal changes [21]. Thermal biosensors take advantage of the fundamental properties of biological reactions (exothermic or endothermic), namely the measurement of heat energy absorbed or released during the reaction. With this feature, the amount of thermal energy released as a result of the reaction with signal detection components is converted into quantitative data, revealing the detection and amount of the analyte [22].

Colorimetric nanobiosensors are of great interest because of their simple and versatile functions. The frequency of absorbed light can vary depending on the shape, size, composition and aggregation state of the nanoparticles. In this regard, MNPs offer an extremely high molar extinction coefficient. Colorimetric nanobiosensors are widely used today for foodborne pathogen detection and work based on the principle of changing plasma coupling between NPs [23,24].

3. Working mechanism of nanobiosensors

Nanobiosensors are used today as a way to detect different analytes, such as antibodies, nucleic acids, pathogens and metabolites, toxic substances, prohibited substances, and the detection of components in the normal composition of food. In simple terms, the working principle of a nanobiosensor starts with the binding of the relevant bioanalytes to the bioreceptors, and then continues by modulating the physicochemical signal associated with this binding. Next, a transducer captures the physiochemical signal and converts it to a signal (Electrical, optical, etc.). The variation in the exposed signal is monitored. Analysis of variation in one or more of the different parameters resulting from signal-induced changes quantifies the presence or absence of the analyte (Figure 1). In addition, the nanostructures in nanobiosensors act as an interlayer between biological agents and physicochemical detector components or biological agents, and the transducer is combined with nanomaterials to form a biosensor [25].

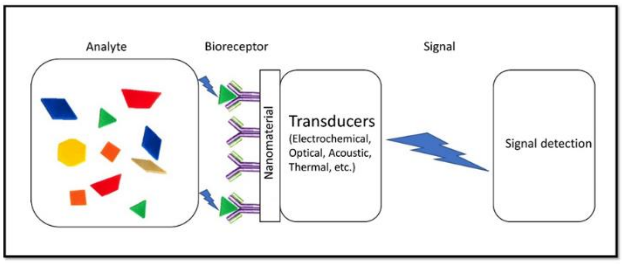

Figure 1. The construction diagram for a nanosensor

4. Their use in food

Today, in terms of food safety, the potential presence of various food additives, drugs, pesticides and fertilizers, pathogenic microorganisms including viruses and bacteria, dioxins, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), heavy metals and biotoxins in foods poses important risks. Moreover, it is clear that various components such as sugars, amino acids, alcohols, organic acids, cholesterol, polyphenols, fatty acids, and biogenic amines must be monitored nutritionally in order to monitor food quality. This situation reveals the need for multidimensional consideration of food safety and quality assurance, and therefore the importance of protecting public health with interventions at every step of the food supply chain [26]. In this context, fast and cost-effective methods should be preferred for the measurements of analytes in the field or on the production line. Moreover, it is possible to perform such analyzes quickly and cost-effectively with nanobiosensors and nanobioanalytical tests instead of time-consuming, costly, and complex applications [27]. The current use of nanobiosensors in foods is discussed in the following subheadings according to their intended use.

4.1. Determination of food components

The food industry needs fast, reliable, and robust sensors at different stages of food processing as well as the final product. Nanotechnology-based biosensor approaches have found their place in various applications for the detection of food components. In this context, Szydłowska-Czerniak et al. [28] developed an AgNP-based nanobiosensor. The performance of AgNP-based nanobiosensor was compared with traditional FRAP, DPPH and FC methods, which show linear correlations in the antioxidant content of 15 types of rapeseed oil. The results revealed significant positive correlations between AgNP-modified FRAP, DPPH, and FC methods for all extracts of rapeseed samples studied. In terms of sensitivity and accuracy, it is remarkable that the analysis of the antioxidant capacity of rapeseed samples with this method gives inexpensive and fast results.

It is known that high intake of caffeine, which is in the structure of some foods, poses a risk to human health. A nanobiosensor capable of detecting caffeine with magnetic molecular imprinted polymeric microspheres (MMIP) prepared using Fe_3O_4 as the supporting core, mesoporous SiO_2 as the intermediate shell, α-methyl acrylic acid as the functional monomer and caffeine as the template has been developed [29]. In this method, MMIPs removed caffeine from beverages, then AgNPs were rapidly screened by colorimetric method. Caffeine, measured semi-quantitatively as ≥ 5 mg L^{-1}, was accurately measured in the 0.1-5 mg L^{-1} range by UV-vis spectroscopy at 393 nm, consistent with HPLC analytical results. The researchers suggested that this method could be used to quickly and precisely analyze caffeine in beverages. In another study, a core-shell molecular imprinted fluorescent nanosensor was developed for the proportional fluorescence and visual detection of folic acid (FA) in foods. For this purpose, the nanosensor was prepared by fixing the printing shell on silica nanoparticles and embedding CdTe quantum dots in the printed shell to provide FA-dependent fluorescent signals. The resulting data revealed a favorable linearity relationship between a limit of detection (LOD) of 48 nM and fluorescence intensity ratio (I449/I619) and FA concentration above 0.23-113 µM under optimum conditions. Qualitative evaluation with visual perception was carried out by evaluating abundant fluorescent color changes from red to pink, and purple to blue. This developed sensor has been evaluated by researchers as having excellent sensing performances such as fast response, high and selective recognition. On the other hand, it has been suggested that satisfactory instantaneous recoveries between 94.8% and 104.2%, which are consistent with the measurement results, were obtained with HPLC-UV [30].

4.2. Food packaging and shelf life

The purpose of food packaging is to increase food shelf life by protecting food against spoilage and bacterial growth in a food or by preventing food nutrient loss. For this purpose, nanotechnology-based approaches used in food packaging offer higher hopes in food packaging by promising longer shelf life, safer packaging, better traceability of food products, and healthier food. Intelligent and active packaging systems produced with nanotechnology will be able to repair tears and leaks (self-healing feature) and respond to environmental conditions (e.g. temperature and humidity changes) [31]. Due to their simplicity, low cost, affordability, and efficiency, Time and Temperature Indicators (TTIs) are widely used today to monitor and demonstrate the quality of foodstuffs [32]. Zhang, et al. [33] developed a nanobiosensor that can show the quality of cakes with AgNP-based TTI. According to the color change resulting from the reaction, they stated that the dark purple color may represent the deterioration and inedibility of the cakes. In another study, a protein-based halochromic nanosensor was designed to evaluate the quality of rainbow trout fillets. In the study, zein nanofibers containing alizarin as an indicator dye were electrospun. The color of the sensor changed to magenta on the 10th and 12th day of cold storage, indicating deterioration. It has been stated that this developed halochromic nanosensor can monitor fish freshness in real-time through color changes [34]. In a similar study [35], cerium nanoparticles (CeNPs) were also used as a multifunctional enzyme mimetic material based on xanthine oxidase to monitor fish freshness, measuring the release of hypoxanthine (HX), a product of nucleotide degradation, in meat and fish, and as a redox-enhancing and chromogenic indicator. The researchers noted the potential for use of this technology as an inexpensive approach to monitoring HX levels, as opposed to traditional multi-step enzyme-based solution assays. In another study [36] an electrospun nanofiber mat based on polyvinyl alcohol and a natural pigment derived from red cabbage (*Brassica oleracea L.*) extract (RCE) was prepared to act as a pH biosensor. The pH sensitivity was calibrated using a color spectrum colorimeter at different pH values of the nanofibers tested using a range of different pH solutions. It has been revealed that this designed mat can be used as a pH sensor and accurately displays pH values in the 2-12 range.

Optical biosensors are widely used in the rapid evaluation of foods due to their simplicity and visualization. In this context, smartphones with high-resolution cameras and advanced computational capabilities draw attention to the development of nanobiosensors as an instrument to reflect the sensitivity of optical sensing. For this purpose, AuNPs show different *E. coli* O157:H7 concentrations and a new biosensor that uses the imaging feature of the smartphone to monitor the color change of AuNPs has been developed [37]. Magnetic nanoparticles (MNPs) modified with capture antibodies and polystyrene microspheres (PSs) modified with detection antibodies (PSs) and catalases were used simultaneously to react with target bacteria in the first mixing channel of the microfluidic chip, a system was developed to quantify bacteria. The color was measured using the smartphone imaging feature. It has been suggested that this biosensor exhibits good specificity and sensitivity for the detection of *E. coli* O157:H7 in chicken samples with a lower detection limit of 50 CFU/mL.

4.3. Food Processing

Some metabolites that are known to be harmful to human health may be released as a result of some undesirable reactions during the processing of foods. In this context, it can contribute to rapid detection, intervention and process regulation in the processing process. Acrylamide is an amide-type organic compound, which is classified as a probable human carcinogen (Group 2A) by the International Agency for Research on Cancer and formed as a result of the Maillard reaction. A nanobiosensor developed for the detection of raw potato glucose content at 150 °C ($r = 0.8985$, $P<0.01$) and 176 °C ($r = 0.9949$, $P<0.01$) revealed a high correlation between the level of acrylamide in fried potato chips [38]. This developed biosensor can be used to quickly predict the formation of acrylamide during industrial potato processing. An electrochemical biosensor based on DNA-carbon dots of N-nitrosodimethylamine (NDMA) and N-nitrosodiethanolamine (NDEA), another mutagenic and carcinogenic food component, has been developed [39]. In this study, after the chitosan carbon dot was deposited on the glassy carbon electrode (GCE), DNA was electrostatically immobilized on the surface of the carbon dots and a sensing electrode (DNA/chiCD/GCE modified electrode) was produced. It was emphasized that it could be a fast and alternative method for the detection of nitrosamines in foods with detection limits of 9.9×10^{-9} M and 9.6×10^{-9} M. In another study [40], a graphene-based nanosensor was developed for in situ monitoring of polycyclic aromatic hydrocarbons (PAHs) in aqueous solutions. The sensor was fabricated using photolithography and etching Au/Ti film on a silicon layer followed by the transfer of a single sheet of graphene prepared separately by chemical vapor deposition (CVD). It has been suggested that this developed sensor can be applied to many contaminated water bodies or engineering systems due to its low detection cost, portability, and ease of use.

4.4. Microbial contamination

Today, a wide variety of biosensors have been developed to detect foodborne pathogens and their toxins [28]. For this purpose, a nanobiosensor based on Förster resonance energy transfer (FRET) between semiconductor nanocrystals (quantum dots, QDs) and dark quencher-labeled peptide probes has been reported for botulin-BoNT serotype E (BoNT/E) detection. Peptide probes contain a specific cleavage site for active BoNT/E. The detection limits were reported as 0.02 and 2 ng/mL for BoNT/E light chain and holotoxin, respectively, and the sensor was reported to give results in a total of 3 hours. It has been suggested that this nanobiosensor, which has been developed with its advantages such as high sensitivity, simple operation, short detection time and can be used in parallel with probes developed for other BoNT serotypes, will be useful for rapid BoNT/E detection and serotype discrimination in food analysis [41].

A nanobiosensor has been developed for fast, easy and high-sensitivity detection of *Staphylococcus aureus (S. aureus)*, another important food pathogen [42]. In this study, a paper-based portable device was produced to detect bacterial cells and a value between 102 – 108 CFU/mL was determined as the linear dynamic range of the colorimetric Au/Pt NC-based optical sensor. Moreover, it has been suggested that this microfluidic paper can detect entire bacterial cells very quickly in five minutes, with high sensitivity in real samples. In a similar study, a biosensor based on superparamagnetic ultra-small iron oxide nanoparticles (USIO NPs) combined with membrane filtration and low-field nuclear magnetic resonance (LF-NMR) was developed for rapid detection of *Salmonella* [43]. In this study, firstly, specific binding of free biotin capture antibodies and detection antibodies to different *Salmonella* targets in milk samples was achieved. The streptavidin-coated USIO NP probes were then coupled with the biotinylated monoclonal antibody to capture *Salmonella*. Finally, polyethersulfone membrane filtration was performed in the final reaction system to remove unbound probes, and the transverse magnetization time of the filtrate was measured by NMR to indirectly reflect the content of the target substance retained in the filter membrane. The researchers reported that this method showed high specificity against *Salmonella* and the limit of detection (LOD) in pure culture and real samples was 2.3×10^3 CFU mL^{-1} in 150 minutes. With a similar approach, direct detection of *Escherichia coli (E. coli)* in food samples is also possible by measuring and detecting light scattered by cells. This type of sensor operates on the basis of binding with a known protein and can be characterized as a bacterium on a silicon chip that can bind to any other *E. coli* bacteria present in the food sample [44].

4.5. Detection of toxic chemicals

The presence of toxic materials such as pesticides, foodborne toxins, and heavy metals in foods is considered a risk to human health. It is also among the possible risks that the materials used in the packaging of foodstuffs leak into the food and cause unwanted exposure [45]. AuNP (30 nm)-based dipstick competitive immunoassay (anti-DDT antibodies (IgY)) assay to detect organochlorine pesticides such as DDT at the nanogram level (ppb) was developed by Lisa, et al. [46]. In this study, the lowest detection limit of DDT was determined as 27 ng mL-1 with optimized conditions. According to the results obtained, the researchers reported that AuNPs nanobiosensor is an appropriate and rapid application for the detection of organochlorine pesticides in food and environmental samples, since AuNPs have agglomeration properties associated with color production.

Cantilever nanobiosensors have emerged as an alternative to traditional analysis methods to monitor heavy metals, highlighted by the detection of substances at the micro and nanoscale through the use of sensor layers. In a study [47] a new cantilever nanobiosensor functionalized with urease enzyme by self-assembled monolayers was developed for the detection of heavy metals (lead, nickel, cadmium, zinc, cobalt, and aluminum) in water. This developed nanobiosensor presented high sensitivity, good stability, and a detection limit over a wide ppb range during 30 days of storage. Researchers reported that the cantilever nanobiosensor with urease enzyme can detect heavy metals in water sensitively and accurately. In another study [48], Au–Ag nanostructures were developed to detect pesticides in tea samples based on a SERS (surface-enhanced Raman spectroscopy) substrate. Pesticides in tea (dichlorophenoxyacetic acid and acetamiprid) could be detected using the potential difference exhibited by different nutrients in complex matrices. It has been suggested that the developed nanosensor has linearity from 1.0×10^{-4} to 1.0×10^3 μg g^{-1}, 2 s detection time, 99.85% recovery and, 4.85% reproducibility.

4.6. Detection of food allergens

Food allergies can cause life-threatening type I hypersensitivity immune responses. While treatment and emergency care interventions can limit the damage of an allergic episode, there is currently no cure for food hypersensitivities. Due to the complexity of food preparation methods in the modern diet, many patients may be accidentally exposed to a known allergen [49]. In this context, rapid and on-site detection of food allergens is of vital importance. To this end, Weng and Neethirajan [50] developed an integrated microfluidic system with quantum dot (QDs) nanoparticles and aptamer-functionalized graphene oxide (GO) for the detection of Ara h 1 allergen. Researchers reported that this nanobiosensor they developed has a detection limit of 56 ng/mL. In a similar study, Speroni et al. [51] developed an enzyme-linked immunosorbent assay (ELISA) based on antibody-coated magnetic microparticles for the detection of Ara h 3/4 allergen in foods. The limit of detection was found to be 0.2 mg, with a linear response range of 2.5 to 15 mg peanuts/kg. In another study, Zhang and Zhou [52] developed an aptamer-based nanosensor immobilized on graphene oxide (GO) and fluorescent surfaces for the detection of tropomyosin. It has been suggested that this nanobiosensor operates in the concentration range of 0.5 to 50 $\mu g/mL^{-1}$ with a detection limit of 4.2 nM.

5. Conclusion

Nanobiosensors are newly emerged quality and safety detection tools with various applications in foods. It is not possible to limit the current developments in our review with this research. There are currently developed and more sensitive nanobiosensors. While current research focuses on the range of applications and advances made in recent years, several challenges remain. Besides the sensible choice of fabrication method, a number of variables can affect the performance of such detection approaches. It is assumed that it is too early to conclude that nanobiosensors developed based on nanotechnology can provide solutions as a single point of solution. Nevertheless, the use of nanobiosensors in food is promising solutions for the future and is considered to have potential for current food quality and safety assessment applications.

Conflict of Interest

No conflict of interest was declared.

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