Utilisation of Quantum Dots in Food Industry

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Introduction

Nanotechnology is an emerging branch of science and technology that deals with structures whose atomic or molecular level dimensions vary from 1 to 100 nm. A nanometer is one billionth of a meter (1 nm=10^{-9}). Earliest known discussion about nanotechnology was considered to be a speech by American physicist Richard Feynman in 1959. The speech was titled, "There's Plenty of Room at the Bottom". Nanotechnology has found applications in various fields like electronics, pharmaceuticals, agriculture, food and beverages, textile, cosmetics, surface coatings etc. The term 'nanotechnology' was first coined by the Japanese scientist Norio Taniguchi, 1974; where he explained the production technology that creates objects and features on the order of a nanometer scale.

The applications of nanotechnology have emerged in the field of food science and technology. Nowadays nanotechnology is being used in various fields of food science and food microbiology, including food processing, food packaging, functional food development, food safety, detection of foodborne pathogens, and shelf-life extension of food and/or food products.

One such application of nanotechnology is a fluorescence detection technique by means of Quantum Dots which are nano-biosensors.

What are Quantum Dots?

Quantum Dots are nanocrystals of semiconductors with narrow, very specific, stable emission spectra. The size of a quantum dot may vary from 2nm to 10nm. They consist of a core, which is most commonly made of cadmium selenide (CdSe), cadmium telluride (CdTe) or Indium phosphide (InP). The core of the quantum dots should exhibit high quantum yield. Quantum yield is the proportion of the light emitted to light absorbed by a fluorescent molecule. Quantum yield is an indicator of the brightness of the molecule.

The Working Principle of the Quantum Dots

The fluorescence is generated when an excited electron relaxes to the ground state. The electron emits energy when traveling back from the excited state to the ground state. The energy necessary from jumping from the ground state to the excited state comes from an external source such as UV light. The distance that the electrons have to travel from the excited state to the ground state is known as band gap. When the band gap is larger, the electron emits more energy. Smaller QDs have a larger band gap, thus, their light is bluer because higher frequency wavelength (more energy) is emitted. Bigger QDs have a smaller band gap, so, the light they emitted is redder because lower frequency is emitted.

These Quantum Dots may be further bioconjugated with several biomolecules to form hybrids which combine the unique optical and magnetic properties of nanoparticles with the specific and selective binding behaviour of the biomolecules. This property makes quantum dots efficient biological fluorescent probes for qualitative and quantitative analysis.

Advantages of Quantum Dots over Traditional Detection Techniques

Fluorescence labelling using organic dyes such as fluorescein isothiocyanate (FITC) or rhodamine 6G (R6G), traditional organic dyes used in biological labelling exhibit a narrow excitation spectra and broad emission spectra. When used in multicolour experiments, their narrow excitation spectra make simultaneous excitation difficult, and their broad emission spectra with long tails at higher wavelengths introduce spectral cross-talk between different detection channels, making quantification difficult among different probes. Semiconductor QDs, with photophysical properties opposite to organic dyes (i.e., broad excitation spectra and narrow symmetric emission spectra), can solve the problems encountered in multicolour experiments where organic dyes are used. Furthermore, surface passivated semiconductor QDs are highly stable against photobleaching as compared to conventional organic dyes.

The method of detection by quantum dots have been found to be easier, cheaper and takes relatively lesser time for detection in comparison to the traditional methods of detection such as GC-MS, LC-MS, AAS etc.

Various Applications of Quantum Dots in Food Industry:

a) Detection of toxins

Hu *et al*., (2014) studied the presence of acrylamide in potato chips using Quantum Dots technique. Acrylamide is a neurotoxin which is found in thermally processed food products such as potato crisps, fries, vegetable crisps, breakfast cereals, baked products like cakes, cookies and other fried baked and roasted products. It is formed due to the Millard reaction between aspargine and reducing sugars. Acrylamide is a carcinogen having high toxicity. Hence rapid detection of this compound in the food products is necessary for food safety.

The Quantitative analysis of the presence of acrylamide in the food products are done mainly by two methods i.e. by Gas chromatography- Mass spectrometry (GC-MS) and Liquid chromatography- Mass spectrometry (LC-MS) (Raffan and Halford, 2019). According to the studies conducted by Hu *et al*., (2014) it was found that method of detection by fluorescence sensing by means of Quantum Dots was a more rapid process as compared to the traditional methods of detection and was conducted at a much lower cost. It was further suggested that this novel technique could be useful for a faster on-line detection of acrylamide during food processing.

b) Detection of trace elements

Wei *et al*., (2012) studied the efficiency of manganese modified CdTe quantum dots to detect trace copper element in beer samples. Beer is one of the most popular alcoholic beverages in the world, and it contains copper that comes from raw materials, crop treatment or manufacturing processes.

Though copper is an essential trace element it becomes toxic if consumed in higher quantity. The copper content in beer also influences the foaming quality and the flavor enhancement. Thus, the determination of copper in beer is important for food safety and public health.

There are several methods of determination of copper in food products such as atomic absorption spectroscopy, adsorptive stripping voltammetry, inductively coupled plasma optical emission spectrometry, X-ray fluorescence spectrometry and cloud-point extraction method. However, most of these methods require sophisticated and relatively expensive apparatus, and the procedures are complicated and relatively time consuming. The method of detection by quantum dots have been found to be easier, cheaper and takes relatively lesser time for detection in comparison to the traditional methods of detection. The quantum dots were found to have high photoluminescence with quantum yield of 84%. The proposed method was successfully applied to the detection of trace copper element in beer samples without any pre-processing, and the results agreed with those obtained by AAS.

c) Detection of foodborne pathogens

Kuo *et al*., (2008) studied the efficiency of antibody-conjugated CdTe quantum dots for *Escherichia coli* detection. Chemically denatured bovine serum albumin (dBSA)-coated water-soluble cadmium telluride (CdTe) quantum dots (QDs), which can effectively improve the chemical stability and photoluminescence quantum yield of CdTe QDs, were successfully conjugated to an anti-Escherichia coli antibody via a cross-linking reaction. The anti-*E. coli* antibody-conjugated CdTe QDs were then used to detect E. coli O157:H7 and *Listeria monocytogenes* using fluorescence microscopy. The results successfully demonstrated the potential of bioconjugated CdTe QDs for broad biological applications, such as fluorescence-based pathogen detection and in vitro or in vivo cell imaging.

d) Detection of flavour compounds

An optical sensor for vanillin in food samples was developed using CdSe/ZnS QDs modified with β-cyclodextrin (β-CDs) by Durán *et al*., (2015). The vanillin-sensor was based on the selective host–guest interaction between vanillin and β-cyclodextrin. Hence the analytical potential of this sensing system was demonstrated by the determination of vanillin in synthetic and food samples (sugar, milk and custard).

Other applications of quantum dots are detection distribution of proteins in food matrices, the successful tagging of food proteins such as gluten and zein and detection of pesticides and herbicides etc.

Conclusion

Food safety is a prime concern to the food industry. The sensitive detection of food contaminants such as pesticides and pathogenic microorganisms is highly desirable to ensure food quality and safety. Conventional methods of detecting pesticides and foodborne pathogens are lacking in terms of sensitivity, specificity, reproducibility and speed. Tests currently used to detect them are time consuming and labour intensive. Biosensors are proving to be favourable tools for the screening of food contaminants like pesticide residues, foodborne pathogens and their toxins, because of their high sensitivity, selectivity, simplicity, reliability and field applicability. Biosensors based on micro- and nanofabrication are emerging in the area of food processing. Biosensors possess many advantages in comparison to conventional techniques in terms of cost per assay, required minimum sample volume, analytical time, and potential for multiple-analyte analysis with high sensitivity and specificity.

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