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APPROPRIATION OF NANOPARTICLE AS FOOD ADDITIVE: A POSSIBILITY

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ABSTRACT

Aim: To review the use of eco-friendly synthesis of Nanoparticle as a food additive and their health implications.
Study Design: A review
Duration of Study: The review was carried out in the duration of 3weeks lockdown, reviewing all literature and data.
Methodology: Information was gathered from journals, literatures or publications which were done holistically. Useful information was gathered over the period of review. The introduction focused on the success of nanotechnology in various aspect of life. Food, additives is a new area of interest because food industries have constantly been in quest to discover the best possible way to preserve food, increase or improve shelf-life, increase or improve nutritional value(s) while saving cost at the same time without adverse effect to health.
RESULTS: This review has explored the various ways in which Nanoparticle could be of immense use in food production, processing and storage. For instance nanostructured materials have been used in food industries to improve quality of food; enhance solubility, improve bioavailability and protective bioactive components for packaging and storage. Examples include nanoemulsions, nanosensors, nanocoating and nanocomposites which have been used to improve additives during processing, to monitor food pathogens and for food packaging respectively. In health, the adverse effect of nanostructured materials has not been well documented, however, it has been used to improve drug delivery and to treat certain diseases; cancer, enhance food digestion and food uptake. This review has provided vast knowledge that can be of immense advantages in food production.
CONCLUSION: Nanotechnology as come with many advantages and has given scientist the room to explore its functions/uses in different aspect of life. In years to come, the world would be a better place with advancement in technology and nanotechnology would be at the hub of that advancement.

Keywords: Eco-friendly, Nanotechnology, Nanobiotechnology, Addivitives, Nanoparticle; Food Additives.

1. INTRODUCTION

The advert of nanotechnology as opened opportunities in wide range of sectors. These have cut across all aspect of life; Agriculture, Health, Materials, and Environmental Science. However, in food, additives is a new area of interest because food industries have constantly been in quest to discover the best possible way to preserve food, increase or improve shelf-life, increase or improve nutritional value(s) while saving cost at the same time without adverse effect to health and environment. For example, increasing nutritional value, development of new tastes and sensations, and creamier textures through nanostructuring of food ingredients with much less (or no additional) fat. It is therefore not surprising that one of the fastest moving sectors to embrace new technologies to realize the potential benefits is the food industry. Many of the world's largest food companies have been reported to be actively exploring the potential of nanotechnology for use in food or food packaging (Berne *et al.*, 2000; Borm *et al.*, 2006).

2. NANOTECHNOLOGY

According to the National Nanotechnology Initiative (NNI), Nanotechnology is the manipulation of materials, systems and devices to produce nanoparticles with at least one dimension sized from 1 to 100 nanometers (NIN, 2004, Lövestam *et al.*, 2010). The prefix "nano" was derived from a Greek word for dwarf; one nanometer (nm) is one billionth (Van *et al.*, 2013; Morais *et al.*, 2014) of a meter. Nanoparticles act as a bridge between bulk materials and atomic or molecular structures. Nanoparticles are of different types, they may be synthesized naturally, unintentionally released or manufactured (Nowack *et al.*, 2007). There are two classifications of nanoparticles; Inorganic nanoparticles i.e. metal/ metal oxides for example Au, Ag (Lateef *et al.*, 2016), Fe_3O_4, TiO_2 etc and Organic nanoparticles i.e. quaternary ammonium compound, cationic quaternary polyelectrolytes and chitosan etc.

3. NANOBIOTECHNOLOGY

Nanobiotechnology is a word describing the synergy between the world of engineering and molecular biology (Morais *et al.*, 2014). Researchers in the field of engineering have been known for decades to be working on shrinking the dimensions of fabricated structures to enable faster and higher density which have yield tremendous result as they were able to acquire the size as small as 20 nm and so also were researchers in the field of molecular biology in the domain of molecular and cellular dimensions ranging from nanometers to micrometers (Morais *et al.*, 2014; Whitesides, 2003). Niemeyer and Mirkin (2004) stated that it is believed that a combination of these disciplines will result in a new class of multifunctional devices and systems for biological and chemical analysis. The wealth of knowledge from the two broad areas of science is embedded in nanobiotechnology, creating a vast research ground for researchers.

Nanobiotechnology provides new insight into many intricate problems in science and technology; analyses of signaling pathways into diseases processes, thus identifying more efficient biomarkers and shedding more light on the action of drugs mechanism (Jain, 2011), manipulation of nanomaterials in order to facilitate the binding of different biomolecules such as bacteria, toxins, proteins and nucleic acids (Crean *et al.*, 2011), bioremediation using nanoparticles and production of nano particles from plant wastes. The use of plant materials for nanoparticles synthesis is a comparatively new and under-researched technique (Huang *et al.*, 2007). Using plant parts such as leaves (Khalil *et al.*, 2011), husk (Lateef *et al.*, 2016), roots (Suman *et al.*, 2013) and stem bark (Shameli *et al.*, 2012) have been successfully used in the synthesis of metal nanoparticles.

4. FABRICATION OF NANOPARTICLE

Top- down and bottom- up are the two approaches to the synthesis of nanomaterials and fabrication of nanostructures (Pathakoti *et al.*, 2017). Here the top-down method is not the most preferred because it exposes the materials to possible stress, contamination and it is also slow. The top-down method is to break down bulk materials through crushing and stabilization by the addition of colloidal protecting agents to reduce the size to nanoscale. While the bottom is more preferred because it uses layer by layer building approach. The bottom-up approach is fundamentally different to the top-down approach, involving the building of nanomaterials from individual atoms that have the ability to assemble in a natural and self-regulating manner (Riley *et al.*, 1999).

4.1 CHARACTERISTICS OF NANOPARTICLE THAT MAKE IT SUITABLE IN FOOD

Size and Surface area

Particles of nanostructured material range from 1 to 100 nm in size. Nanostructured material (NSM) consists of interfacial layers, which have ions and organic and inorganic molecules that are responsible for all the alterations in the properties of the matter. NSM are mainly classified into four categories: zero-dimensional nanoparticles (0D NSM), one-dimensional nanoparticles (1D NSM), two-dimensional nanoparticles (2D NSM) and three-dimensional nanoparticles (3D NSM) (Hett *et al.*, 2004).

Primarily nanoparticles are characterized by evaluating the distributed particle size and morphology of the material. Electron microscopy helps in the evaluation of nanoparticle size, as well as morphology. Various studies have highlighted the effect of the size of nanoparticles on their application. Nanomaterials can be used as bioactives in functional foods (Liang *et al.*, 2006). Reducing the particle size of bioactives may improve the availability, delivery properties and solubility of the bioactives and thus their biological activity, because the biological activity of a substance depends on its ability to be transferred across intestinal membranes into the blood (Shegokar *et al.*, 2010). Smaller particles are likely to combine during storage and help in the transportation of the dispersed nanoparticles. The smaller the size of the nanoparticles, the larger the surface area, which results in faster release. Polymer degradation is also affected by the size of the particles (Betancor *et al.*, 2008).

The specific surface area of a particle depends on its shape, size, pore size distribution, porosity and roughness. Specific surface area is used to design a heterogeneous catalyst with high specific surface area (e.g., silica, zeolites) (Amador and MartindeJuan, 2016).

Surface Charge

One of the most important characteristics to determine various characteristics of a nanoparticle is the surface charge. It helps in the determination of the colloidal stability (Tohver *et al.*, 2001; Pochard, 2003), nanostructure of the material, self-assembly of the nanoparticle (Duan *et al.*, 2004), structure of nanocomposites, function of nanocomposites (Kickelbick, 2007) and photocatalysis (Astruc, 2008). The electrostatic interaction of a nanoparticle with the environment, such as the bioactive compounds, is determined by the surface charge. The stability of colloidal nanomaterials is generally analyzed by the zeta-potential of its nanoparticles (Bhatia, 2016). Zeta-potential is the value of the surface charge of a nanoparticle at specific environmental conditions of the medium, such as pH, temperature, ionic strength, etc. It is measured by assessing the potential difference between the surface of shear and the outer Helmholtz plane and thus gives us the stability of the sample (Bhatia, 2016). Zeta-potential values are either positive or negative, ensuring the stability or avoiding the agglomeration of the particle. The pH of the solution determines the ionization of surface groups and, therefore, the final surface charge density (de Britto *et al.*, 2012). Normally for the layer by layer (LBL) deposition technique, the pH of the solution should be selected so that the signs of the electrical charges on the particle surface and adsorbing polyelectrolyte are opposite, and the magnitude of the charges on both species is sufficiently high (Chen and Wagner, 2004).

Antimicrobial Property

Nanoparticles that exhibit antimicrobial property either kill the microorganisms or decrease their growth rate. Antibacterial agents are broadly classified into two categories: bactericidal (kills the bacteria) or bacteriostatic (decreasing the growth rate of bacteria) (Santos, 2013). The antimicrobial property of the nanoparticle depends on certain properties, such as size, surface area, morphology of the crystal reactive sites etc (Santos, 2013; Allaker, 2010). The interaction of nanoparticles is also different for Gram-positive and Gram-negative bacteria. For gram-negative bacteria, the penetration of the particles depends on the size, charge and other properties of the material (Taylor, 2011; Pal *et al.*, 2007; Lellouche *et al.*, 2012; Shankar *et al.*, 2004).

5. ADDITIVES

These are chemicals or plant extracts that are added to food to improve its taste, shelf life or its nutritional value(s). Food additives are substances added to food to preserve flavor or enhance its taste and appearance. Some additives have been used for centuries; for example, preserving food by pickling with vinegar, salting, as with bacon, preserving sweets or using sulfur dioxide as in some wines. With the advent of processed foods in the second half of the 20th century, many more additives have been introduced, of both natural and artificial origin (Pandey and Upadhyay, 2012).

6. NANOPARTICLES IN FOOD

Application of nanotechnology in food science is going to impact the vital aspects of food and related industries from food safety to the molecular synthesis of new food products and ingredients (Chen *et al.*, 2006). The unique features of these nanostructures differ from their parent structures physically, chemically and biologically. Several recent reports and reviews have identified potential applications of nanotechnology for the food sector to improve food safety, to enhance packing and lead to improved processing and nutrition (Sekhon, 2014, Dasgupta *et al.*, 2015; Chaudhry *et al.*, 2008; Kour *et al.*, 2015; Narayanan *et al.*, 2012; Pradhan *et al.*, 2015; He *et al.*, 2016).

Increasing the shelf-life of food, food safety, coloring, flavoring and nutritional additives using the antimicrobial ingredients for food packaging are some of the important applications of nanotechnology in the food industry (Chaudhry *et al.*, 2008; Lee, 2010). In packaging of food materials and finished food product, nanotechnology has also proven to be vital. Nanotechnology has major advantages in its usage for packing in comparison with the conventional ways using polymers, which may include merits such as enhanced barrier, mechanical and heat-resistant properties, along with biodegradability (De Azeredo, 2009). In addition to enhanced antimicrobial effects, nanomaterials can be used for detection of food spoilage through nanosensors (McClements *et al.*, 2012).

6.1 SOME NANOSTRUCTURED MATERIALS IN FOOD

Recently, nanostructured materials have been introduced in food. However, due to the size of some food constituent, some natural ingredients of food are of nanoscale. For example proteins which are of globular size of about 10nm-100nm are of nanoscale or are achieved by homogenization, Lipids and Polysaccharides which are about 1nm in size are also of nanoscale due to their size. In food industry, synthetic nanostructures that are of grave importance are Polymeric Nanoparticles (Nps), Liposomes, Nanoemulsions, Nanocomposites and Nanocoatings. These materials enhance solubility, improve bioavailability, facilitate controlled release and protect bioactive components during manufacture and storage (Chang and Chen, 2005).

6.1.1 POLYMERIC NANOPARTICLE

Food-grade biopolymers such as proteins or polysaccharides can be used to produce nanometer-sized particles (Gupta *et al.*, 2005; Ritzoulis *et al.*, 2005; Riley *et al.*, 1999). A typical example is micelles; a spherical structure of size 5-100nm has the ability to encapsulate nonpolar molecules such as lipids, vitamins, and antioxidants. Micelles binds with elements and enable them to be more water soluble, this is generally referred to as Microemulsion. An important application of microemulsion is to provide anti-oxidation effectiveness because of the possibility of a synergistic effect between hydrophilic and lipophilic antioxidants (Pathakoti *et al.*, 2017). One of the most common components of many biodegradable biopolymeric nanoparticles is polylactic acid. It is commonly available from a number of manufacturers (Pathakoti *et al.*, 2017). Polylactic acid is regularly used to encapsulate and deliver drugs, vaccines, and proteins, but it has certain limitations; it is quickly removed from the bloodstream and remains isolated in the liver and kidney (Pathakoti *et al.*, 2017). As its purpose as a nanoparticle is to deliver active components to other areas of the body, polylactic acid needs an associative compound such as polyethylene glycol to be successful in this regard (Taylor *et al.*, 2005).

6.1.2. LIPOSOMES

Liposomes are spherical bilayered vesicles of phospholipids (Mozafari *et al.*, 2008). Liposomes have been used in the food industry to encapsulate functional ingredients, and more recently, they have been explored for their ability to integrate food antimicrobials that could aid in the protection of food products against growth of spoilage and pathogenic microorganisms (Singh *et al.*, 2012). Lipid-based nanoencapsulation can potentially improve the solubility, stability and bioavailability of foods, thus preventing unwanted interactions with other food components (Pathakoti *et al.*, 2017). Nanoliposomes also help in controlled and specific delivery of nutraceuticals, nutrients, enzymes, vitamins, antimicrobials, and additives (Mozafari *et al.*, 2008). Liposomes have a smaller size and larger interfacial surface area for contact with biological tissues and thereby provide greater bioavailability of encapsulated compounds (Chang *et al.*, 2005; Liu *et al.*, 2015; Kumar 2000).

6.1.3 NANOEMULSIONS

Nanoemulsions are colloidal dispersions with droplet sizes ranging from 50nm to 1000nm. They are used to produce food products for flavored oils, salads dressing, personalized beverages, sweeteners and other processed foods (Garti, 2008). They can be used to decontaminate equipment without compromising the standard of products, appearance or flavor. Nanosized functional compounds that are encapsulated by the self-assembled nanoemulsions are used for targeted delivery of Lutein; β-carotene; Lycopene; vitamins A, D and E_3; co-enzyme Q10; and omega-3 fatty acids (Choi *et al.*, 2011). Stable double-layered capsaicin-loaded nanoemulsions were stabilized with natural polymers such as alginate and chitosan for use as a functional ingredient delivery system (Jasinska *et al.*, 2009). Functional food components can be integrated within the droplets (McClements *et al.*, 2000) regularly to allow a slowdown of chemical degradation process by engineering the properties of the interfacial layer surrounding them (Gu *et al.*, 2005). Another application of nanoemulsion includes bottled drinking water and milk fortified with vitamins, minerals, and antioxidants (Huang *et al.*, 2015).

6.1.4 NANOCOMPOSITE

Using the polymer in nanocomposite for food packaging is one of the good alternatives for conventional packaging materials (glass, paper, and metals) due to their functionality and low cost (Silvestre *et al.*, 2011). Nanocomposites are polymer matrices reinforced in the nanofillers (nanoclays, nanooxides, carbon nanotubes and cellulose microfibrils), where one of the phases has at least one, two, or three dimensions less than 100nm in size (Bastarrachea *et al.*, 2011). Several synthetic (polyaminde, polystyrene, nylon and polyolefins) and natural (chitosan, cellulose and carrageenan) polymers have been used in food packaging (Bastarrachea *et al.*, 2011; Rhim *et al.*, 2013). However, due to environmental concerns, there is a growing demand for biodegradable packaging with the use of biopolymers that are either natural or synthetic (polyvinyl alcohol, polylactide, and polyglycolic acid) (Shiju and Guliants, 2009).

6.1.5 NANOCOATING

Nanocoatings are one of the most important topics within the range of nanotechnology. Through nanoscale engineering of surfaces and layers, a vast range of functionalities and new physical effects can be achieved (Luther, 2004). Many synthesis techniques for production of nanostructured coatings have been developed such as sputtering, laser ablation, sol/gel technique, chemical vapour deposition, gas-condensation, plasma spraying, and electrochemical deposition (Luther, 2004). Chemical vapour deposition includes chemical reaction of input materials in the gas phase and deposition of the product on the surface. Physical vapour deposition (PVD) includes transforming the material into the gaseous phase and then deposition on the surface (Aliofkhazraei, 2011). The impact of an atom or ion on a surface produces sputtering from the surface. Unlike many other vapour phase techniques there is no melting of the material. Sputtering is done at low pressure on cold substrate. In laser ablation, pulsed light from an excimer laser is focused onto a solid target in vacuum to boil off a plum of energetic atom. A substrate will receive a thin film of the target material. The sol-gel process is well adapted for ceramics and composites at room temperature (Luther, 2004).

Many application of nanocoating has been adopted in various fields; in engineering to prevent corrosion, scratch proof etc. In food industry, nanocoating can be adopted to allow easy digestion and absorption of drugs or food supplement drugs in humans.

6.2 APPLICATIONS OF NANOSTRUCTURE MATERIALS IN FOOD

The applications of nanostructured materials in food science and technology can be categorized into packaging, process technology, antimicrobials and food ingredients, additives, preservatives etc. Its usage in foodstuff can be categorized into Direct and Indirect use (Pathakoti *et al.*, 2017). Direct use refers to incorporation of nanostructured substances and materials in foodstuff and must also be declared as such (Pathakoti *et al.*, 2017). Some of the direct applications include fragrances, coloring agents, antioxidants, preservatives, and biologically actives components (Vitamins, omega-3fatty acids, polyphenols etc.) (Pathakoti *et al.*, 2017). Indirect use comprises the use of nanostructured materials in packaging technology (McClements *et al.*, 2012) and sensors or the use of proficiently nanostructured catalyzers for the hydration of fats (Stankovic *et al.*, 2009; Moraru *et al.*, 2005).

The use of microencapsulated additives in food is already well established. For example, microencapsulion has been used to mask the taste and odour of tuna fish oil, added to bread for health benefits (e.g. “Tip Top-up” brand bread from George Weston Foods, Australia) (Cientifica, 2006). For food processing, the nanoencapsulation of food ingredients and additives could serve as protection, flavor enhancer, taste concellant, controlled release, and better dispersability for insoluble food ingredients and additives. Most nano-sized or nanoencapsulated health supplements and nutraceuticals are claimed for enhanced absorption and bioavailability in the body (Cientifica, 2006). The presence of nano-sensors in food for the detection of pathogens makes the process quick, susceptible and effortless. Some food products also have nano-sized transport systems for the addition of nutrients and supplements, such as antioxidants, vitamins, minerals, flavours, colour and preservatives (Sekhon, 2010).

The nanocarrier system is added to protect the additives and ingredients during the processing of the food product. However, there are some health concerns about the toxic effect of using nanoparticles on food in which there have not been any established fact against the use. These nanoparticle food products differ from the properties of the macroparticles of the same elements and may cause toxicity on interaction with a biological system (Das *et al.*, 2009).

6.3 NANOSENSORS

Another fundamental application of nanotechnology is in monitoring food pathogens and chemicals. Nanosensors in conjunction with polymers are used to monitor food pathogens and chemical, drug storage and transit processes in smart packaging (Baeumner, 2004; Lerner *et al.*, 2011). Several recent reports indicated that nanosensors are able to detect toxins and food pathogens in the packaging (Bastarrachea *et al.*, 2011; Yang *et al.*, 2011; Li and Sheng, 2014). Nanosensors for food analysis, flavors, drinking water and clinical diagnostics have also been developed (Vo-Dinh *et al.*, 2001) and Nanoparticles can also be incorporated as nanostructured transducers of biosensor devices (Plexus Institute, 2006). A low-cost nanobioluminescent spray (Gfeller *et al.*, 2005) was developed which has the ability to glow when it comes in contact with microbes in food which invariably indicates the presence of microbial contamination.

Nanocantilevers are used for pathogen detection and recently a rapid biosensor (i.e micromechanical oscillators) was developed for the detection of bacterial growth of *Escherichia coli* (Lange *et al*., 2002). The basis of the detection is the change in resonance frequency as a function of the increasing mass on a cantilever array, which can detect *E. coli* within 1hour which is faster than any conventional plating method that requires 24 hours to produce result (Pathakoti *et al.*, 2017). Using a series of cantilevers with different molecular recognition elements together in an array mounted on a single chip can be used to detect multiple toxins and microorganisms (Mabeck and Malliaras, 2006; Zhao and Hao, 2013). Additional nanosensors developed based on the molecular imprinted polymer technology include those used for the detection of trypsin, glucose, catechol and ascorbic (Male *et al.*, 2004; Wang *et al.*, 2003; Wolfrum *et al.*, 2008; Ambrosi *et al.*, 2008; Rodriguez *et al.*, 2013).

6.4 NANOPARTICLE TO IMPROVE FOOD INGREDIENTS

The nanostructured food ingredients are being developed to ascertain the effect on how to improve taste, colour, flavour, and texture in food. The processes commonly used for producing nanostructured food products include nano-emulsions, surfactant micelles, emulsion bilayers, double or multiple emulsions and reverse micelles (Weiss *et al.*, 2006).

6.5 NANOENCAPSULATED PROBIOTICS

Probiotics are the mixture of active bacterial species into yoghurts and fermented milk, fruit-drinks, cheese and pudding, which, when taken, have beneficial effect(s) on the consumer. It helps to improve the immune system of the consumer and also increase the presence of beneficial bacteria species in the body. The encapsulation of the product increases the shelf life of the food. Nanoencapsulation favors the development of specific bacterial probiotic, which can be delivered to the gastro-intestinal tract where it can interact with specific receptors (Sekhon 2010). Vidhyalakshmi *et al.* (2009) reported that the encapsulated probiotic material improved viability with the acidic food product and survival strength in the harsh environmental conditions. Kalal *et al.* (2016) encapsulated probiotic powder of bitter gourd juice and found that the viability of the *Lactobacillus casei* in the product is significantly good when encapsulated with maltodextrin.

6.6 ACTIVE FOOD PACKAGING

Food package is a very essential aspect of food production and this is to reduce contamination by microorganisms which can cause food spoilage. Nanotechnology explored this area and has the ability to deliver a safer product with longer shelf-life. Another application of active packaging is the controlled-release packaging, where nanocomposite can be also be used as delivery systems, thereby helping the migration of functional additives such as minerals, probiotics and vitamins into food (Grsveland-Bikkera and de Kruifa, 2006). Silver nanoparticles are used in packaging materials to preserve food for longer periods by killing microorganisms in 6 minutes (Degant and Schwechten, 2002; Sharman, 2005). Nylon nanocomposites providing proving barriers to oxygen and carbon dioxide flow have also been used in food packaging to maintain freshness and block out smells in food (Pathakoti *et al.*, 2017). A typical example is multilayer polyethylene terephthalate (PET) bottles for beer and alcoholic beverages (Sharman, 2005; Duncan, 2011). Active packing includes the usage of metal and metal oxide nanoparticles have antimicrobial agents in the form of nanocomposites for food packaging. Titanium dioxide, zinc oxide, copper, copper oxide and silver-based nanofillers are used due to their antimicrobial properties (Lee 2010). The antibacterial activities of metal nanostructures are mostly dependent on various factors such as large surface area, size, shape, particle internalization and chemical fictionalization (Diaz-Visurraga and Garcia, 2010).

6.6.1 Nanocoating for Food Packaging and Protection

Nanocoating is another area explored by researchers to improve food quality. A thin-edible nano-coatings layer of about 5mm thick are created on the outer surface of fruits and vegetables, meat, cheese, freshly prepared foods and bakery products. This prevents food from contact to the atmosphere and moisture that releases antioxidants, enzymes, and antimicrobial agents from handling or transportation. This coating helps in reducing food spoilage and, hence, increases the shelf life of the food. Dhital *et al*. (2017) developed an edible coating on “Chandler” strawberries to increase their shelf life. Antibacterial edible nanocoating can be applied directly to bakery goods. Musso *et al*. (2017) developed edible smart gelatin film based on curcumin and gelatin. The film has high antioxidant property and changes colour when it comes in contact with media at different pH level.

Another application of nanocoating on food surfaces is its high-performance abilities for resisting the development of biofilms. Nanoparticles are used to control the release of antimicrobial agents from food surfaces or any other surfaces, reducing the colonization of the microorganisms, as well as inhibiting their propagation. This area can be explored in pipeline construction and protection. These materials coated with nano-particle are effective for a longer duration, prevent the growth of pathogenic bacteria and avoid food spoilage. There are different examples nanoparticles that have been synthesized, such as gold, silver, zincoxide, titaniumoxide and many more have show effectiveness as a coating for several food materials. Yemmireddy *et al*. (2017) developed a nanocoating of TiO_2 for the surfaces of chopping boards and found significant microbial reduction on such surfaces (Yemmireddy *et al.*, 2017).

6.7 NANOPARTICLES IN HEALTH

There have been huge concerns about the effect of nanoparticles in human. Although, adverse effect of nanostructured materials have not been properly documented. However, nanostructured materials can be of immense advantages to treat, diagnose and control biological system. Nanoparticles can enter the human body in several ways; through the skin, lungs and intestinal tract due to their sizes. These features have enable nanoparticles to be of immense use in cosmetics to improve skin texture and cream absorption, improve digestion and uptake by the Gastrointestinal walls etc. Synthetic nanostructured biomaterials can be designed to self-assemble and create structures for tissue engineering, effectively mimicking biomineralization processes (Murphy and Mooney, 2002). Self-assembled peptides can direct mineralization of hydroxyapatite including formation of collagen fibrils which is of interest in mineralized tissue repair (Hartgerink *et al.*, 2001). Light irradiation of gold-coated silica spheres trigger the release of heat that can destroy cancer cells (Lok, 2004; Goho, 2003; NCT, 2003). Gold nanoparticles themselves inhibit the growth of blood vessels, such growth is an important process in the growth of tumours (NCT, 2003). Disinfection of surfaces is possible using UV photocatalytic oxidation with nanocrystalline TiO_2 (Ku¨hn *et al.*, 2003; Yu *et al.*, 2005)

Artificial mechanical red blood cells (respirocytes) are mimics for the oxygen and carbon dioxide transport function of red blood cells. They can deliver 236 times more oxygen per unit volume than a natural red blood cell (Bogunia-Kubik and Sugisaka, 2002). Adsorption of antibodies on assemblies of single wall carbon nanotubes (SWCNT) forms the basis of an amperometric immunosensor.(O'Connor *et al.*, 2004).

6.7.1 DIGESTION OF NANOSTRUCTURED MATERIALS IN FOOD

The three constituents of food; proteins, carbohydrates and lipids undergo different digestive patterns in the human body. However, a common factor between the three is that digestion of their constituents occurs at the nanoscale. Based on this, it could be argued that the processing of foods at the nanoscale would simply improve the speed or efficiency of their digestion, uptake, bioavailability and metabolism in the body. Indeed, within the nutrition market there are already supplements that claim to contain di- and tri- peptides, and are thus more readily digestible (Crisalle, 2007).

6.7.2 NANOTECHNOLOGY IN DELIVERY SYSTEMS

Nanotechnology is evolving and as such many areas to be explored are coming into view. These may be dendrimers, liposomes or micelles whose function is to deliver something, either to the food as such, or to the person ingesting it. It has been mentioned how these may be exploited for increased uptake of for example vitamins. They may also be used for a controlled release of preservatives, antioxidants, additives or other substances in the food (Luykx *et al.*, 2008). For instance, the use and release of antioxidant can be controlled through this technology only when needed in food digestion.

6.7.3 DENDRIMERS AND DRUGS

There are been much expectation for nanotechnology to revolutionize the administration of drugs, particularly in treatment of cancer. They may increase the bioavailability of a poorly soluble drug, or protect the drug from degradation in the stomach, for example by using archaeosomes. These are liposomes made from lipids from archae bacteria that contain an ester bond, instead of the ether bond used by other organism. The ester bond is a lot more stable in extreme pH or temperature, so they may be used for an adequate oral delivery of substances, that otherwise would be degraded in the acidic stomach (Luykx *et al.*, 2008).

7 CONCLUSION

Food is an essential part of living. Without it, life as we know it would have been extinct. Nanotechnology has improved food quality immensely and has proven to be an effective means to process, improve food quality and preserve food. Its application is not limited to an aspect of food production; it can be effective in processing, production and preservation of food. Nanoparticle in food have improved uptake in the body due to their sizes and surface structure.

However, the effect or impact of Nanoparticles to health has been a thing of concern for the food and drug regulatory bodies across the world. So it is hence encouraged that the effect of nanoparticles to health should be further studied.

REFERENCES

Aliofkhazraei, M. (2011). Synthesis, Processing and Application of Nanostructured Coating. In: *Nanoengineering Material*. p212. ISBN 978-3-642-17666-2

Allaker, R (2010). The use of nanoparticles to control oral biofilm formation. *J. Dent. Res*. 89, 1175–1186.

Amador,C. Martinde Juan, L. (2016). Strategies for Structured Particulate Systems Design. In Computer Aided Chemical Engineering; Martín, M.,Eden ,M.R., Chemman gattuval appil, N.G., Eds.; Elsevier: Amsterdam, The Netherlands, Volume 39, pp. 509–579.

Ambrosi A, Morrin A, Smyth MR, Killard AJ. (2008). The application of conducting polymer nanoparticle electrodes to the sensing of ascorbic acid. *Anal Chim Acta*. 609: 37-43.

Astruc, D. (2008). Nanoparticles and Catalysis; John Wiley & Sons: Hoboken, NJ, USA.

Baeumner A (2004). Nanosensors identify pathogens in food. *Food Technol*. 58: 51-5.

Bastarrachea L, Dhawan S, Sablani SS. (2011). Engineering properties of polymeric –based antimicrobial films for food packaging: a review. *Food Eng Rev*. 3: 79-93.

Betancor, L.; Luckarift, H.R. (2008). Bioinspired enzyme encapsulation for biocatalysis. *TrendsBiotechnol*. 26: 566–572.

Bhatia, S. (2016). Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications. In Natural Polymer Drug Delivery Systems; Springer: Berlin/Heidelberg, Germany pp. 33–93.

Bogunia-Kubik, K. and M. Sugisaka (2002), *BioSystems*, 65: 123–138.

Chang YC, Chen DGH. (2005). Adsorption Kinetics and thermodynamics of acid dyes on a carboxymethyylated chitosan-conjugated magnetic nano-absorbent. *Macromol Biosci* 5:254-61

Chaudhry Q, Scotter M, Blackburn J, Ross B, Boxall A, Catle L, Aitken R. (2008). Applications and implications of nanotechnologies for the food sector. *Food Addit Contam Part A chem. Anal Control Expo Risk Assess*. 25: 241-58

Chen H, Weiss J, Shahidi F (2006). Nanotechnology in nutraceuticals and functional foods. *Food.Tech*. 60: 30-6

Chen, C.-C.; Wagner, G.(2004). Vitamin E nanoparticle for beverage applications. *Chem. Eng. Res. Des.*, 82: 1432–1437.

Cheng Y, Xu Z, Ma M, Xu T. (2008). Dendrimers as drug carriers: applications in different routes of drug administration. *J Pharm Sci*. 97:123-43

Cheng Y, Zhao L, Li Y, Xu T. (2011). Design of biocompatible dendrimers for cancer diagnosis and therapy: current status and future perspectives. *Chem Soc Rev*. 40:2673-703

Choi AJ, Kim CJ, Cho YJ, Hwang JK, Kim CT. Characterization of capsaicin-Loaded nanoemulsions stabilized with alginate and chitosan by self-assembly. *Food Bioprocess Tech* 2011; 4: 1119-26

Cientifica Report. 2006. "Nanotechnologies in the Food Industry" published August 2006. Available: www.cientifica.com/www/details.php?id=47. Accessed 24 October 2006.

Crean C, Lahiff E, Gilmartin N, Diamond D, O'Kennedy R. (2011). Polyaniline nanofibres as templates for the covalent immobilization. *Synthetic Metals*.; 3:285.

Crisalle L. 2007. Types of Protein Differences in Quality. Available: www.exerciseandnutritionworks.com/t-protowhey1.aspx. Accessed 30 July 2007.

Das, M.; Saxena, N.; Dwivedi, P.D. (2009). Emerging trends of nanoparticles application in food technology: *Safety paradigms. Nanotoxicology* 3: 10–18.

Dasgupta N, Ranjan S, Mundekkad D, Ramalingam C, Shanker R, Kumar A.(2015). Nanotechology in agro-food: from filed to plate. *Food Res Int*. 69: 381-400

De Azeredo H.M.C. (2009). Nanocomposites for food packaging applications. *Food Res. Int*; 42: 1240-53

de Britto, D.; de Moura, M.R.; Aouada, F.A.; Mattoso, L.H.; Assis, O.B. (2012). N,N,N-trimethyl chitosan nanoparticles as a vitamin carrier system. *Food Hydrocoll.*, 27: 487–493.

Dhital, R.; Joshi, P.; Becerra-Mora, N.; Umagiliyage, A.; Chai, T.; Kohli, P.; Choudhary, R. (2017).Integrityofediblenanocoatingsanditseffectsonqualityofstrawberriessubjectedtosimulatedin-transitvibrations. *LWT Food Sci. Technol*. 80: 257–264.

Duan, H.; Wang, D.; Kurth, D.G.; Möhwald, H. (2004). Directing self-assembly of nanoparticles at water/oil interfaces. Angew. *Chem. Int. Ed.*, 43: 5639–5642.

European Food safety authourity (EFSA) (2009). The potential risks arising from nanoscience and nanotechnology on feed safety. *J EFSA*. 958:1-39

Garti N. (2008). Delivery and controlled release of bioactives in foods and nutraceuticals. Cambridge, England: Elsevier. Woodland Publishing Co.

Gfeller KY, Nugaeva N, Hegner M. (2005). Micromechanical oscillators as rapid biosensor for the detection of active growth of *Escherichia coli*. *Biosens Bioelectron*. 21:528-33

Goho, A. (2003). *Sci. News*, 164: 381–382.

Graveland-Bikkera JF, deKruifa CG. (2006). Unique milk protein based nanotubes: food and nanotechnology meet. *Trends Food Sci Tech*. 17:196-203.

Gu YS, Decker AE, McClements DJ. (2005). Production and chanracterization of oil-in water emulsions containing droplets stabilized by multilayer membranes consisting of beta-lactoglobulin, iota-carrageenan and gelatin. *Langmur*. 21: 5752-60

Gupta AK, Gupta M. (2005). Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications. *Biomaterials*. 26: 3995- 4021

Hartgerink, J. D., E. Beniash and S. I. Stupp. (2001) *Science,* 294: 1684–1688.

Hayden O, Haderspo C, Krassnig S, Chen X, Dickert FL. (2006). Surface imprinting strategies for the detection of trypsin. Analyst. 131:1044-50.

He X, Hwang HM. (2016). Nanotechnlogy in food science: functionality, applicability and safety assessment. *J Food Drug Anal*. 24:671-81

Hett, A. (2004). Nanotechnology: Small Matter, Many Unknowns; Swiss Reinsurance Company: Zürich, Switzerland.

Huang J, Li Q, Sun D, Lu Y, Su Y, Yang X, Wang H, Wang Y, Shao W, He N, Hong J, Chen C. (2007). Biosynthesis of silver and gold nanoparticles by novel sundried Cinnamomum camphora leaf. *Nanotechnology*. 18:105104.

Huang JY, Li X, Zhou W. (2015). Safety assessment of nanocomposite for food packaging application. *Trends Food Sci Technol*. 45: 187-99.

Jain KK. (2005). The role of nanobiotechnology in drug discovery. *Drug Discov. Today.* 10:1435.

Jasinska M, Dmytrow I, Mitnuiewicz-Malek A, Wasik K. (2010). Cow feeding system versus milk utility for yoghurt manufacture. *Acta Sci Pol Technol Aliment.* 9: 189-99.

Kalal, A.Y.; Hiregoudar, D.S.; Nidoni, U. (2016). Nanoencapsulation of Probiotic Bitter Gourd Juice Powder. *Int. J. Agric. Sci. Res.* 6: 9–20.

Khalil MH, Ismail EH, El-Baghdady KZ, Doaa M. (2013). Green synthesis of silver nanoparticles using olive leaf extract and its antibacterial activity. *Arab. J. Chem.*; 7:1131-1139.

Kickelbick, G. (2007). Hybrid Materials: Synthesis, Characterization, and Applications; John Wiley & Sons: Hoboken, NJ, USA.

Kostarelos,K.;Lacerda,L.;Pastorin,G.;Wu,W.;Wieckowski,S.;Luangsivilay,J.;Godefroy,S.;Pantarotto,D.; Briand, J.-P.; Muller, S. (2007). Cellular uptake of functionalized carbon nanotubes is independent of functional group and cell type. *Nat. Nanotechnol*. 2: 108–113.

Kour H, Malik AA, Ahmad N, Wani TA, Kaul RK, Bhat A. (2015). Nanotechnology – new lifeline for food industry. *Crit Rev Food Sci Nutr*

Ku¨hn, K. P., I. F. Chaberny, K. Massholder, M. Stickler, V. W. Benz, H. Sonntag and L. Erdinger (2003), *Chemosphere,* 53: 71–77.

Kumar MNVR. (2000). A review of chitin and chitosan applications. *React Funct. Polym* 46: 1-27.

Lange D, Hagleitner C, Hierlemann A, Brand O, Baltes H. (2002). Complementary metal oxode semiconductor cantilever arrays on a single chip: mass-sensitive detection of volatile organic compounds. *Anal Chem*. 74:3084-95.

Lateef A, Ojo SA, Folarin BI, Gueguim-Kana EB, Beukes LS. (2016). Kolanut (Cola nitida) mediated synthesis of silver– gold alloy nanoparticles: Antifungal, catalytic, larvicidal and thrombolytic applications. *J Clust Sci*. 27:1561–1577.

Lee KT. (2010). Quality and safety aspects of meat products as affected by various physical manipulations of packaging materials. *Meat Sci*. 42:1240-53

Lellouche, J.; Friedman, A.; Lahmi, R.; Gedanken, A.; Banin, E. (2012). Antibiofilm surface functionalization of catheters by magnesium fluoride nanoparticles. *Int. J. Nanomed*., 7: 1175–1188.

Lerner MB, Goldsmith BR, McMillon R, Dailey J, Pillai S, Singh SR, Johnson ATC. (2011). A carbon nanotube immunosensor for *Salmonella. AIP Adv*. 1:0442127.

Li Z, Sheng C. (2014). Nanosensors for food safety. *J Nanosci Nanotechnol*. 14: 905-12.

Liang, S.-S.; Makamba, H.; Huang, S.-Y.; Chen, S.-H. (2006). Nano-titanium dioxide composites for the enrichment of phosphopeptides. *J. Chromatogr*. 1116: 38–45.

Liu W, Ye A, Singh H. (2015). Progress in applications of liposomes in food systems. In:Sagis LMC, editor. Microencapsulation and microspheres for food applications. New York, NY: Academic Press. P. 152-70

Lok, C. (2004), Technol. Rev. 107: 81.

Lövestam G, Rauscher H, Roebben G, Klüttgen BS, Gibson N. (2010). Considerations on a definition of nanomaterial for regulatory purposes. Publications Office of the European Union.

Luther, W. (2004). Industrial Application of Nanomaterials- Chances and Risks, Future Technologies Division of VDI Technologiezentrum GmbH,

Luykx DM, Peters RJ, van Ruth SM, Bouwmeester H. (2008). A review of analyticalmethods for the identification and characterization of nano delivery systems in food. *J Agric Food Chem*. 56:8231-47

Mabeck JT, Malliaras GG. (2006).Chemical and biological sensors based on organic thin-film transistors. *Anal ioanal Chem*. 24: 383-53.

Male KB, Hrapovic S, Liu YL, Wang DS, Luong JHT. (2004). Electrochemical detection of carbohydrates using copper nanoparticles and carbon nanotubes. *Anal Chim Acta*. 516:35-41.

McClements DJ, Decker EA. (2000). Lipid oxidation in oil-in-water emulsions: impact of molecular environment on chemical reactions in heterogeneous food systems. *J Food Sci*. 65: 1270-82

McClements DJ, Xiao H. (2012). Potential biological fate of ingested nanoemulsions: influence of particle characteristics. *Food Funct*. 202-20

Morais MG, Vilásia GM, Daniela S, Patricia P, Jorge AVC. (2014). Biological applications of nanobiotechnology. *J. Nanosci. Nanotechnol*. 14(1).

Moraru CI, Huang Q, Takhistov P, Dogan H, Kokini JL. (2005). Food nanotechnology: current developments and future prospects. *Global issues Food Sci*. 70: R1-10.

Mozafari MR, Johnson C, Hatziantoniou S, Demetzos C. (2008). Nanoliposomes and their applications in food nanotechnology. *J liposome Res*. 18: 309-27

Murphy W. L. and D. J. Mooney (2002), *Nat. Biotechnol.*, 20: 30–31.

Musso, Y.S.; Salgado, P.R.; Mauri, A.N. (2017). Smart edible films based on gelatin and curcumin. *Food Hydrocoll*. 66: 8–15.

Nano-drug may starve tumours, (2004). *New Sci.*, 184: 17.

Nanoshells for cancer therapy (2003). Mater, *Today*, 6: 6

Narayanan A, Sharma P, Mudgil BM. (2012). Applications of engineered particulate systems in agriculture and food industry. *Kona Powder Part J*. 30: 221 -35

National Nanotechnology Initiative (NNI). (PDF). 2000.4.

Niemeyer CM, Mirkin CA. (2004). Nanobiotechnology: Concepts, applications and perspectives. Wiley, New York.

Nowack B, Bucheli TD. (2007). Occurrence, behavior and effects of nanoparticles in the environment. *Environ Pollut*. 150:5–22.

O'Connor, M., S. N. Kim, A. J. Killard, R. J. Dorster, M. R. Smyth, F. Papadimitrakopoulos and J. D. Rusling (2004). *Analyst*, 129: 1176–1180.

Pal, S.; Tak, Y.K.; Song, J.M. (2007). Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the gram-negative bacterium *Escherichia coli*. *Appl. Environ. Microbiol.* 73: 1712–1720.

Pathakoti K, Manubolu M. Hwang H.(2017), Nanostructures: Current uses and future applications in food science, *Journal of Food and Drug Analysis*.30:1-9. http://dx.doi.org/10.1016/j.jfda.2017.02.004

Plexus Institute. New nanotechnology food research. If it glows don't eat it. 2006 Available from: http://www.plexusinstitute.org/news-events/show_news.cfm?id=164[Accessed20 Apr 2009].

Pochard, I.; Boisvert, J.P.; Persello, J.; Foissy, A. (2003). Surface charge, effective charge and dispersion/aggregation properties of nanoparticles. *Polym. Int.* 52: 619–624.

Pradhan N, Singh S, Ojha N, Shrivastava A, Barla A, Rai V, Bose S. (2015). Facets of nanotechnology as seen in food porocesing, packaging and preservation industry. *Biomed Res Int*. http://dx.doi.org/10.1155/2015/365672.

R. M. Pandey and S. K. Upadhyay (2012). Food Addictive, Division of Genetics, Plant breeding & Agrotechnology, National Botanical Research Institute, Lucknow, India

Rhim JW, Park HM, Ha CS. (2013). Bio-nanocomposites for food packaging applications. *Prog Polym Sci*. 38: 1629-52.

Riley T, Govender T, Stolnik S, Xiong CD, Garnett MC, Illum L, Davis SS. (1999). Colloidal stability and drug incorporation elements of micellar-like PLA-PEG nanoparticles.*Colloids Surf B*. 16:147-59

Ritzoulis C,Scoutaris N, Papademetriou K, Stavroulias S, Panayiotou C. Milk protein-based emulsion gels for bone tissue engineering. *Food Hydrocol* 2005. 19: 575-81

Rodriguez F, Sepulveda HM,Bruna J, Guarda A, Galotto MJ., (2013). Development of cellulose eco-nanocomposites with antimicrobial properties oriented for food packaging, *Packag Technol Sci*. 26:149-60.

Santos, C.; Albuquerque, A.; Sampaio, F.; Keyson, D. (2013). Nanomaterials with antimicrobial properties: Applications in health sciences. In Microbial Pathogens and Strategies for Combating Them: Science, Technology and Education; Formatex Research Center: Badajoz, Spain, Volume 4, p. 2.

Sekhnon B.S. (2010). Food nanotechnology – an overview. *Nanotechnol Sci Appl*. 3:1-5

Sekhon BS. (2014). Nanotechnology in agri-food production: an overview. *Nanotechnol Sci Appl*. 7: 31-53

Shameli K, Ahmad MB, Jaffar Al-Mulla EA, Ibrahim NA, Shabanzadeh P, Rustaiyan A. (2012). Green biosynthesis of silver nanoparticles using Callicarpa maingayi stem bark extraction. *Molecules*. 17:8506–8517.

Shankar, S.S.; Rai, A.; Ahmad, A.; Sastry, M. (2004). Rapid synthesis of Au, Ag, and bimetallic Au core–Ag shell nanoparticles using Neem(Azadirachtaindica)leafbroth. *J.Colloid Interface Sci*. 275: 496–502.

Shegokar, R.; Müller, R.H. (2010). Nanocrystals: Industrially feasible multifunctional formulation technology for poorly soluble actives. *Int. J. Pharm*., 399: 129–139.

Sherman LM. Chasing nanocomposites.(2005). Available from: http://www.ptonline.com/articles/200411fa2.html[Accessed 5 Sept 2012]

Shiju NR, Guliants VV. (2009). Recent developments in catalysis using nanostructured materials. *Appl Catal A*. 356: 1-17.

Silvestre C, Duraccio D, Cimmino S. (2011). Food packaging based on polymer nanomaterials. *Prog Polym Sci*. 36:1766-82.

Singh H, Thompson A, Liu W, Corredig M. (2012). Liposomes as food ingredients and nutraceutical delivery systems. In: Garti N, McClements Dj, editors. Ebcapsulation technologies an delivery systems for food ingredients and nutraceuticals. Cambridge, UK: Woodhead Publishing Ltd. p 287-318.

Stankovic M, Gabrovska M, Krstic J, Tzetkov, Shopska M, Tsacheva T, Banovic P, Edreva-Kardjieva R, Jovanovic D. (2009). Effect of silver modification on structure and catalytic performance of Ni-Mg/diatomite catalysts for edible oil hydrogenation. *J Mol Catal A Chem*. 297: 54-62.

Suman TY, Rajasree SR, Kanchana A, Elizabeth SB. (2013). Biosynthesis, characterization and cytotoxic effect of plant mediated silver nanoparticles using Morinda citrifolia root extract. *Colloids Surf. B*. 106: 74–78.

Taylor TM, Davidson PM, Bruce BD, Weiss J. (2005). Liposomal nanocapsules in food science and agriculture. *Crit Rev Food Sci Nutr*. 45: 587-605.

Taylor, E.; Webster, T.J. (2011). Reducing infections through nanotechnology and nanoparticles. *Int. J. Nanomed*. 6: 1463–1473.

Tohver,V.;Chan,A.;Sakurada,O.;Lewis,J.A. (2001). Nanoparticle engineering of complex fluid behavior. *Langmuir*. 17: 8414–8421.

Vidhyalakshmi, R.; Bhakyaraj, R.; Subhasree, R. (2009). Encapsulation "the future of probiotics"—A review. *Adv. Biol. Res*., 3: 96–103.

Vo-Dinh T, Cullum BM, Strokes DL. (2001). Nanosensors and biochips: frontiers in biomolecular diagnostics. *Sens Actuators B: Chem*. 74: 2-11.

Wang SG, Zhang Q, Wang RL, Yoon SF. (2003). A novel multi-walled carbon nanotube-based biosensor for glucose detection. *Biochem Biophys Res Commun*. 311:572-6.

Weiss, J., Takhistov, P., and McClements, D.J. (2006). Functional Materials in Food Nanotechnology, *J. Food Sci*. 71(9): R107-R116.

Whitesides GM. (2003). The right size in nanobiotechnology. *Nature. Biotechnol*. 21: 1161.

Wolfrum B, Zevenbergen M, Lemay S. (2008). Nanofluidic redox cycling amplication for the selective detection of catechol. *Anal Chem*. 80: 972-7.

Xiao, Y.; Wiesner, M.R. (2012). Characterization of surface hydrophobicity of engineered nanoparticles. *J. Hazard. Mater*. 215: 146–151.

Yam KL, Takhistov PT, Miltz J. (2005). Intelligent packaging: concepts and applications. *J Food Sci*. 70: R1-10

Yang JY, Li Y, Chen SM, Lin KC. (2011). Fabrication of cholesterol biosensor based on cholesterol oxidase and multiwall carbon nanotube hybrid composites. *Int J Electrochem Sci*. 6: 2223-34

Yemmireddy, V.K.; Hung, Y.-C. (2017). Photocatalytic TiO2 coating of plastic cutting board to prevent microbial cross-contamination. *Food Control*. 77: 88–95.

Yu, J. C., W. Ho, J. Yu, H. Yip, P. K. Wong and J. Zhao (2005), *Environ. Sci. Technol.*, 39: 1175–1179.

Zhao P, Hao J. (2013). Tert-butylhydroquinone recognition of molecular imprinting electrochemical sensor based on core-shell nanoparticles. *Food Chem*. 139:1001-7.