

Contents lists available at http://www.albertscience.com

ASIO Journal of Microbiology, Food Science & Biotechnological Innovations (ASIO-JMFSBI) Volume 1, Issue 1, 2015, 01-07

FUTURE ASPECT OF ANTIMICROBIAL NANO-PRODUCT IN FOOD PROCESSING, PACKAGING AND SAFETY

Richa Saxena¹, Swati Hardainiyan¹ and B. C. Nandy^{†2}

¹Department of Food Sciences and Biotechnology, ²Department of Pharmaceutical Science, Jayoti Vidyapeeth Women's University, Jaipur - 303122, Rajasthan, India

ARTICLE INFO

Review Article History

Received: 18 August, 2015 Accepted: 21 October, 2015

Corresponding Author:

†B. C. Nandy

Jayoti Vidyapeeth Women's University, Jaipur - 303122, Rajasthan, India.

Email: talktobankim@gmail.com

ABSTRACT

Nanotechnology is innovative frontiers of this century and food nanotechnology has potential to revolutionize the food industry. The purposes of nanosciences to the agriculture and food sector are reasonably current assessed with their exploitation in drug delivery and pharmaceuticals. Various researchers have acknowledged well the potential of nanotechnology to lead all the food industries in the 21st century. Even though valuable functions of nanotechnology to foods are still limited, numerous fundamental concepts found in nanoscale have been recognized well. Several crucial challenges as well as determining of important composites, producing most approving intake levels, increasing adequate food delivering matrix and product formulation including the safety of the products need to be addressed. As food microbiology is affected, nanotechnology offers novel agents to inhibit growth of spoilage and pathogenic microbes, to prevent their attachment to surfaces, and even to eliminate them. Other applications provide tools for investigating microbes by detecting their attachment to food contact surfaces or specifying microbes and their growth. The new form of disparity affects not only the activity of a given element or molecule against microorganisms, but also modifies metabolic and material transport systems of uni or multicellular organisms. While allowing technological progression in utilizing the microbiological and biochemical efficiency of nanoparticles, guarded actions have to be applied to make sure food and environmental safety. This review proposed the information regarding to cover some of the developments in nanotechnology and their applicability to food and nutraceuticals systems. It shows a number of nanoscale-sized structures that are uniquely relevant to the food industry, the several food industrialized methods that could benefit from nanotechnology and nanotechnology's applicability to the formulation and storage of food, together with recognizing the outstanding challenges.

Keywords: Nanoparticles, food product, antimicrobials

© www.albertscience.com, All Right Reserved.

INTRODUCTION

Nanotechnology is a multidisciplinary field that focuses on the understanding and development of materials based on nanoscale structures [1]. Most of the research on nanotechnology focused on the electronics, medicine, and automation sector. Its applications are not limited and can applied to diverse areas like textiles and be pharmaceutical and food industries [2]. The information gained from these areas could be adapted for the use of food and agriculture products, such as for applications in food safety (e.g., detecting pesticides and microorganisms), in environmental protection (e.g. water purification), and delivery of nutrients [3-6]. In present times, in "Nanotechnology" is an essentially modern scientific field that is constantly developing as a broad area of research with respect to dairy and food processing, packaging,

safeguarding and advancement of functional foods. Food and dairy producer, agricultural manufacturers and consumers could achieve a further competitive position through nanotechnology [7]. Growing crop yields is a principal objective of farmers in undeveloped countries. Nanotechnologies can improve the efficiency of pesticides and fertilizer to enhance crop vields [8-10]. Furthermore genetic manipulation or nutrition delivery of the nanostructure of plants and animals can also be potential to additional improve farming yields. The emergence of nanotechnology in animal husbandry has been accounted in undeveloped countries [11]. Whereas new nanomaterials could assist farmers to achieve these goals, they can also potentially produce unfavorable effects on human health and in the environment [12].

Nanoparticles can be integrated into accessible food to deliver nutrients, improved the absorption of nutrients by the body and also could enhance product shelf life. The food nanotechnology are utilized to develop the texture of food components, encapsulate food components or additives, growing new tastes and sensations, organizing the release of flavors and rising the bioavailability of nutritional constituents [5]. In contrast, the success of these enhancements will be dependent on consumer approval and the exploration of regulatory issues. Furthermore, 200 companies are conducting research in nanotechnology and its application into food products and further of its functionalities become evident, the level of significance is certain to enhance [13,14]. The Eleventh ASEAN Food Conference [15] (2009) reported that Food technology is considered as one of the industry sectors where nanotechnology will play a significant position in the future. It is frequently illustrious among two forms of nano-foods applications known as food additives and food packaging. Nano-scale food additives may for example be used to control product shelf life, texture, flavor, nutrient composition or even detect food pathogens and offer functions as food quality indicators. In the context of food packaging, nanotechnologies are principally considered to be of use to increase product shelf life, designate spoilt ingredients or normally enhance product quality, e.g., by preventing gas flow across product packaging [16]. While it affects to the food industry, nanotechnology involves using biological molecules such as sugars or proteins as target-recognition groups for nanostructures that could be used, for example, as biosensors on foods [17]. Such biosensors could serve as detectors of food pathogens and other contaminants and as devices to track food products. Nanotechnology could also be helpful in encapsulation systems for defense beside environmental issues. On the other hand, it can be used in the design of food ingredients such as flavors and antioxidants. The goal is to progress the quality of such constituents although reducing their When the combination concentration. of novel constituents into foods achieves attractiveness, better investigation of delivery and restricted- release systems for nutraceuticals will happen [18-20].

Even though nanotechnology can potentially be helpful in all areas of food production and processing, a lot of techniques are moreover too expensive or too impractical to implement on a commercial scale. Therefore, nanoscale methods are mainly commercial in the following regions of the food industry: progress of innovative determined materials, food formulations, food processing at microscale and nanoscale levels, product improvement and storage [21]. The information on 'Nanofoods' from the Helmut Kaiser Consultancy (2009) examines an increasing growth in the enlargement of food-related nano-products and patent applications [22].

Fundamentally the customer demand for secure natural minimally processed food has forced the food industry also to reduce the quantity of synthetic antimicrobial agents or to substitute them with natural alternatives. Still, lots of these natural compounds are not as effective as the synthetic additives, more expensive, or can negatively interact with food mechanism. In this standpoint, encapsulation procedures offer an effectual safeguard of antimicrobial complexes against chemical reactions and adverse interactions with other components in food, diminish migration, improve solubility and conserve the bioactive constituent's stability during storage and food Moreover, encapsulation of bioactive processing. and constituents organizes delivery progress bioavailability and absorption [23-25]. Although microencapsulation methods may security guard of antimicrobial constituents against evaporation or degradation, the elevated surface area to quantity ratio of the nano-encapsulation methods (methods in the nanometer scale, smaller than 100 nm) can enhance the application of the antimicrobials in definite food areas wherever microorganisms are preferably situated and get better passive cellular absorption methods that can lead to superior antimicrobial activity [26]. Furthermore, the nano-encapsulation procedures are useful to integrate antimicrobial agent in substance utilized for food packaging [27].

In contrast, the nano-encapsulation methods have tremendous continued-release properties, sub-cellular size and biocompatibility with tissue and cells, permit variation in the bioavailability of drugs and get better the pharmacokinetic reports of many actives [28]. In addition, encapsulated antimicrobial compounds decreased their toxicity, the resistance is defeat, and the cost of utilizing them is decreased since fewer quantity of the active is needed [29]. The limits of the entire nanoencapsulation systems for their utilization in food industry are associated to their high production costs and lack of allocated substances [30].

Application of Nanotechnology in Food Processing

Nanotechnology has prospective applications in all aspects food processing, food packaging and food monitoring. Manufacture of useful foods such as soft drinks, chocolate, chips and ice cream are advertised as healthy foods by reducing fat, carbohydrate or calorie content or by rising protein, fibre or vitamin stuffing. Production of foods accomplished of modifying their colour, flavour or nutritional properties according to a person's nutritional requirements, allergies, or taste preferences, manufacture of stronger flavourings, colourings and nutritional additives and lowering costs of components. Raising the shelf life of the products by using packaging substances, which can discharge antimicrobials or control air and moisture exchange with the environment can be completed also by nanotechnology methods [31].

Nowadays people are in search of additional dietary supplements. This is because various nutrients in food are spoiled in the digestive tract, which is actually a sophisticated organ. Since the oral cavity to the colon, each part repots an inclusive diverse environment. On the other hand, there is a numeral of aspect affecting the absorption of food in the body for infants, children, the elderly and individuals who suffering from gastrointestinal diseases. A number of nutrition has been damaged in the digestive tract. A method or nanocarriers that bring nutrition to precise places is called a "nutrition delivery system". The Chitosan nanocarrier is the example of one of these systems [32]. Extracting nutrition from raw resources is a significant ingredient of the food industry. Through fast distribution technology, conventional systems for processing food are being substitute by new techniques. Certainly, nanotechnology will play a major responsibility

in this development. In food processing, such techniques may develop food processing yields and reduce spoilage of nutrition. To prevent undesirable properties on consumer health, nutrition delivery systems have to be made with biodegradable materials [33]. Now, many nanofood products are in improvement. By 2010, it is projected that retailing of nanofoods will be appeal almost 6 billion US dollars. Nanofoods which include nanoscale components and additives are previously accessible on the supermarket shelves. Nestle and Unilever are investigated to be rising nano size emulsion-based ice cream with a lower fat content however that preserve a fatty texture and flavour [34]. Nanoparticles are included to numerous foods to get better flow properties, colour and stability during processing or to enhance shelf life. For instance, aluminosillcate substances are frequently utilized as anticaking representatives in granular or fine particles processed foods, whereas anatase titanium dioxide is an ordinary food whitener and brightener preservative, utilized in confectionery, a few cheeses and sauces [35].

Food additives are one more developing source for utilization of nanoparticles in foods. The Institute of Medicine. U.S National Academy of Sciences defines Functional Foods as foods that offers a health benefit further than traditional nutrients which they enclosed. Nano-encapsulation entails an active ingredient in a nanosize capsule. Nanoencapsulation is presently the second largest area for nanotechnology application in the food sector [36]. It is used as a strategy to harness a controlled delivery system for food ingredients and additives in processed food [14]. Dairy products, breads, beverages and cereals are at present equipped with minerals, vitamins, bioactive peptides, probiotics, antioxidants and plant sterols. Some of these active components are nowadays being added to foods as nanoparticles or at particles of a few hundred nm in size [37].

Aquanova, a German Company, has developed a nanotechnology based on carrier system using 30 nm micelles to encapsulate active ingredients such as vitamins C & E and fatty acids, which can be used as preservatives. Aquanova markets these micelles as "NovaSol". The German industry magazine "Fleischwirtschaft" claims that NovaSol offers considerable advantages of faster meat processing, cheaper ingredients, higher colour stability and ready to use liquid form. These nanoadditives have been available to German manufacturers since 2006 [38].

Kraft Foods and NanoteK consortium have plans to incorporate the electronic tongue (which is chemical change based biosensor) into foods to release accurately controlled amounts of the suitable molecules for the customized tailor-foods [37, 39].

A Hungarian company has developed an ice gel for soft drinks or ice-cream containing CO_2 bubbles of 1-10 nm in diameter for effervescence. Nanotech spray is available in which Nanodroplets 87 nm is used to enhance the uptake of vitamin B_{12} and other supplements for usage in foods [40].

Application of Nanotechnology in Food Packaging

Most primitive commercial applications of nanotechnology in the food sector are considered as food packaging. Concerning about 400-500 nano-packaging foodstuffs are projected to be in marketable utilization, whereas nanotechnology is forecasted to be used in the fabrication of 25% of all food packaging inside the next decade. The noteworthy principle of nano-packaging is to place longer shelf life by improving the barrier properties of food packaging to decrease gas and moisture exchange and UV light exposure [41]. Since 2003, more than 90% of nanopackaging was depend on nanocomposites, wherein nanomaterials were utilized to recover the barrier properties of plastic packaging for foods and dairy products. The studies of Anonim [36], (2009) revealed that the most vigorous area of food nanosciences research and development is packaging: the worldwide nano-facilitated food and beverage packaging market was 4.13 billion US dollars in 2008 and has been estimated to develop to 7.3 billion by 2014, on behalf of an annual development rate of 11.65%. Nano packaging applications as Food Contact Materials (FCMs) are projected to produce from a \$66 million business in 2003, to more \$360 million by 2008 [42].

The functions for Food Contact Materials (FCMs) using nanotechnology is as follow:

FCMs (Food Contact Materials) integrating nanomaterials to get better packaging properties specifically gas barrier properties, temperature/moisture stability, flexibility, light and flame resistant, transparency, mechanical stability).

Smart or Intelligent food packaging assimilating nanosensors for good judgment and indication of biochemical and microbial changes, release of enzymes, flavours nutraceuticals, antimicrobials and antioxidants to extend shelf-life [43].

Active Food Contact Materials (FCMs) is that integrated nanoparticles with oxygen scavenging properties or antimicrobial [42].

Antimicrobial Food Packaging

One of the most capable innovations in smart packaging is the use of nanotechnology to develop antimicrobial packaging [27]. Antimicrobial packaging systems are significant for the food industry and can also extend the product shelf life and preserve food safety by reducing the growth rate of microorganisms [44]. Baeumner, (2004) reported that food packaging incorporates nanomaterials can be "smart," which means that it can respond to environmental conditions or restore itself or attentive a consumer to infectivity or the occurrence of pathogens [45]. Antibacterial agents are of significance to a number of industrial sectors consisting environmental, food, synthetic textiles, packaging, healthcare, medical care, as well as construction and decoration. Antimicrobial food packaging materials have to extend the lag phase and reduce the growth rate of microorganisms in order to extend shelf life and to maintain product quality and safety [27]. The requirement to package foods in a resourceful mode for transportation and storage, beside among the growing consumer claim for fresh, convenient and protected food products signifies a bright future for antimicrobial packaging. Though, more information is needed on the chemical, microbiological and physiological effects of these systems on the packaged food especially on the issues of nutritional quality and human safety. Until now, research on antimicrobial packaging has focused mostly on the development of various methods and model systems, while slight attention has been paid to its preservation efficacy in actual foods. Research is necessary to recognize the food that can benefit most from

antimicrobial packing materials [46]. Antimicrobial nanoparticles that have been synthesized and examined for applications in antimicrobial packaging and food storage packages contain silver oxide nanoparticles, zinc oxide, magnesium oxide nanoparticles and are in particles formed since the fermentation of a bacterium [47-49]. Nano silver, Nano magnesium oxide, nano copper oxide, nano titanium dioxide and carbon nanotubes are also forecasted for future treatment in antimicrobial food packaging [14, 50, 51]. Kodak company is developing antimicrobial packaging for food products that will be commercially available in 2005 and 'active packaging,' which absorbs oxygen [52]. Other companies include Fresher Longer TM Miracle Food Storage Containers" and "Fresher Longer TM Plastic Storage Bags" from Sharper Image® USA, "Nano Silver Food Containers" from A-DO Korea, and "Nano Silver Baby Milk Bottle" from Baby Dream[®] Co. Ltd. (South Korea). Oxygen scavenging packaging using enzymes among poly ethylene films has also been developed [53]. An active packaging application could also be designed to stop microbial growth once the package is opened by the consumer and rewrapped with an active-film portion of the package [54]. Zinc oxide quantum dots were utilized as a powder, bound in a polystyrene film (ZnO-PS), or suspended in a poly vinyl prolidone gel (ZnO-PVP) as antimicrobial packaging against Listeria monocytogenes, Salmonella enteritidis, and Escherichia coli 0157:H7 [55]. Foods such as cheese, sliced meat, and bakery that are prone to spoiling on the surface can be protected by contact packaging imbued with antimicrobial nanoparticles. Antifungal active paper packaging developed by Rodriguez et al., (2008) incorporating cinnamon oil with solid wax paraffin using nanotechnology as an active coating was shown to be used as an effective packaging material for bakery products [56]. Working with oregano oil and apple puree, Rojas-Grau et al. (2006) have created edible food films that are able to kill E. coli bacteria [57].

Safety Issues and Future Trends of Nanotechnology in Food Industries

Recently, food packaging must been made with static materials, but active and smart materials have also been marketed. Antibacterials, Enzymes, and absorbent substances not only increase shelf life and get better storage conditions but also make food distribution much easier. Zinc oxide, manganese oxide and silver nanoparticles are examples of these active particles in anti-microbial properties for packaging [58]. Gold nanostructures, carbon nanotubes, quantum dots (QD), and other nanostructures have been or can be used as sensors of microbes or other tests for safety of food [59, 60, 61].

Launois, (2008) showed that silver nanoparticles could get better the safety of the world's food supply, according to a research project at Iowa State University in the United States of America. Silver nanoparticles cannot now be added directly to foods as tiny is known about their unfavorable effects on human health and their impact on ecological systems. On the other hand the research programmed is examining how silver nanoparticles could work as antimicrobial agents in foods, with the aim of developing food-related relevance's such as microberesistant fabrics or non bio-fouling surfaces. This can lead to new approaches for killing food-borne pathogens and enhancing the food safety. Launois also added that nanoparticles could provide us with multi-component antimicrobial mixtures that would be physically wellmatched with other compounds for killing microorganisms and improving food safety [62]. Nanomaterials may generate threats of environment pollution or still harmful effects on health of human [63-65]. According to our information about the safety of used nanomaterials in food and nutrition industries is short.

In the field of Research and development, active and smart packaging materials are very vigorous and develop in relation among the search for environment affable packaging solutions. In this situation, the real challenge is a design of tailor-made packaging and will involve the use of annul engineering move toward based on food requirements and not any longer only on the accessibility of packaging materials. Nanotechnologies are supposed to play a most important role at this time, taking into account all extra safety contemplations and filling the presently existing gap in knowledge. Nanotechnology will be involved in the developed of controlled release of active agents and for targeted indicators. Innovative nonmigratory materials for new functions for instance inpackage food processing are also a capable field of development [66]. In a common way, three main support for related to safety issues with active and intelligent or smart packing;

(a) Labeling, with the aim to avoid waste and error by the downstream users or consumers, e.g. to keep away from sachets from being consumed;

(b) Movement of active and intelligent substances should be mistrustfully judged with all breakdown products, similar to function of their toxicity. The implementation of releasing active packaging during food legislation shall be directly related to movement phenomena. evaluating migration implies to develop offered migration tests over and above mass transfer modeling tools because those existing, or recommended for conventional plastics, are not modified to active and intelligent systems;

(c) usefulness of the packaging: lastly in several specific cases, the capability of the packaging to perform the preserved function can increase safety issues like for any food protection technology, e.g. delivering a additive or absorbing oxygen in a proper way for preventing microbial growth not including antimicrobial resistance or pathogen more than growth, or giving consistent information on pathogenic bacteria occurrence for direct indicators.

A supple legislative structure and suitable testing methods are required for supporting such a highly novel field, i.e. to continue not only with the market as it is, but also as it will be [66]. Dowling et al., (2004) reported that various nanomaterials enter into the human body. According to a report, the British Royal Society comments that we may face a nano-toxicity disaster in the future. This report calls for avoiding nanotechnology in products until there is an inclusive understanding of the environmental and health risks of revelation to nanoparticles [7].

Regulations about Safety of Nanomaterials

Recent application of nanotechnology in sectors of food and agricultural industry is limited because toxicological and regulatory concerns are a big worry [67]. On the other hand, nanotechnology is individual used to get better the

Page 1

safety and quality of food throughout the encapsulation and protection of antimicrobials that are extremely unstable in food [68]. At the present time no unique regulations for the relevance or use of nanotechnology in foods in the United States (FDA) and Europe (EFSA, 2009) [69]. The European Union regulations for food packaging and food have suggested that for the beginning of new nanotechnology, definite testing procedures and standards of safety are required [70]. Inside United States, nanofoods and the largest part of the food packaging are regulated by the USFDA [71], whereas in Australia, nanofood stabilizers and constituents are regulated by FSANZ (Food Standards Australia and New Zealand), under the Food Standards Code [72]. In the India, regulations of food safety are introduced but not sufficient for the supervising safety of nanoparticles. Existing laws are insufficient to assess risks caused by nano based on foods and packaging because: (a) Toxicity threats stay very poorly understood because of their exclusive properties; (b) toxicity are not evaluated as new chemicals according to several regulations (c) recent coverage and safety methods are not proper for nano-materials and (d) lots of safety evaluations use private industry studies up to now, there is no international regulation of nano-products or nanotechnology [14, 50].

Risks of Nanotechnology in Food Sector

In the upcoming days, the industry of food plans to comprehend the possible of nanotechnology to enlarge shelf life customize flavors, get better health of human and Instead of compensation portions. well being. nanotechnology also provides disadvantages, more than ever the effect to the environment and human health, and several sectors will receive the risk of nanotechnology relevance, the main concerned focusing on the effect of nanotechnology on human health. Nanotechnology foods with real profits for the consumer will be easier to market than nanotechnology foods with no clear consumer benefits. Intended for the industry, it capacity be attractive to assume to facilitate attitudes toward nanotechnology foods will be more positive if a nanotechnology product with a attractive benefit is on the market. Usually, the contacts of nanoparticles on the body depend on the properties like mass, chemical composition, particle size, surface properties and how the entity nanoparticles are aggregating mutually. The positions of penetration, probable accumulation and translocation of nanoparticles in the body may also find out the probable risks of nanoscale materials [5]. In March 2006, it was reported by ETC Group that more than 70 people go through from respiratory problems and were hospitalized after using the nanotechnology bathroom cleaner [13]. Here are a lot of food materials and constituents which have nanostructure in nature. On the other hand, the opening of manufactured nanoparticles interested in food chain may result in accumulation of toxic impurities in foods, badly affecting human health. However, there are some nano-particle products which have no harmful effects. Like an example, the toxicity of assured materials such as selenium might be considerably decreased even as its particle size was reduced to nano-scale [5]. Moreover those, the majority of people favor the natural food while the healthfulness of natural and artificial foods was specified to be the same.

So, the number of food products including nano-scale substances is still little in the market [73].

In food industries, the main priority is quality and safety of food, so health risk assessments in these areas are essential. Since nanoparticles have entered food and related industries, toxicology research of nanoparticles is essential. Researchers in this area should pay special attention to the gastrointestinal absorption and possible side-effects of nanoparticles. Nanoparticles can have serious effects on health when they accumulate in high concentrations in tissues, eventually leading to tissue dysfunction or damage. With the increasing use of nanomaterials, concerns are also growing between experts but with increasing information of nanomaterials toxicity. public have not participate in this issue. Perhaps the main reason for contradictory information on the toxicity of nanoparticles is in terms of characterization and tests [74]. Therefore it is necessary to establish standard protocols for risk assessment. Moreover, the difference between humans and laboratory animals prevents extrapolation of the results [75].

CONCLUSIONS

Nanotechnology have unique properties in the field of food and their related industries (agriculture, packaging, and food processing) which can be used to improve color, flavour, taste, texture and reliability of foodstuffs, increased absorption and bioavailability of nutrients and enhance product's shelf life. However, these unique properties may sometimes lead to indefinite and occasionally have hazardous side-effects to ecosystems and even in people. The key role of nanotoxicology is to offer clear guidelines and roadmaps for decreasing risks in the optimal use of nanomaterials. Exposures routes in industrial workers and consumers of food products that contain nanomaterials must be studied carefully. Regulatory bodies, such as FDA, should author guidance with respect to the criteria to be followed in evaluating the safety of food, food packaging and additional utilization of nanomaterials with novel properties. Innovative advancement and standardized test procedures to study the impact of nanoparticles on living cells are urgently required for the assessment of potential hazards concerning to human exposure to nanoparticles. With a precise understanding of the properties of nanomaterials such as size, dose, surface chemistry and structures, this will provide useful and safe food products. To formulate full utilization of nanotechnology in the food and related industries, there must have a thorough understanding of nanomaterials.

REFERENCES

- 1. Huang, Z., Chen, H., Yip, A., (2003). Longitudinal patent analysis for nanoscale science and engineering: country, institution and technology field, J. Nanoparticle Research, 5 (34): 333–363.
- Jochen, W., Monika, G., and Stuttgart, H., (2013). Nanotechnology in the food industry, Ernaehrungs Umschau International, 60(4): 44–51.
- Roco, M.C., (2003). Nanotechnology: convergence with modern biology and medicine. Curr. Opin. Biotechnol. 14: 337–346.
- 4. Van Amerongen, A., Barug, D., and Wageningen, M.L., (2005). Rapid Methods for Biological and Chemical Contaminants in

Page

Food and Feed; Wagenigen Academic Publishers: the Netherlands.

- Chau, C.F., Wu, S.H., and Yen, G.C., (2007). The development of regulations for food nanotechnology. Trends Food Sci. Technol. 18: 269-280.
- 6. Ulijn, R.V., (2007). Bioresponsive hydrogels. Mater. Today. 10: 40–48.
- Dowling, A., Clift, R., Grobert, N., Hutton, D., Oliver, R., O'neill, O., (2004). Nanoscience and nanotechnologies: opportunities and uncertainties. London: The Royal Society & The Royal Academy of Engineering Report. 61-4.
- 8. LIU, J., ZHANG, Y.d., and ZHANG, Z.M., (2009). The Application Research of Nano-biotechnology to Promote Increasing of Vegetable Production. Hubei Agricultural Sci. 1: 041.
- Teng, B.S., Wang, C.D., Yang, H.J, Wu, J.S., Zhang, D., Zheng, M., (2011). A protein tyrosine phosphatase 1B activity inhibitor from the fruiting bodies of Ganoderma lucidum (Fr.) Karst and its hypoglycemic potency on streptozotocin-induced type 2 diabetic mice. J. Agr. Food Chem. 59(12): 6492-6500.
- Seabra, A.B., Rai, M., and Durán, N., (2013). Nano carriers for nitric oxide delivery and its potential applications in plant physiological process: A mini review. J. Plant Biochem. Biot: 1-10.
- 11. Eguchi, E., Cecato, U., and Silva, S., (2013). The way of nanotechnology in Brazil animal production. PUBVET. 7(8).
- 12. SERVICE, RF. (2004). Nanotechnology grows up. Science (Washington, D C). 304(5678): 1732-4, doi: 10.1126/science. 304.5678.1732.
- 13. ETC Group, (2006). Action Group on Erosion, Technology and Concentration. Nanotech product recall underscores need for nanotech moratorium: is the magic gone?. from http://www.etc group.org/upload/ publication/ 14/01/ nrnanorecallfinal.
- 14. Chaudhry, Q., Scotter, M., Blackburn, J., Ross, B., Boxall, A., Castle, K., Aitken, R., Watkins, R., (2008). Applications and implications of nanotechnologies for the food sector. Food Additives Cont. 25: 241-58.
- 15. The Eleventh ASEAN Food Conference, (2009).21–23 October; Bandar Seri Begawan, Brunei Darussalam.
- Nickols-Richardson, S.M., and Piehowski, K.E., (2008). Nanotechnology in nutritional sciences. Minerva Biotechnol., 20: 17–126.
- Charych, D., Cheng, Q., Reichert, A., Kuziemko, G., Stroh, N., Nagy, J., Spevak, W., and Stevens, R.A., (1996). 'Litmus test' for molecular recognition using artificial membranes. Chem. Biol., 3: 113–120.
- Imafidon, G.I. Spanier, A.M., (1994). Unraveling the secret of meat flavor. Trends Food Sci. Technol. 5: 315- 321.
- 19. Lawrence, M.J., and Rees, G.D., (2000). Microemulsion-based media as novel drug delivery systems. Adv. Drug Deliv. Rev. 45: 89-121.
- Haruyama, T., (2003). Micro and nanobiotechnology for biosensing cellular responses. Adv. Drug Deliv. Rev. 55: 393– 401.
- Nel, A., Xia, T., M[°]adler, L., and Li, N., (2009). Toxic potential of materials at the nanolevel. In Progress in Nanotechnology: Applications; Acers, Ed.; Wiley: New York. : 622–627.
- Helmut Kaiser Consultancy Group. (2009). Study: Nanotechnology in Food and Food Processing Industry Worldwide, 2006–2010-2015. Helmut Kaiser Consultancy Group: Beijing, 2009.
- 23. Augustin, M., Sanguansri, A.L., and Bode, O., (2006). Maillard reaction products as encapsulants for fish oil powders, J. Food Sci. 71(2): E25–E32.
- 24. Champagne, C.P., and P. Fustier, (2007). Microencapsulation for the improved delivery of bioactive compounds into foods, Curr. Opinion Biotechnol. 18(2):184–190.
- 25. Mc Clements, D.J., Decker, E.A., Park, Y., and Weiss, J., (2009). Structural design principles for delivery of bioactive

components in nutraceuticals and functional foods, Critical Reviews in Food Science and Nutrition, 49(6): 577–606.

- 26. Weiss, J., Gaysinsky, S., Davidson, M., and McClements, J., (2009). Nanostructured encapsulation systems: food antimicrobials, in Global Issues in Food Science and Technology, chapter 24, pp. 425–479, Academic Press, New York, NY, USA, 2009.
- Appendini, P., and Hotchkiss, J.H., (2002). Review of antimicrobial food packaging. Innovative Food Sci. Emerging Technol. 3113: 126.
- Reis, C.P., Neufeld, R.J., Ribeiro, A.J., and Veiga, F., (2006). Nanoencapsulation I. methods for preparation of drug-loaded polymeric nanoparticles, Nanomedicine: Nanotechnology, Biology, and Medicine, 2(1): 8–21.
- 29. Ansari, M., Khan, H., Khan, A., Singh, S., Saquib, Q. and Musarrat, J., (2014). Gum arabic capped-silver nanoparticles inhibit biofilm formation by multi-drug resistant strains of Pseudomonas aeruginosa, J. Basic Microbiol. 54:1–12.
- Fang, Z., and Bhandari, B., (2010). Encapsulation of polyphenols-A review, Trends Food Sci. Technolo. 21(10): 510–523.
- Daniells, S., (2007). Thing big, think nano. Food Navigator.com Europe 19 December 2007.Available at: http://www.foodnavigator.com/news/ng.asp?n=82109 (accessed 21 December 2007).
- Zhang, C., Ding, Y., Ping, Q., Yu, L., (2006). Novel chitosanderived nanomaterials and their micelle-forming properties. J. Agr. Food Chem. 54(22): 8409-8416.
- 33. Dingman, J., and Rehs, D., (2008). Nanotechnology: Its impact on food safety. J. Environ Health. 70(6): 47-50.
- 34. Renton, A., (2006). Welcome to the world of nanofoods. Guardian Unlimited UK 13 December 2006. Available at: http://observer.guardian.co.uk/foodmonthly/futureoffood/s tory/0,,1971266,00.html (accessed 17 January 2008).
- 35. Ashwood, P., Thompson, R., and Powell, J., (2007). Fine particles that adsorb lipo-polysaccharide viabridging calcium cations may mimic bacterial pathogenicity towards cells. Exp Biol Med. 232(1): 107-117.
- 36. Anonim, (2009). Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO). Report of Joint FAO/WHO Expert Meeting on the Application of Nanotechnologies in the Food and Agriculture Sectors: Potential Food Safety Implications. [cited 18 December 2009] Available from: http://www.fao.org/ag/agn/agns/files/ FAO_WHO_Nano_Expert_Meeting_Report_Final.pdf.
- Shelke, K., (2008). Hidden ingredients take cover in a capsule. http://www.foodprocessing.com/articles/2005/421.html (accessed 17 January 2008).
- Fleischwirtschaft, (2006). Available at: http://www.aquanova.de/media/public/publikationen2006/ Fleischwirtschaft_ProfWeber_NovaSOL_060502.pdf (accessed 24 December 2007).
- Duke, M.C., Lim, A., Luz, S.C., and Nielsen, L., (2008). Lactic acid enrichment with inorganic nanofiltration and molecular sieving membranes by pervaporation. Food Bioprod Process. 86: 290-95.
- Bouwmeester, H., (2007). Health impact of nanotechnologies in food production. Available: http://www.rivm.nl/ bibliotheek/ digitaldepot/healthimpactnanotechnologies.pdf.
- 41. Sorrentino, A., Gorrasi, G., and Vittoria, V., (2007). Potential perspectives of bio-nano composites for food packaging applications. Trends Food Sci. Technol. 18: 84-95.
- 42. Scrinis, G., and Lyons, K., (2007). The emerging nanocorporate paradigm: nanotechnology and the transformation of nature, food and agri-food systems. Int. J. Sociol. Food Agri. 15: 22-44.
- Cha, D., and Chinnan, M., (2004). Biopolymer-based antimicrobial packaging: A review. Critic. Rev. Food Sci. Nutrit. 44: 223-37.

Page

- Coma, V., (2008). Bioactive packaging technologies for extended shelf life of meat-based products. Meat Sci., 78(2): 90–103.
- 45. Baeumner, A., (2004). Nanosensors identify pathogens in food. Food Technol. 58: 51-5.
- 46. Suppakul, P., Miltz, J., Sonneveld, K. and Bigger, S.W., (2003). Active packaging technologies with an emphasis on antimicrobial packaging and its applications, J. Food Sci. 68(2): 408–420.
- 47. Sondi, I., and Salopek-Sondi, B., (2004). Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria. Journal of Colloid and Interface Science, 275: 177–182.
- Jones, N., Ray, B., Ranjit, K.T., and Manna, A.C., (2008). Antibacterial activity of ZnO nanoparticle suspensions on a broad spectrum of microorganisms. FEMS Microbiology Letters, 279: 71–76.
- 49. Gadang, V.P., Hettiarachchy, N.S., Johnson, M.G., and Owens, C., (2008). Evaluation of antibacterial activity of whey protein isolate coating incorporated with Nisin, grape seed extract, malic acid, and EDTA on a turkey frankfurter system. Journal of Food Science, 73(8): 389-394.
- Miller, G., and Senjen, R., (2006). Out of the laboratory and on to our plates- Nanotechnology in food and agriculture. Available:http://www.foeeurope.org/activities/nanotechnol ogy/Documents/Nano_food_report. Pdf. 2006.
- Doyle, M.E., (2006). Nanotechnology: A brief literature review. Available: http://www.wisc.edu/fri/briefs/ FRIBrief_Nanotech_Lit_Rev.pdf.
- 52. Asadi, G., and Mousavi, M., (2006). Application of Nanotechnology in Food Packaging. Available: http://iufost.edpsciences.org.
- 53. Lopez, R.A., Gavara, R., and Lagaron, J.M., (2006). Bioactive packaging: turning foods into healthier foods through biomaterials. Trends Food Sci.Technol. 17: 567-75.
- 54. Brody, A.L., (2004). Case studies on nanotechnologies for food packaging. Food Technol. 7: 102-7.
- 55. Sun, D.T., Jin, J.Y., Su, H., Zhang, J., and Sue, H.J., (2009). Antimicrobial efficacy of Zinc Oxide Quantum Dots against Listeria monocytogenes, Salmonella enteritidis, and Escherichia coli O157:H7. J. Food Sci. 74: M46-M52.
- 56. Rodriguez, A., Nerin, C., and Batlle, R., (2008). New cinnamonbased active paper packaging against Rhizopusstolonifer food spoilage. J. Agricultural Food Chem, 56(15): 6364–6369.
- 57. Rojas-Grau, M.A., Bustillos, A.R.D., Friedman, M., Henika, P.R., Martin-Belloso, O., and Mc Hugh, T.H., (2006). Mechanical, barrier and antimicrobial properties of apple puree edible films containing plant essential oils. Journal of Agricultural and Food Chemistry, 54: 9262–9267.
- 58. Rhim, J.W., Hong, S.I., Park, H.M., and Ng, P.K., (2006). Preparation and characterization of chitosan-based nanocomposite films with antimicrobial activity. J. Agric. Food Chem., 54 (16): 5814–5822.
- 59. Lin, C.C., Yeh, Y.C., Yang, C.Y., Chen, C.L., Chen, G.F., and Chen, C.C., (2002). Selective binding of mannose encapsulated gold nanoparticles to type 1 pili in Escherichia coli. J. Am. Chem. 124(14): 3508-9.

- Yang, L., and Li, Y., (2006). Simultaneous detection of Escherichia coli O157: H7 and Salmonella Typhimurium using quantum dots as fluorescence labels. Analyst. 131(3): 394-401.
- 61. Zhou, R., Wang, P., Chang, H.C., (2006). Bacteria capture, concentration and detection by alternating current dielectrophoresis and self assembly of dispersed single wall carbon nanotubes. Electrophoresis. 27(7): 1376-85.
- Launois, A., (2008). Nanoparticles could improve food safety. http://www.meatprocess.com/news/ng.asp?=84601nanotechnology. (Accessed11 Apr. 2008).
- 63. Colvin, V.L., (2003). The potential environmental impact of engineered nanomaterials. Nat Biotechnol. 21(10): 1166-70.
- 64. Scrinis, G., (2008). On the ideology of nutritionism. JSTOR. 8(1): 39-48.
- 65. Taghavi, S.M., Momenpour, M., Azarian, M., Ahmadian, M., Souri, F., and Taghavi, S.A., (2013). Effects of Nanoparticles on the Environment and Outdoor Workplaces. Electron. Physician. 5(4): 706-12.
- 66. Dainelli, D., Gontard, N., Dimitrios Spyropoulos, Zondervanvan den B.E., and Tobback, P., (2008). Active and intelligent food packaging: legal aspects and safety concerns. Trends Food Sci. Technol. 19: S103- S112.
- 67. Takeuchi, M.T., Kojima, M., and Luetzow, M., (2014). State of the art on the initiatives and activities relevant to risk assessment and risk management of nanotechnologies in the food and agriculture sectors, Food Research International.
- Dons'i, F., Annunziata, M., Sessa, M., and Ferrari, G., (2011). Nanoencapsulation of essential oils to enhance their antimicrobial activity in foods,LWT- Food Sci. Technol. 44(9): 1908–1914.
- 69. EFSA, (2009). Scientific Opinion of the Scientific Committee on a request from the European Commission on the Potential Risks Arising from Nanoscience and Nanotechnologies on Food and Feed Safety. The EFSA J 2009:958: 1-39.
- Halliday, J., (2007). EU Parliament votes for tougher additives regulation. Food Navigator.com 12.07.
- Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappel, L.M., Aviles-Vazquez, K., Salon, A., Perfecto, I., (2007). Organic agriculture and the global food supply. Renew Ag. Food Sys. 22: 86-108.
- 72. Bowman, D., and Hodge, G., (2006). Nanotechnology: Mapping the wild regulatory frontier. Futures. 38: 1060-1073.
- Ebbesen, M., Andersen, S., and Besenbacher, F., (2006). Ethics in nanotechnology: Starting from scratch. Bull. Sci. Technol. Soc. 26(6): 451–462.
- 74. Suh, W.H., Suh, Y.H., and Stucky, G.D., (2009). Multifunctional nanosystems at the interface of physical and life sciences. Nano Today. 4(1): 27-36.
- 75. Maynard, A.D., and Kuempel, E.D., (2005). Airborne nanostructured particles and occupational health. J Nanopart Res. 7(6): 587-614.