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Review Article

Role of Nanotechnology in Food Era

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ABSTRACT

Nanotechnology is the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties. Owing to the greater surface area of nanoparticles per mass unit, they are expected to be more biologically active than larger sized particles of the same chemical composition. This offers several perspectives for food applications. Nano-food can be defined as food that has been produced or packaged by nanotechnology techniques Nanoparticles for instance, be used as bioactive compounds in functional foods. Bioactive compounds that can be found naturally in certain foods have physiological benefits and might help to reduce the risk of certain diseases, including cancer. By reducing particle size, nanotechnology can contribute to improve the properties of bioactive compounds, such as delivery properties, solubility, prolonged residence time in the gastrointestinal tract and efficient absorption through cells. In the food industry, several novel applications of nanotechnologies have become apparent, including the use of nanoparticles, such as micelles, liposomes, nanoemulsions, biopolymeric nanoparticles and cubosomes, as well as the development of nanosensors, which are aimed at ensuring food safety. However, despite the increased marketing efforts in the nanotechnology sector, research into nanotechnology of food and food-related products is only just beginning to develop. Currently, the potential risks of nanomaterials to human health and to the environment are unknown. The 2006 report of the Institute of Food Science and Technologists mentions that 'size matters' and recommends the use of nanoparticles in the food sector only after safety has been proven following vigorous testing. Special attention should also be given to consumer attitudes towards food nanotechnology. Taking lessons from the GM arguments across European countries, it is crucial to discuss the benefits and risks of this highly promising technology. Governments should consider appropriate labeling and should also set down regulations that will help to increase consumer acceptability.

Key words: Nanotechnology, food, packaging, health.

INTRODUCTION

Over the past few decades, the evolution of a number of new science disciplines and technologies has revolutionized the food sector. Most notable among these are biotechnology, cognitive sciences, information technology (IT) and, more recently, nanotechnology, which is a broad interdisciplinary area of research, development and industrial activity that involves the manufacture, processing and application of materials that have one or more dimensions of the order of 100 nanometers (nm) or less (BSI 2005). The concept of nanotechnology was first envisaged by Professor Richard P Feynman, winner of the Nobel Prize in Physics 1965, in his 1959 lecture. There is Plenty of 'Room at the Bottom' in which he explored the possibility of arranging matter at the atomic level. [1] The term 'nanotechnology' was not coined however until 1974, when Professor Norio Taniguchi of Tokyo Science University used it to refer to the ability to engineer materials precisely at the nanoscale. The advance of nanoscience picked up pace in the 1980s and 1990s, with the development of tools that allowed the observation and manipulation of matter at the nanoscale. Nanotechnologies are now applied in a variety of sectors such as the food, pharmaceutical and healthcare, automotive and electronic industries. [2-6]

Nanotechnology is the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties. The definition of nanotechnology is based on the prefix "nano" which is from the Greek word meaning "dwarf". [7] In more technical terms, the word "nano" means 10^{-9}, or one billionth of something. Nanotechnology is an enabling technology that has opened up new avenues of R&D in a number of fields, including medicine, cosmetics, agriculture and food, and is being used as a means to understand how physicochemical characteristics of nano-sized substances can change the structure, texture and quality of foodstuffs. Nanotechnology is defined as any engineered materials, structures and systems that operate at a scale of 100 nanometers (nm) or less (one nanometer is one billionth of a meter). [8] To put this scale into perspective, a strand of DNA is 2.5 nm wide, a red blood cell is 7000 nm, while a human hair is about 80,000 nm wide. [4] Convergence of nanotechnology with other technologies is also leading to further innovations that are expected to make a major impact on production, processing, storage, transportation, traceability, safety and security of food. [6,8-13]

Principle:

Nanomaterials have a relatively bigger surface to volume ratio which increases reactivity and changes the mechanical, electrical, and optical properties of the particles. [14,15]

Approaches of Nanotechnology in food sector:

For food applications, nanotechnology can be applied by two different approaches, either 'bottom up' or 'top down'. [16-18] The top-down approach is achieved basically by means of a physical processing of the food materials, such as grinding and milling. For example, dry-milling technology can be used to obtain wheat flour of fine size that has a high water-binding capacity. This technology has been used to improve antioxidant activity in green tea powder. As the powder size of green tea is reduced to 1000 nm by dry milling, the high ratio of nutrient digestion and absorption resulted in an increase in the activity of an oxygen-eliminating enzyme. By contrast, self assembly and self organization are concepts derived from biology that have inspired a bottom-up food nanotechnology. [19] The organization of casein micelles or starch and the folding of globular proteins and protein aggregates are examples of self-assembly structures that create stable entities. Self organization on the nanometer scale can be achieved by setting a balance between the different non-covalent forces Owing to the greater surface area of nanoparticles per mass unit, they are expected to be more biologically active than larger sized particles of the same chemical composition. This offers several perspectives for food applications.

Nanoparticles can, for instance, be used as bioactive compounds in functional foods. [20,21] Bioactive compounds that can be found naturally in certain foods have physiological benefits and might help to reduce the risk of certain diseases, including cancer. By reducing particle size, nanotechnology can contribute to improve the properties of bioactive compounds, such as delivery properties, solubility, prolonged residence time in the gastrointestinal tract and efficient absorption through cells . Omega 3 and omega 6 fatty acids, probiotics, prebiotics, vitamins and minerals have found their applications in food nanotechnology as bioactive compounds. [22,23]

Types of Nanostructure:

Nanotextured Surface: Generation of nanotextured surface involve microwave assisted hydro- or solvo-thermal treatments of polymer films coated on surfaces. It involves the transformation of polymer film into uniform islands of regularly shaped, nanometer-sized polymers for obtaining either superhydrophilic or superhydrophobic surfaces.

Nanotubes: these can be made by folding the sheet made from nano biopolymer. Carbon nanotubes have been widely used as a nonfood applicationof nanotechnology. These structures have been used as low-resistance conductors or catalytic reaction vessels among other uses. It has been shown that certain globular proteins from milk (such as hydrolyzed α-lactalbumin) can be made to selfassembleinto similarly structurednanotubesunderappropriate environmental conditions. This technique is applicable to other proteins as well and has been explored to assist in the immobilization of enzymes or to build analogues to muscle-fiberstructures. [24-27]

Nanoparticles: it can be synthesis by two process like attrition and pyrolysis. Attrition means macro or micro scale particles are ground in a ball mill, a planetary ball mill, or other size reducing mechanismIn the food industry, several novel applications of nanotechnologies have become apparent, including the use of nanoparticles, such as micelles, liposomes, nanoemulsions, biopolymeric nanoparticles and cubosomes, as well as the development of nanosensors, which are aimed at ensuring food safety. Pyrolysis means a vaporous precursor (liquid or gas) is forced through an orifice at high pressure and burned. The resulting solid (a version of soot) is air classified to recover oxide particles from by-product gases.

Engineered Nanoparticles: These molecules are covalently bonded, and thus are persistent and generally rather robust, though they may have important surface properties such as catalysis, and they may be prone to aggregate[2]. Examples of engineered nanoparticles include titanium dioxide nanoparticles. Nanosilver is also finding a growing use in a number of consumer products, including food and health food, water, and food contact surfaces and packaging materials. Indeed, the use of nanosilver as an antimicrobial, antiodorant, and a (proclaimed) health supplement has already surpassed all other ENMs currentlyin use in different sectors. [28]

Self-assembled nanostructures: These molecules are held together by weak forces, such as hydrogen bonds and the hydrophobic interaction. The weakness of these forces renders them mutable and transient; examples include soap micelles, protein aggregates (for example the casein micelles formed in milk), liposomes and nanosomes and the microcapsules and nanocapsules made from biopolymers such as starch. [29] The crystalline structures in starch, and processed starch-based foods that determine gelatinization and influence the nutritional benefits during digestion, the fibrous structures that control the melting, setting, and texture of gels, and the two dimensional nanostructure formed at oil-water and air-water interfaces that control the stability of food /dairy foams and emulsions. [2,30]

Current scenario of India in the field of Nanotechnology

Nanotechnology has been described as the new industrial revolution and both developed and developing countries are investing more in this technology. [31] As the next major technology wave, nanotechnology will be revolutionary in a social and economic way (Table 1). Developing countries are already aware that nanotechnology can be applied to many of their pressing problems and they realize that the industrialized countries will not place these applications at the top of their to-do list. [32-34]

India. In India, this tiny technology covers a wide gamut of field. As India is the leading runner of nanotechnology so the government of India established the Nanoscience and Technology Initiative in the later part of the 2001 through Department of Science and Technology (DST), New Delhi and invested about Rs. 350 Crores (2002-06) and granted approval for the Nanomission worth Rs. 1000 crores for next five years. [35] The Council for Scientific and Industrial Research (CSIR), India's premier R&D body, holds numerous nanotechnology related patents, including novel drug delivery systems, production of nanosized chemicals, and high temperature synthesis of nanosized titanium carbide. In the industrial sector, Nano Biotech Ltd. is doing research in nanotechnology for multiple diagnostic and therapeutic uses. Dabur Research Foundation is involved in developing nanoparticle delivery systems for anticancer drugs. Similarly, Panacea Biotec has made advances in novel controlled-release systems, including nanoparticle drug delivery for eye diseases, mucoadhesive nanoparticles, and transdermal drug delivery systems. [32]

Table1- Selected Developing Countries and Their Nanotechnology Activity

Front Runner	China South Korea India	National government funding program Nanotechnology patents Commercial products on the market or in development
Middle Ground	Thailand Philippines South Africa Brazil Chile	Development of national government funding program Some form of existing government support (research grants) Limited industry involvement Numerous research institutions
Up and Comer	Argentina Mexico	Organized government funding not yet established Industry not yet involved Research groups funded through various science and technology institutions

Food Nanotechnology

Nano-food' can be defined as food that has been produced or packaged by nanotechnology techniques. [36] Nanoscale molecules show greater chemical reactivity or greater catalytic behaviour compared with classical molecules. [37] Nanotechnology for food-packaging aims at reducing ultraviolet UV-light exposure or microbial growth. Moreover, food safety can be improved by nano-sensors able to detect pathogens or contaminants. [20] In today's world, food materials are often considered not only a source of nutrients but also as having to contribute to the health of consumers. Most of the nanoparticles used traditionally belong to the group of colloids (i.e. emulsions, micelles, mono- and bi-layers). One of the first colloidal gold dispersions was prepared by Michael Faraday in the middle of the 18th century. The particles were attracted to each other through Van der

Waals forces, which give them colloidal stability. In colloidal particles, steric stabilization is achieved by adsorbing polymers and surfactants on the surface. Nanoparticles could be further stabilized by coating them with molecules that can form chemical bonds. [38,39]

In the food industry, several novel applications of nanotechnologies have become apparent, including the use of nanoparticles, such as micelles, liposomes, nanoemulsions, biopolymeric nanoparticles and cubosomes, as well as the development of nanosensors, which are aimed at ensuring food safety. However, despite the increased marketing efforts in the nanotechnology sector, research into nanotechnology of food and food-related products is only just beginning to develop. [40] Some examples of the use of nanotechnology in food products are cooking oils that contain nutraceuticals within nanocapsules, nanoencapsulated flavor enhancers and nanoparticles that have the ability to selectively bind and remove chemicals from food. The main reasons for the late incorporation of food into the nanotechnology sector are issues associated with the possible labeling of the food products and consumer-health aspects. The knowledge gained from these sectors 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 in delivery of nutrients. [41]

Nanotechnology and food packaging

The use of nanomaterials in food packaging is already a reality. Nanotechnology can be used in plastic food packaging to make it stronger, lighter or perform better. Antimicrobials such as nanoparticles of silver or titanium dioxide can be used in packaging to prevent spoilage of foods. Another addition is the introduction of nanoparticles of clay into packaging to block oxygen, carbon dioxide and moisture from reaching the food, and also aids in preventing spoilage. Chemical giant Bayer produces a transparent plastic film called Durethan which contains nanoparticles of clay. Durethan 7 is an engineering plastic based on polyamide 6 and polyamide 66; these particles offer an excellent combination of properties which include high strength and toughness, abrasion resistance, chemical resistance, and resistance to cracking. Durethan is used in various industries and applications, including packaging film for the medical field and food packaging. The nanoparticles are spread throughout the plastic and are able to block oxygen, carbon dioxide and moisture from reaching fresh meats or other foods. The advantage of using nanoclay is it also makes the plastic lighter, stronger and more heat-resistant. Durethan film material with nanoparticles combines the advantages of polyamide 6 and ethylene vinyl alcohol (EVOH) to produce an inexpensive but still very airtight packaging material. The embedded nanoparticles prevent gases from penetrating the film and also keeping moisture from escaping.

Advantages of nanomaterials in food-packaging:

- ✓ Bioactive packaging materials need to be able to keep bioactive compounds, such as prebiotics, probiotics, encapsulated vitamins or bioavailable flavonoids, in optimum condition until they are released in a controllable manner into the food product. [41-43] Bioactive-packaging materials [44] can help to control oxidation of food stuffs and to prevent the formation of off-flavors and undesirable textures of food. Bioactive compounds that are encapsulated into the packaging itself are a promising approach because this would allow the release of the active compounds in a controllable manner. Several already approved food additives could be used for such nanoencapsulation, including carrageenan, chitosan, gelatin, polylactic acid, polyglycolic acid and alginate. [38,42,46]

- ✓ Nanosensors: In addition to food packaging, food preservation is also of great importance for the food industry. Food spoilages can be detected with so-called nanosensors, for example, an array of thousands of nanoparticles designed to fluoresce in different colors on contact with food pathogens. Taking into account the crucial importance of time in food microbiology, the main aim of nanosensors is to reduce the time. [45] The potential benefits of using nanotechnology in food include the ability to monitor the quality of food, and its surrounding environment, through the use of nanosensors.Antimicrobial biosensors and controlled release technology may provide new approaches to food safety in the future.New textures and flavours may be realised with "release on demand" functionality. [47]

Types of nanosensors and application in the food sector:

Various types of nanosensors are used in food industries to increase shelf life of products. Similarly, several food additives, including benzoate, sorbate, p-hydroxybenzoic acid esters and glutamate, to evaluate the performance of different types of electrophoresis methods within a chip-setup and found that, for different additives, different detection methods proved to be optimal. In the food-analysis market, devices produced with the so-called nanoelectromechanical systems (NEMS) technology are already in use and these systems contain moving parts ranging from nano- to milli-meter scale, which might serve as developing tools in food preservation. They can control the storage environment and act as active 'sell by' devices. [38,48]

Nanocantilevers are pioneer in set of biosensors. Their detection principle is based on their ability to detect biological-binding interactions, such as between antigen and antibody, enzyme and substrate or cofactor and receptor and ligand, through physical and/or electromechanical signaling. [49] Nanocantilever devices have already had tremendous success in studies of molecular interactions and in the detection of contaminant chemicals, toxins and antibiotic residues in food products. [50] The silicon surface of nanocantilevers can be modified to attach antibodies, resulting in a change of the resonant frequency depending on the attached mass were able to detect Escherichia coli, which is an indicator of fecal pollution of water and food products, with the help of a cantilever coated with agarose. [51]

Currently, no regulations exist that specifically control or limit the production of nanosized particles and this is mainly owing to a lack of knowledge about the risks. Despite this lack of regulation and risk knowledge, a handful of food and nutrition products that contain nanoscale additives are already being sold, such as iron in nutritional drink mixes, micelles that carry vitamins, minerals and phytochemicals in oil and zinc oxide in breakfast cereals. The US Food and Drug Administration require manufacturers to demonstrate that the food ingredients and food products are not harmful to health, yet this regulation does not 'specifically' cover nanoparticles, which could become harmful only in nanosized applications. Public perception of nanotechnology is another important factor that will affect the realization of nanotechnology approaches in the food industry, as seen in the example of genetically modified (GM) foods. Similar to GM foods, consumers cannot directly judge the benefits of a food derived from nanotechnology and any benefits need to be explained to the consumer. However, it is likely that some products engineered with nanotechnology will be accepted more easily by the public than others. [38,52-54]

Major food and nutrition companies integrating nanotechnology

Kraft and Nestle foods are the companies currently designing, "smart foods" that are intended to interact with the consumers so they can personalize their food, by changing color, flavor, and nutrients on demand. Kraft is developing a clear tasteless drink that contains hundreds of flavors in latent nanocapsules, by using a microwave you would be able to trigger the release of the color, flavor, concentration and texture of the individual's choice. The technique of nanoencapsulation, or creating nanocapsules, involves coating a nanoparticle so that its contents are released in a controlled way. [1] It has been suggested that the number of companies currently applying nanotechnologies to food could be as high as 400. A number of major food and beverage companies are reported to have an interest in nanotechnology. These include Altria, Nestle, Kraft, Heinz and Unilever, as well as small nanotech start-up companies. [2,55] It is also widely anticipated that the number of companies applying nanotechnologies to food will increase dramatically in the near future. Considering such rapid developments in this field, and the global setup of international food companies, it is not unreasonable to anticipate that more nanofood products will appear on the EU markets within the next few years.

H.J. Heinz Friesland Food

- ✓ Grolsch
- ✓ Kraft Foods
- ✓ Cargill
- ✓ Pepsi-Cola Company
- ✓ ConAgra Foods
- ✓ Nestle
- ✓ Hershey
- ✓ Unilever
- ✓ Campina
- ✓ General Mills

Food Law Regulations

It is recognised that the application of nanotechnology may present new challenges in terms of safety, regulatory and ethical considerations, while offering many potential benefits to manufacturers and consumers. [41] In terms of current regulatory approaches in the European Union, it is generally considered that potential uses of nanotechnologies in the food and feed area will be covered by the existing regulatory framework, either by the principles of the general food law (EC 178/2002) or by specific approval processes. Major gaps in existing regulations were not identified in a review undertaken by the UK Food Standards Agency, but there is uncertainty in some areas as to whether a number of specific applications of nanotechnologies would be picked up consistently, for example the introduction of nanoscale preparations of existing food ingredients, or currently approved food additives. [56] As food and feed regulations are harmonised at EU level, any action to address such uncertainties would need to be taken forward by the European Commission. A review recently completed by the Commission has indicated that the existing EU legislation is broadly adequate to cover potential risks of nanotechnology-based products, although in some areas, specific supporting instruments (guidelines, test protocols, standards) may need to be developed and some provisions clarified or adapted, in order to ensure the full effectiveness of the existing legislation in practice. [57] In the event that a nano-ingredient falls outside the scope of the Novel Food Regulation, the general safety articles of the EU Food Law Regulation (178/2002) would apply, which require that food placed on the market is safe. A joint statement on nanomaterial toxicology issues, the independent UK Committees on Toxicity, on Mutagenicity, and on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (COT, COM, COC) stated that there is no need to develop a new approach to risk assessment of nanomaterials, but there is a clear need to provide hazard identification data on the widest possible range of nanomaterials. [58] In the absence of such data, the Committees stated that it was not possible to derive conclusions about the spectrum of toxicological effects that might be associated with nanomaterials. [47]

CONCLUSION

Nanotechnology is becoming increasingly important for the food sector. Promising results and applications are already being developed in the areas of food packaging and food safety. The incorporation of nanomaterials into food packaging is expected to improve the barrier properties of packaging materials and should thereby help to reduce the use of valuable raw materials and the generation of waste. Edible nanolaminates could find applications in fresh fruits and vegetables, bakery products and confectionery, where they might protect the food from moisture, lipids, gases, off-flavors and odors. Natural biopolymers of nanosize scale, such as polysaccharides, can be used for the encapsulation of vitamins, prebiotics and probiotics and for delivery systems of drugs or nutraceuticals. In the food sector, one of the most important problems is the time-consuming and laborious process of food quality-control analysis. Innovative devices and techniques are being developed that can facilitate the preparation of food samples and their precise and inexpensive analysis. From this point of view, the development of nanosensors to detect microorganisms and contaminants is a particularly promising application of food nanotechnology. However, there are social and ethical issues of using nanotechnology in the food sector that must be considered. Currently, the potential risks of nanomaterials to human health and to the environment are unknown. Special attention should also be given to consumer attitudes towards food nanotechnology. Taking lessons from the GM arguments across European countries, it is crucial to discuss the benefits and risks of this highly promising technology. Governments should consider appropriate labeling and should also set down regulations that will help to increase consumer acceptability. Evidently, nanotechnology offers tremendous opportunities for innovative developments in food packaging that can benefit both consumers and industry. The application of nanotechnology shows considerable advantages in improving the properties of packaging materials, but we are still in the early stages and will require continued investments to fund the research and development to better understand the advantages and disadvantages of nanotechnology used for a variety of food products till packaging to encapsulation of nutraceuticals etc.

REFERENCES

1. Lam D. Packaging Applications Using Nanotechnology. San Jose State University. 2010. 2-13p.
2. Chaudhry Q, Scotter LM, Blackburn LJ, Ross B, Aoxall A, Castle, Watkins R. Applications and implications of nanotechnologies for the food sector.

Food Additives and Contaminants. 2008; 25(3): 241–258.
3. ETC Group. Action Group on Erosion, Technology and Concentration. Down on the Farm; the impact of Nanoscale Technologies on Food and Agriculture. 2004. http://www.etcgroup.org.
4. Miller G, Senjen R. Friends of the Earth Australia Nanotechnology project.2008. Available from: http://www.nano.foe.org.au
5. Morris VJ. Nanotechnology and its future in new product development. Journal of the Institute of Food Science and Technology.2006; 20 (3)15-17.
6. Morris VJ. Nanotechnology in the food industry. New Food Mag. 2008; 4:53–5.
7. Dingman J. Nanotechnology: Its Impact On Food Safety. (Guest Commentary).J Environ Health.2008 Jan 1.
8. Moraru, CI, Panchapakesan CP, Huang Q, Takhistov P, Liu S, Kokini, JL. Nanotechnology: a new frontier in food science. Food Technol. 2003; 57(12):24–29.
9. Bouwmeester H, Dekkers S, Noordam M, et al. Health impact of nanotechnologies in food production. Report 2007.014. RIKILT – Institute of Food Safety, Wageningen UR and National Institute of Public Healthand the Environment; Center for Substances and Integrated Risk Assessment, 2007. Available from: www.rikilt.wur.nl/NR/rdonlyres/ BDEEDD31-F58C-47EB-A0AA23CB9956CE18/54352/ R2007014. pdf, 95 pp.Chaudhry.pdf.
10. Food Safety Authority of Ireland. The Relevance for Food Safety of Applications of Nanotechnology in the Food and Feed Industries. Food Additives, Chemical Contaminants & Residues. Abbey Court Lower Abbey Street. Dublin. 2008. www.fsai.ie.
11. Groves K. Potential benefits of micro and nano technology for the food industry: does size matter? New Food Mag. 2008; 4: 49–52.
12. Kuzma J, VerHage P. Nanotechnology in agriculture and food production: anticipated applications. Project on Emerging Nanotechnologies. Washington DC, Woodrow Wilson International Center for Scholars, September 2006. Available from: www.nanotechproject.Org.
13. Sekhon BS. Food nanotechnology – an overview. Nanotechnology, Science and Applications. Dove Medical Press. 2010; 3: 1–15.
14. Green CJ, Sarah NS. Nanotechnology: A Review of Exposure, Health Risks and Recent Regulatory Developments. National Collaborating Centre for Environmental Health 2011; 1: 4-22.
15. Scown TM, Aerle RV, Tyler CR. Review: Do engineered nanoparticles pose a significant threat to the aquatic environment? Crit Rev Toxicol. 2010: 40(7):653-70.
16. Karluss T, Philip S. Research Strategies for Safety Evaluation of Nanomaterials, Part I: Evaluating the Human Health Implications of Exposure to Nanoscale Materials. Toxicological Sciences. 2005; 87(2): 316-21.
17. Ravichandran R. Nanoparticles in drug delivery: potential green nanobiomedicine applications. Int. J. Nanotechnol. Biomed. 2010; 1:108-130.
18. Drexler KE. Molecular engineering: An approach to the development of general capabilities for molecular manipulation. Proceedings of the National Academy of Sciences of the United States of Americ.1981; 78:5275–78.
19. Royal Society and the Royal Academy of Engineering. Nanoscience and Nanotechnologies: Opportunities and Uncertainties. Royal Society and Royal Academy of Engineering, London, UK. 2004.116p.
20. Weiss J, Takhistov P and McClements D. Functional materials in food nanotechnology. Journal of Food Science.2006; 71 (9): 107-115.
21. Huang Q, Yu H, Ru Q. Bioavailability and Delivery of Nutraceuticals Using

Nanotechnology. Journal of Food Science. 2010; 75: 50–57.
22. Shibamoto T, Kanazawa K, Shahidi F. Functional food and health: an overview. ACS symposium series 993. *Functional food and health*. Washington , DC : Oxford Univ. Press.2008. 1–6p.
23. Vaclavik VA *and* Christian EW. Essentials of Food Science. New York : Springer. 2008. 46 p.
24. Graveland Bikker JF, De Kruif CG. Unique milk protein-based nanotubes: food and nanotechnology meet. Trends Food Sci Technol: 2006; 17(5):196–203.
25. Graveland Bikker J, De Kruif CG. Self-assembly of hydrolysed alpha-lactalbumin into nanotubes. FEBS J. 2005: 272(1); 550.
26. Graveland Bikker JF, Schaap IAT, Schmidt CF et al. Structural and mechanical study of a self-assembling protein nanotube. Nano Lett. 2006; 6(4):616–21.
27. Graveland-Bikker JF, Fritz G, Glatter O. Growth and structure of α-lactalbumin nanotubes. J. Appl. Cryst. 2006; 39:180-84.
28. Woodrow Wilson International Centre for Scholars.*The Nanotechnology consumer Inventory*. 2009. Available at: www.nanotechproject. org/inventories/consumer.
29. Chen H, Weiss J, Shahidi F. Nanotechnology in nutraceuticals and functional foods. Food Technology. 2006; 603:30–6.
30. Rudolph MJ. Cross-industry technology transfer. Food Technol. 2004; 58: 32-34.
31. Qureshi AM, Swaminathan K, Karthikeyan P, Ahmed KP, Sudhir, Mishra UK. Application of nanotechnology in food and dairy processing: An Overview. Pak. J. Food Sci. 2012; 22(1): 23-31.
32. Singer PA, Buentello F, Daar AS. Harnessing Nanotechnology to Improve Global Equity. Issues in Sci and Tech. 2005; 1: 58-64.
33. Court EB, Daar AS, Persad DL. et al. Tiny Technologies for the Global Good. *Nano Today*. 2005 (4); 14–15.
34. Buentello FS, Persad DL, Court EB, Martin DK, Daar AS. Nanotechnology and the Developing World. Plos Med. 2005; 2: 97.
35. Patra D, Haribabu E, Basu PK. Nanoscience and Nanotechnology: ethical, legal, social and environmental issues. Current Science. 2009: 96(5):651-57.
36. Joseph T, Morrison M. Nanotechnology in Agriculture and Food. A Nanoforum report available from: http://www.nanoforum.org/dateien/temp/nanotechnology%20in%20agriculture%20and%20food.pdf?08122006200524. 2006 (Accessed January 17 2008).
37. Gaskell G, Eyck TT, Jackson, J. et al. Public attitudes to nanotechnology in Europe and the United States. Nature Materials. 2004; 3:496.
38. Sozer N and Kokini JL. Nanotechnology and its applications in the food sector. Trends in Biotechnology. 2009; 27 (2):82-89.
39. Fendler JH. Colloid chemical approach to nanotechnology. Korean J Chem Eng.2001; 18:1–13.
40. Yih TC, Al Fandi M. Engineered nanoparticles as precise drug delivery systems. J. Cell. Biochem.2006; 97:1184–1190.
41. Chau, CF, Wu SH, Yen GC. The development of regulations for food nanotechnology. Trends Food Sci. Technol. 2007; 18: 269–280.
42. Lopez-Rubio A, Gavara R, Lagaron, JA. Bioactive packaging: Turning foods into healthier foods through biomaterials. Trends in Food Science and Technology. 2006; 17:567 – 75.
43. Brody AL. Edible packaging. Food Technol. 2005; 56: 65–66.
44. Guerra NP, Macias CL, Agrasar AT. et al. Development of a bioactive packaging cellophane using Nisaplin as biopreservative agent. Lett. Appl. Microbiol.2005; 40: 106–110.

45. Kumar MNVR. A review of chitin and chitosan applications. React. Funct. Polym. 2000; 46: 1–27.
46. Bhattacharya S, Jang J, Yang L. et al. Biomems and nanotechnology based approaches for rapid detection of biological entitities. J Rapid.Methods Auto Microb. 2007; 15:1–32.
47. Food Safety Authority of Ireland-The relevance for food safety application of nanotechnology in food and feed industries. Published by Food Safety authority of Ireland. Abbey Court, Lower, Abbey Street Dublin. 2008. ISBN-I 904465-59-5.
48. Ritter SK. An eye on food. Chem Eng News. 2005; 83: 28–34.
49. Hall RH. Biosensor technologies for detecting microbiological food borne hazards. Microbes Infect.2002; 4:425–32.
50. Ramirez FN. Cantilever biosensors. Biotec Apl. 2006; 23: 320–23.
51. Gfeller KY, Nugaeva N, Hegner M. Micromechanical oscillators as rapid biosensor for the detection of active growth of Escherichia coli. Biosens. Bioelectron. 2005; 21: 528–33.
52. Lee CJ, Scheufele DA, Lewenstein BV. et al. Public attitudes toward emerging technologies. Sci. Commun. 2005:27: 240–267.
53. Cobb MD, Macoubrie J (2004) Public perceptions about nanotechnology: risks, benefits and trust. J. Nanopart. Res.2004; 6:395–405.
54. EC. Eurobarometer Survey on Europeans, Science and Technology. European Commission. 2001. http://dx.doi.org/10.3886/ICPSR03341).
55. Cientifica Report. 2006. ‘‘Nanotechnologies in the Food Industry’’; published August 2006. Available: www.cientifica.-com/www/details.php?id¼47.
56. Food Standards Agency. Draft FSA regulatory review on nanotechnology in food: issue for comment. Food Technology. 2006;3: 30-36.
57. EC. Commission Recommendation on a Code of Conduct for Responsible Nanosciences and Nanotechnologies Research. 2008. http://ec.europa.eu/research/sciencesociety/document_library/pdf_06/nanocoderecommendation- pe0894c08424_en.pdf.
58. COT. UK Committees on toxicity, mutagenicity and carcinogenicity of chemicals in food, consumer products and the environment (COT, COM, COC). Joint statement on nanomaterial toxicology. 2005. http://cot.food.gov.uk/pdfs/cotstatements2005nanomats.pdf.

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