A REVIEW

FOOD SCIENCE RESEARCH JOURNAL;
Volume 2 Issue 2
(October, 2011) Page : 219-225

Received : August, 2011; Accepted : September, 2011

Recent trends in application of nanotechnology in food processing

SHARANAKUMAR HIREGOUDAR, VENKATESH MEDA, B.V. PATIL AND K.T. RAMAPPA

ABSTRACT

Food is the substance or material consumed by the consumer to provide a nutritional support for the body and pleasure. The "right to an adequate standard of living, including adequate of food", as well it is the "fundamental right to be free from hunger". The application of nanotechnology in food processing may help to consumers to control their food habits and balance the dietary and also care the consumers need and safety. For the present growing population, an appropriate incorporation of food additives for consumers were very essential, especially who suffering from different chronic diseases and imbalanced food. To meet out the present growth nest, nanoscience and nanotechnology may play a vital role to surrogate the future needs of the hamlet. Among different processing methods, food encapsulation, smart packaging and different sensors will boost the technology to the greater heights.

Hiregoudar, Sharanakumar, Meda, Venkatesh , Patil, B.V. and Ramappa, K.T. (2011). Recent trends in application of nanotechnology in food processing, *Food Sci. Res. J.,* **2** (2) : 219-225.

Key Words : Nanotechnology; Food processing; Encapsulation; Packaging; Sensor

INTRODUCTION

The National Nanotechnology Initiative (NNI) defines the nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale [1]. The nanoscale is expressed or coined in different ways, one nm is one thousandth of a micrometre (μm), one millionth of millimetre (mm) and one billionth a metre (m). The expression nanoscale is used to refer to objects with dimensions on the order of 1-100 nm. To distinguish the nanoscale, it must be noticed that a strand of DNA is 2.5nm wide; a protein molecule is 5 nm wide[2]. It can be manipulated at the atomic or molecular scale by multidisciplinary approach[3]. The arrangement of those molecules at a single strand and design complex of systems may differ with specific feature required by understanding the individual molecular structures and its forces caused on the material[4].

Background of nanotechnology:

The coining of word nanotechnology began with the physicist Richard Feynmam in 1960[5] and Professor Norio Taguchi (1974) expanded and highlighted with more relevant as atom by atom or molecule by molecule [6]. In later days, Drexler (1981) expressed the scale in microscopic level [7]. But at present it is diversified into most of the booming cutting edge areas by manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties [8]. This revolution may change the present scenario, especially in the food industry by developing different processed food products during process, packaging, transportation, and consumption. But most of the meals are consumed by the consumer containing fats, liposomes, flavours and other components are ranging from 50nm to 500nm[9]. Therefore, the application of nanotechnology would differ with the consumer or condition requirement especially in food industry. But food safety and food security are the need to the future thrust in particular to the nanotechnology concern. The major cause of foodborne illness commonly called "food poisoning", is by bacteria, toxins, viruses, parasites, and prions can be monitored by nano sensors[10]

Importance of nanotechnology:

Food is the depending factor through agriculture, by increasing in food supply, which means forward and backward linkages. This growing trend would sustainable by using proper agricultural practices. This approach helps to the consumer demand, encourages acceptance and local self-reliance. The Institute of Food Technologists (IFT)

defines food science as "a multi discipline in which biology, physical sciences and engineering are used to study the nature of foods, the causes of their deterioration and the principles underlying food processing", and food technology as the "application of food science to the selection, preservation, processing, packaging, distribution and use of safe, nutritious and wholesome food". In the advent of technological revolution by introduction of novel technologies like microwave, irradiation, different packaging techniques will keep the food fresh and enhances the shelf life in our daily diets. Nanotechnology will playing a vital importance in different engineering properties of many foods in nanoscales. The introduction of nano materials in food packaging could lead to foods that are healthier, tastier and safer for longer period[11] . In present and future trend of food production, processing and consumption is based on the requirement, instead of need of the food. At present, the people of different parts of the country have had an increasing trend towards consumerism which is the use of food supplements, food for a specific group of person (such as dieters, women or athletes), the use of functional and nutraceutical foods (fortified foods)[12] and a more ethnically diverse diet [13].

Overview of nano foods:

In different parts of the country, consumers are consuming the nano particles by knowingly or unknowingly in many foods. Milk, for example, contains nanoscale fat globules, micelles and whey proteins and many food-processing techniques. Milling, churning, homogenization, spray drying and encapsulation will separate the nano particles. It is important to note that humans have been consuming nanomaterials and nanoparticles for ages [14] During the digestion the size of the food particle would smaller than the micro or even nano scale. But still it needs to be proper evaluation before down sizing and preferring to human beings to consume.

The available nanofoods contain nanoscale ingredients and additives for different food products. Nestle and Unilever are reported nanosize emulsion-based ice cream with a lower fat content [15], Aquanova developed a 30 nm micelles to encapsulate active ingredients of vitamin C and E and fatty acids, used as preservatives [16]. BioDelivery Sciences, for Bioral Omega-3 nano cochleates of 50 nm are more effective in use of bakery industry for preparation of cake, muffins, pasta, chips and candy bars [17]. Nutralease reported the nano self-assembled structured liquids for encapsulations of nutraceuticals are released into the membrane [18]. BASF developed the Solu E 200 BASF and synthetic lycopene for fat soluble [19]. Shenzen Become Industry and Trading Co, reported the 160 nm nanoparticles for Nano tea [20]. 300 nm iron (Sun Active Fe) used for fortified fruit juice by High Vive [21], Jamba juice Hawaii for daily vitamin boost [22] and toodler health for oat chocolate nutritional drink [23]. Shefer and Shefer (2003 a, b and c) developed the encapsulated system results in nanospheres or microspheres. This system was used widely in baked goods, refrigerated/frozen batters, tortillas and flat breads, processed meat products, seasonal confectionery, specialty products, chewing gums, dessert mixes, and nutritional foods [24,25,26]. Bayer reported Durethan KU 2-2601, polymer based nano particle for food packaging material to prevent penetration of oxygen [27]. Apart from these many of the world's leading food companies including H.J. Heinz, Nestle, Hershey, Unilever, and Kraft are investing heavily in nanotechnology applications for development of nano food [28].

Impact of food towards hungriness:

The highest rates of population growth increases above 1.8 per cent per year from 1950s to 1970s, but the growth rate peaked at 2.2 per cent in 1963, and declined to 1.10 per cent by 2009 [29], whereas world hunger is projected to reach a historic high in 2009 with 1,020 million people going hungry every day, according to new estimates published by FAO, 2010a [30].

Jacques Diouf, FAO Director-General expressed "A dangerous mix of the global economic slowdown combined with stubbornly high food prices in many countries has pushed some 100 million more people than last year into chronic hunger and poverty". The silent hunger crisis affecting one sixth of all of humanity poses a serious risk for world peace and security[31]. This impact may recall the Darwin theory and principle. Keeping in view, many of the food industries, different government agencies and various public domains are toeing to resolve the future burning issue.

Need of nanotechnology in food:

The basic concept of nanotechnology is positioning and controlling the particles from microscopic to nano level. At the molecular scale, the idea of holding and positioning molecules is new and almost shocking. However, Richard Feynman (1960), the Nobel prize winning physicist, said that nothing in the laws of physics prevented us from arranging atoms the way we want: "…it is something, in principle, that can be done; but in practice, it has not been done because we are too big." Various laurels worked on different areas using the concept of nanotechnology and gained its advantages. Recently the application of nanoparticle in food was started and some of the food

products are lying with different brands on the market. To keeping the needs of the consumer demand, it is essential for the safe of food and meantime certain regulation to be framed for the safety of the consumer [32].

The recent trend in development of various cutting edge technologies are booming in the market due to cheaper, reliability, efficient, less time and energy from conventional production. The change is dramatic; the potentials are immense and off course risks. But main cause of increasing and speeding these technologies within the next couple of years may be population and climate change. To meet out the growing population, lifestyle of communities and social changes in respective food habits, the nanoscience and nanotechnology may help to fullfill the needs of the people. The importance of the nano foods are the dietary supplement for the consumers who suffering from different chronic diseases. But, the approach of nanotechnology also improves the manufacturing high quality by using biosensor for bacteria identification, safe food in the packaging system during storage and nanoencapsulation for development of sustainable resources are emerging applications[33, 34, 35].

Nanotechnology has potential applications in all aspects of food sectors including preliminary, secondary and tertiary processings. In various food process chain the application begins with food production, food processing, food packaging, food monitoring and production of functional foods and development of foods capable of modifying their colour, flavour or nutritional properties as well as production of stronger flavourings, colourings, emulsions, beverages, food additives, probiotics, nutraceuticals, pigments and pharmaceutical ingredients [36, 37, 38, 39, 40, 41, 42]. However, these technologies may help to minize the too many problems facing by the producer, processer and consumers in future days.

There are many applications of nanomaterials used in different food applications on industrial scale. A less than 100 nm size particle of titanium dioxide is used for food additive and antimicrobial agent for food packaging and storage containers and also used as whitener in confectionery[43, 44]. Silver nanoparticles for antimicrobial agents in food packaging, storage containers, and also as health supplement[45]. Zinc and zinc oxide are used as nutritional additives in food packaging[46]. Silicon dioxide and carbon are used as food additives for food packaging [47]. Platinum and gold nano-wires are used as biosensors to improve the food analysis[45].

Food production:

Nanotechnology can be applied in all phases of the food cycle "from farm to fork". It supports for the growth of agriculture and food production in the form of nanosensors for monitoring cropping system and pest control by early identification of animal or plant diseases. These nanosensors can help enhance production and improve food safety. The sensors function as external monitoring devices and do not end up in the food itself. Nanomaterials can also be introduced in or on the food itself to enrich its quality parameters. The effectiveness of pesticides may be improved by providing proper nozzles during fertigation. Identification, monitoring and management of the crop and climatic conditions. Planning the crop schedules (spraying, weeding, attack of insects and pests, crop maturity, irrigation, harvesting etc). These can be monitored and managed in precision farming system by use of nanoscience.

Food processing:

Processing is broad term in the food industry. In the present scenario, most of the consumers are depending upon processed foods. During the process, if the food changes either in the form of physical, chemical, biological and nutraceutical, it is called as processed food. There are enormous food processing techniques used, which produce nanoparticles. But most of the nanoparticles are in colloidal particles used in development of nanocapsules [48, 49]. The different emulsions are using in the salad dressing industries[50], different chocolate syrups, sweeteners (stevia), flavoured oils (vanspati) and many other processed foods[51]. The formation of nanoparticles and nanoscale emulsions can result from food processing techniques such as high pressure valve homogenization, dry ball milling, dry jet milling, spray drying and ultrasound emulsification. Most of food manufacturers are unaware about the nanoparticles, these processing techniques are used precisely due to change of texture and flow properties of the food. This process will help to manufacture more attractive and consumer satisfaction. In case of filtration, various membrane filters having micro and nano sieves can be used for filtration in food processing. Nanoparticles can also be used for encapsulating valuable food ingredients such as minerals in coating of another ingredient. The nano sensors will detect and identify the food quality and safety during packaging. This might save the food and safe the consumer.

Role of sensors:

Identification or detection of nano or small amount of a physical / chemical / biological contaminant in food system is another potential use of nanotechnology. The exciting possibility of combining biology and nanoscale technology into sensors is promising as it will take a

significantly reduced response-time to sense a potential problem. The packed products with nano-sensors are designed to track the internal or external conditions of food products, pellets and containers, throughout the supply chain. For such smart or intelligent packaging can monitor temperature or humidity over time and provide relevant information, during changing colour. Some of these sensors in the Georgia Tech in US used modified carbon nanotube as biosensor to detect microorganisms, toxic substances and spoilage of foods or beverages[52]. Opel, makes Opalfilm of 50nm carbon black nanoparticles used as biosensor to monitor the colour change in response to food spoilage [53]. Titanium dioxide nanoparticles of oxygen-sensing inks were used as Tamper proofing [54].

Nano-sensors were developed by researchers at both Purdue and Clemson Universities by using different nanoparticles. These nanoparticles could be used to detect any food pathogen which will affect the cause of change of colour and flavour. The application of nanotechnologies on the detection of pathogenic organisms in food and the development of nanofood safety was also studied at the Bioanalytical Microsystems and Biosensors laboratory at Cornell University. These studies focused on the development of rapid and portable biosensors for the detection of pathogenic organisms in the environment and foods. This system focuses on the very rapid detection of pathogens in routine drinking water testing, food analysis, environmental testing and in clinical diagnostics[24, 25, 26]. These sensors can provide the information about the product safety before consumption. In case of packaging industries, nano sensors will provide the information pertaining to the purity and quality of food to the consumer. These sensors may play as a tiny Robert in future. It will help to consumer to save (by food poisoning), safe (by nutritionally), serve (by nutraceutical and functional) and also minimise the wastage of food (by save), till spoilage (by safe), help to satisfaction (by serve). This concept may boom in the food industries and helping to the save the children/human beings by food security.

Impact of societal risk:

The converging of new technologies could reinvigorate the battered agrochemical, agrobiotech and food industries, igniting the enhancement of food production. A grass root level research to be undertaken in collaboration of Government, NGO, Self-Help Groups (SHGs), Rural women etc by focussing the nano particles. This will convince the societal impact and its risk of the invisibly small particle for the public acceptance. A basic experiment needs to be demonstrated during the survey for accepting the new concepts. A handful of food and nutrition products containing invisible, unlabeled and unregulated nano-scale additives are already commercially available, explaining those known products for better understanding. Likewise, a number of physical, chemical and biological formulated products released by the different firms are available in the retail stores, can be focussed. Proper government regulatory measures are to be developed in surveillance and social control.

Current regulatory:

The UK Food Standards Agency (FSA) published a (draft) review for the implications and risk assessment in relation to applications of nanotechnologies in food (Draft report of FSA regulatory review, 2006). The health implications of food processing produce nanoparticles and nanoscale emulsions also warrant for food regulations, such foods investigated for food safety standards [55]. The European Food Safety Authority (EFSA) has the responsibility of the independent scientific committees on food. But there is no provision for development of specific measures to deal with the nanocomponents. To ensure the effect of new technologies in food and agriculture, public involvement is essential [56, 57]. The most of the food packaging is regulated by the United States Food and Drug Administration (US FDA), while organic chemicals are regulated by the Environmental Protection Agency (EPA). However, neither EPA nor FDA has recognized nanomaterials[58]. The US FDA stated that the approved commercial available chemicals approved for commercial use, do not legally require any additional authorization [59]. In Australia, nanofood additives and ingredients are regulated by Food Standards Australia and New Zealand (FSANZ), it is regulated under the food standards code[60].

Scope of the application:

Richard Feynman (1960) who described the concept of 'building machines" atom by atom in his talk at Caltech titled "There is plenty of room at the bottom". Later Eric Drexler, wrote the book titled 'Nano systems, Molecular machinery, manufacturing and computation". Future applications by nanotechnology by Dr. A.P.J. Abdul Kalam, former President of India, expressed during the foundation on nanoscience and nanotechnology in India[61]. Prof. C.N.R. Rao, pioneered and fostered the nanoscience research in India. For the current growing of world population and food production trends, a nanosceince in food will improve the livelihood and reduces the risk involved *i.e.*, a food scarcity and its safety.

Conclusion:

Nanotechnology is the multidisciplinary approach,

whereas in food industry which suffice, production, processing, packaging, storage, food quality, food safety, dietary supplement, functional and nutraceutical foods etc to the future consumers. Finally application of nanotechnology in food will help to assess the consumer to feed the food as per the nutritional requirement, but not need of the consumers as the safety point of view.

Acknowledgement:

The authors would like to express sincere thanks to the University of Agricultural Sciences, Raichur, Karnataka, India for funding. The authors would also thank to the University of Saskatchewan, Canada for their technical support.

Address for correspondence :
K.T. RAMAPPA
University of Agricultural Sciences,
RAICHUR (KARNATAKA) INDIA

Authors' affiliations :
SHARANAKUMAR HIREGOUDAR AND VENKATESH MEDA
University of Saskatchewan,
SASKATOON, CANADA

B.V. PATIL
University of Agricultural Sciences,
RAICHUR (KARNATAKA) INDIA

LITERATURE CITED

1. http://www.nano.gov/html/facts/whatIsNano.html. What is nanotechnology?, Accessed on 9.8.2010.

2. Roco, M. (2001). From vision to the implementation of the US National Nanotechnology Initiative. Journal of Nano Particle Research, **3**:5-11.

3. Roco, M.C., Williams, R.S. and Alivasatos, P. (1999). Nanotechnology research directions: IWGN Workshop Report, Kluwer Academic Publishers: Norwell, MA.

4. Warad, H.C. and Dutta, J. (2010). Nanotechnology for agriculture and food systems – A view, School of Advanced Technologies, AIT, Thailand, accessed on 12.8.2010 http://faculty.ksu.edu.sa /shoeib / Lectures / Mic%20521 / Students%20 Activities / Nanotechnology / Nanotechnology.pdf.

5. Feynman, R. (1960). There is plenty of room at the bottom (reprint from the speech given at the annual meeting of the West Coast section of the American Physical Society. Engineering Science, **23**: 22–36.

6. Taniguchi, N. (1974). On the basic concept of Nano-technology. In: Proceedings of International Conference on Production Engineering Tokyo, Part II, vol. 2. Japan Society of Precision Engineering, pp. 18–23.

7. Drexler, K. (1981). Molecular engineering: an approach to the development of general capabilities for molecular manipulation. *Proc. Nat. Acad. Sci*., (USA), **78**:5275–5278.

8. http://www.nanowerk.com/nanotechnology/reports/reportpdf/ report61.pdf, Nanoforum Report: Nanotechnology in agriculture and food, Accessed on 20.8.2010.

9. http://www.biopharmasci.com/downloads/NanoNano.pdf, Nano-Nano: What would Mork say? Accessed on 9.8.2010.

10. Byron F. and Brehm-Stecher (2009). Food Nanotechnology. *Manufacturing Confectioner*, **89** (10) : 37 -50.

11. Sekhon, Bhupinder, S. (2010). Food nanotechnology – an overview. *Nanotechnology*, *Science & Applications*, **3**:1-15

12. Chen, H., Weiss, J. and Shahidi (2006). Nanotechnology in nutraceuticals and functional foods. *Food Technology*, **60**(3): 30-36.

13. Magnuson, Bernadene A. (2009). Nanoscale materials in foods: existing and potential sources, Intentional and Unintentional Contaminants in Food and Feed, Chapter 4: pp. 47-55.

14. Chun, Lin Ai (2009). Will the public swallow nano food?, *Nature Nanotechnology*, **4**:790 - 791.

15. http://www.foodnavigator.com / news / ng.asp? n=82109, Accessed on 15 September 2010).

16. http://www.aquanova.de / media / public / publikationen2006 / Fleischwirtschaft_Pro fWeber_NovaSOL_060502.pdf, Accessed on 15 September 2010).

17. http://www.biodellveryscience.com/ bioralnutrients.htlm, Accessed on 23 September, 2010

18. http://www.nutralease.com/technology.asp, Accessed on 23 September , 2010

19. http://www.humannutrition.basf.com, Accessed on 29 August, 2010.

20. http://www.369.comcn/Er/nanotea.htm, Accessed on 30 August, 2010.

21. http://www.highwive.com/sunactiveiron.htm, Accessed on 19 October , 2010.

22. http://jambajuicehawaii.com/vitaboost.asp, Accessed on 19 October , 2010.

23. http://www.toddlehealth.net/OatChocolate.php, Accessed on 23 September, 2010.

24. Shefer, A. and Shefer, S. (2003). Biodegradable bioadhesive controlled release system of nano-particles for food products, U.S. Patent 2003a; 6565873 BI.

25. Shefer, A. and Shefer, S. (2003b). Multi component biodegradable bioadhesive controlled release system for food products. U.S. Patent 2003b; 6589562 BI.

26. Shefer, A. and Shefer S. (2003c). Multi component controlled release system for oral care, food products, nano beverages. U.S. Patent 2003c; 20030152629 AI.

27. http://www.research. bayer.com/edition_15/ 15_polyamides. pdfx, Accessed on 21 November 2010

28. http://www.forbes.com/investmentnewsletters/2005/08/ 09/nanotechnology-kraft-hershey-cz_ jw_ 0810soapbox _inl.html?partner=rss, Accessed on November 21, 2010.

29. U.S. Census Bureau, Population Division, 2010 (www.census.gov), Accessed on November 23, 2010

30. F.A.O. (2010a). Achieving food security in Times of crisis. Report, 2009. (www.fao.org), Accessed on 23 November, 2010

31. F.A.O. (2010b). More people than ever are victims, Report 2009. (www.fao.org), Accessed on 23 November, 2010

32. Dingman, J. (2008). Nanotechnology: Its impact on food safety, Journal of Environmental Health, 2008, **70**(6):47-50.

33. David, Pereira, Perfecto Paseiro, Losada, Inmaculada, Angulo, William, Greaves and Jose M., Cruz (2009). Development of a polyamide nanocomposite for food industry: Morphological structure, processing and properties. *Polymer Composites*, **30**(4): 436-444.

34. Siegrist, M., Stampfli, N., Kastenholz, H. and Keller, C. (2008). Perceived risks and perceived benefits of different nanotechnology foods and nanotechnology food packaging, Appetite, **51**(2): 283-290

35. Valdes, M.G., Gonzalez, A.V.C., Calzon, J.A.G. and Diaz-Garcia, M.E. (2009). Analytical nanotechnology for food analysis, Microchim. Acta, **166**: 1-19.

36. Chaudhry, Q., Scotter, M., Blackburn, J., Ross, B., Broxall, A. and Castle, L. (2008). Applications and implications of nanotechnologies for the food sector. *Food Additives and Contaminants*, **25**:241-258.

37. McClements, D., 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**:577-606.

38. Wang, L., Auty, M.A.E. and Kerry, J.P. (2010). Physical essessment of composite biodegradable films manufactured using whey protein isolate, gelatin and sodium alginate. *J. Food Engg.* **96**:199-207.

39. Chang, P.R., Jian, R., Yu, J. and Ma, X. (2010). Fabrication and characterization of chitosan nanoparticles/plasticized-starch composites. *Food Chemistry*, **120**: 736-740.

40. Bouchemal, K., Briancon, S., Perrier, E. and Fessi, H. (2004). Nano-emulsion formulation using spontaneous emulsification: solvent, oil and surfactant optimization. *Internat. J. Pharmaceutics*, **280**:241-251.

41. Soppimath, K.S., Aminabhavi, T.M., Kulkarni, A.R. and Rudzinski, W.E. (2001). Biodegradable polymeric nanoparticles as drug delivery devices. *J. Controlled Release*, **70**:1-20.

42. Tiede, K., Boxall, A.B.A., Tear, P.S., Lewis, J., David, H., Hassello, M. (2008). Detection and characterization of engineered nanoparticles in food and the environment. *Food Additives & Contaminants*, **25**:795-821.

43. Long, T.N., Saleh, R., Tilton, R., Lowry, G. and Veronesi, B. (2006). Titanium dioxide (P25) produces reactive oxygen species in immortalized brain microglia (BV2): Implications for nanoparticle neurotoxicity. Environ. Sci. Technol., **40**(14):4346-4352.

44. Ashwood, P., Thompson, R. and Powell, J. (2007). Fine particles that adsorb lipopolysaccharide viabridging calcium cations may mimic bacterial pathogenicity towards cells. Experimental Biology & Medicine, **232**(1):107-117.

45. Wang, B., Feng, W.W. , Wang, M., Wang, T., Gu, Y., Zhu, M., Ouyang, H., Shi, J. , Zhang, F., Zhao, Y., Chai, Z., Wang, H. and Wang, J. (2007). A cute toxicological impact of nano- and submicro-scaled zinc oxide powder on healthy adult mice. *J. Nanoparticle Res.,* **10**(2):263-276.

46. Brunner, T., Piusmanser , P., Spohn, P., Grass, R., Limbach, L., Ruinink, A.B. and Stark, W. (2006). In vitro cytotoxicity of oxide nanoparticles: Comparison to asbestos, silica and the effect of particle solubility. *Environ. Sci. Technol*., **40**:4374-4381.

47. Chen, M. and Mikecz, A. Von (2005). Formation of nucleoplasmic protein aggregatesimpairs nuclear function in response to SiO_2 nanoparticles. *Experiment Cell Res.,* **305**:51-62.

48. Augustin, A.M. and Hemar, Y. (2009). Nano- and micro-structured assemblies for encapsulation of food ingredients. *Chemical Society Reviews*, **38**:902-912.

49. Urbán-Morlán, Z., Ganem-Rondero, A., Melgoza-Contreras, L.M., Escobar- Chávez, J.J., Nava Arzaluz, M.G. and Quintanar-Guerrero, D. (2010). Preparation characterization of solid lipid nanoparticles containing cyclosporine by the emulsification diffusion method. *Internat. J. Nano Medicine*, **5**: 611-620.

50. Evdoxia, Papalamprou, Georgios, Doxastakis and Vassilios, Kiosseoglou (2006). Model salad dressing emulsion stability as affected by the type of the lupin seed protein isolate, *J. Sci. Food & Agriculture*, **86**(12):1932-1937.

51. Mozafari, M., Flanagan, J., Matia, L., Merino, M., Awati, A., Omri, A., Suntres, Z. and Singh, H. (2006). Recent trends in the lipid-based nanoencapsulation of antioxidants and their role in foods. *J. Sci. Food & Agriculture*, **86**:2038-2045.

52. Nachay, K. (2007). Analyzing Nanotechnology. Food Technology. January 2007:34-36.

53. http://www.foodmanufacture.co.uk/news/fullstory.php/aid/4282/The smart_money_is_on _intelligent _design.html, Accessed on 23 September 2010.

54. http :// www. foodproductiondaily.com /news/ng.asp?n=71537-reach-fdfchemicals, Accessed on 23 September, 2010

55. Bowman, D. and Hodge, G..A. (2010). *Small matter of regulation*: An international review of nanotechnology regulation. *Columbia Sci. & Technol. Law Review.,* **8**:1-32.

56. http://www.nanotec.org.uk/finalReeport.htm, Accessed on 23, September, 2010

57. http://www.foodnavigator.com/ news/ng.asp?n=78139-additivesregulation enzymes-flavourings, Accessed on 2 December, 2010.

58. Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappel, L.M., Aviles-Vazquez, K., Salon, A. and Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture & Food Systems*, **22**(2):86-108.

59. http://www.fda.gov/nanotechnology/taskforce/report 2007.html, Accessed on 10 September, 2010.

60. Bowman, D. and Hodge, G. (2006). Nanotechnology: Mapping the wild regulatory frontier. *Futures*, **38**:1060-1073.

61. Anonymous (2010). Convergence of technologies and world knowledge platform., 2007,www.ansit.wordpress.com, Accessed on 23 September, 2010.