Review Article

The Emerging Usage and Applications of Nanotechnology in Food Processing Industries: The new age of Nanofood

Alok Prakash, Dr. Shampa Sen*, Rishabh Dixit
School of Biosciences & Technology, Vellore Institute of Technology, Vellore, Tamilnadu 632014, India.
***Corresponding author's E-mail:** shampa.iitg@gmail.com

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ABSTRACT

Food nanotechnology is currently an emerging area of research interest, and it widens the horizon of food industry for a varied range of products. Nanotechnology is basically being used in food processing, food safety, food packaging, Quality Control & Quality Assurance, Food Additives, detection of bacterial and fungal contamination in food products using nano – biosensors, and nanoencapsulation of bioactive food ingredients. Nanobiotechnology is capable to solve the very complex set of engineering and scientific challenges in the food processing industries. In the current review article, bird eye view on the history of nanotechnology, and the emergence of a new field of science known as Nanofood, is presented.

Keywords: Nanotechnology, food processing, food additives, nanoencapsulation, Nanofood.

INTRODUCTION

The structure and properties of matter can be controlled at nanometric scale, and this leads to the utilisation of materials for the new and exciting research fields, in which the nanotechnology and biology is merging together. The size scale between 1 nanometer and 100 nanometres is referred as 'Nanoscale'. Nanotechnology makes it possible to improve the quality of food products by altering the physiochemical characteristics of nano sized constitutes of the food products. Nanotechnology in combination with other technologies contributes for the increment in the rate of food production, food storage, food transportation, traceability and security. One of the best examples of integration of technologies for the benefit of food sector is "Nano biosensor". It has been possible by the combined effort of Bioengineering, Nanotechnology and Software engineering.

The application of nanotechnology is at a diverse scale in food industry including food packaging, storage, and quality monitoring (Figure1). Nanotechnology is also applied to create on – demand interactive food, allowing consumers to consume modified food based on their nutritional needs and tastes. It is obvious from the recent studies that Food Nanotechnology is now shifting from the research laboratories to the shelves of supermarket and the kitchen tables which are an indication of the revolution in food systems[1]. The current paper aims at providing a review of the current and future prospects of nanotechnology in the foods processing sector, its applications with regards to the consumer safety.

The term "Nanofood" means the food products which has been brought to the consumers using nanotechnology tools and techniques and may have mixture of Nanomaterials in an acceptable range.

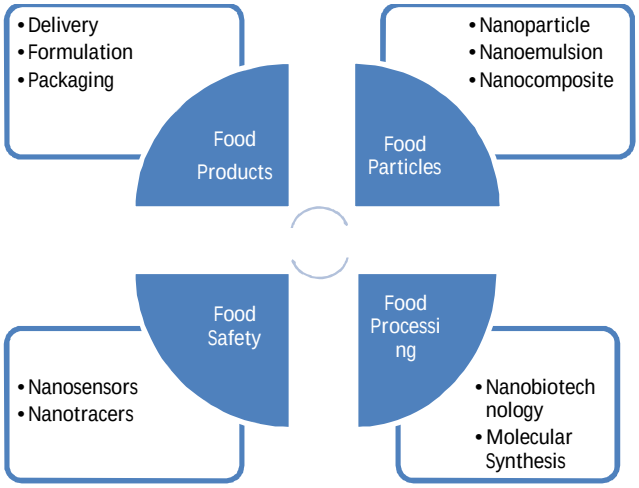

Figure 1: Applications of Nanotechnology in various branches of food processing.

Naturally Occurring Nano – food

Many naturally available foods, containing components at Nanoscale level have been consumed safely for generations. The presence of Nanoscale components are determined by their structures. Various raw materials of food, for e.g. Protein, Starch, and Fat, undergo several structural changes at the Nanoscale level during normal food processing[2].

It has been reported for the presence of self – assembled nanotubes from hydrolysed milk proteins α – lactalbumin, which makes it a potential novel carrier for nanoencapsulation of supplements, nutrients, and pharmaceuticals[3].

Also, casein micelles have been found to be functioning as nanovehicles for protection, entrapment and delivery of sensitive hydrophobic nutraceuticals to other food products[4].

Dairy technology is a collaboration of microbiology and nanotechnology which has existed for a long period of time. Homogenised milk has the droplets at Nanoscale level. Dairy industry basically utilises three nanosized and microsized structures, namely, fat globules, whey proteins and casein micelles, to build all varieties of foams (whipped cream and ice cream), emulsions (butter), Plastic solids (Cheese), Complex liquids (milk), and gel networks (Yoghurt).

The recent use of nanotechnology in the food processing industries

There has been a rapid development in the application of nanotechnology in food processing industries. The major arena of applications includes the alteration of food texture, food encapsulation, sensations and taste developments along with enhancing the bioavailability of the food nutrients. Even the league of food packaging has been enhanced by the usage of nanotechnology, which developed a new material with ameliorated barrier, antimicrobial and mechanical dominions.

Nanotechnology in food packaging

The food products must be of good quality, safe, good sensory attributes, inexpensive and with a good shelf life. This can be achieved with a good quality food packaging material. Biodegradable packaging materials originating from renewable sources have been the attraction for current food scientists[5]. Polylactic acid (PLA) has been found to be one of the most promising packaging materials due to its biocompatibility, thermo plasticity and good proceassibility[6]. The pure polymers are often insufficient to be used for food packaging due to low medium gas barrier attributes, thermal stability and low solvent water resistance[7]. The distribution of "nonoclays" at Nanoscale level, with a high aspect ratio of 100-1500 and extremely high surface-to-volume ratio of 700-800 m^2/g, has found to be effective to improve the polymer matrix in terms of mechanical, gas barriers and optical properties at low filler content i.e. less than 5% by weight[8-11]. The food packaging industry finds poly lactic acid and clay nanocomposites to be of a great advantageous processing material. This is basically due to the property of enhanced barrier mechanism against water vapour transmission[12].

Silver Nanoparticles has been used as antimicrobial food packaging material since the ancient periods. In history, drinks were used to be stored and served in silver vessels, milk was stored along with a silver spoon, and these were practiced to increase the shelf life of the food and beverages. The NASA space shuttles and Russian MIR space stations used silver as sterilising agent for drinking water[13]. Later, even the FDA modified the food additive regulations and allowed the direct incorporation of silver nitrate as a disinfectant to the commercially available beverages, which was packaged in bottles, at a concentration below 17µg/kg[14]. These antimicrobial packaging reduces the growth rate of microorganisms and hence keeps the food safe for consumers. It consists of antimicrobial Nanoparticles layers in between the packaging materials, or a sachet of antimicrobial Nanoparticles in the food package or a bioactive agent coated on the surface of packaging materials, which inhibits the microbial growth[15].

Polymer – Clay Nanocomposites (PCN) is also a novel food packaging substance. These are used now days for packaging because of their reduced weight, high tensile strength, heat resistant property, better barrier property against Carbon Dioxide, Oxygen, moisture and Ultraviolet along with the property of preserving the flavours in food and beverages[16-20]. PCN has been developed since 80s and Toyota was the first company to bring it to the consumers.

Rodriguez et al and Rojas – Grau et al has developed effective packaging materials for foods such as sliced meat and bakery products. These are antifungal active paper packaging which consists of Cinnamon oil and solid wax paraffin. Also, edible food films have been developed with apple puree and Oregano oil which is capable to kill E. coli bacterial population[21,22].

Nano – encapsulations

Surface modification of Nanoparticles is important for various applications in food processing[23-27]. The surface can be modified by coating or encapsulation of these Nanoparticles. This is found to be applied in controlled release of genes, drugs, nutraceuticals, and various bioactive agents. This controlled release mechanism protects the particle from immediate degradation, controls the release rate, targets the delivery point, and prolongs the active duration of nutraceuticals and other bioactive agents. Improvement of site specific drug delivery by encapsulating nano – poly D,L – Lactic Acid (PLA) with drugs, has been studied by *Leroux et al*[28]. The results from his experiment indicated that the encapsulated, drug loaded nanoparticles of D,L – PLA, in poly ethylene glycol (PEG), was protected from the absorption by human Monocytes cells. This reveals that encapsulation will avoid the phagocytic absorption and hence increase the circulation time of food and drug nanoparticles[29].

Quality monitoring of food products

Food quality monitoring is in utmost need in the food processing market because of the consumers demanding safe and hygienic food and at the same time, due to the government rules and regulations for ensuring food safety. Also, Nanotechnology is used these days to increase the bioavailability of many vitamins as well as their precursors. The vitamins and precursors which are insoluble in water can be solubilised by a nanoparticle formulation. These formulated additives are mostly used in fruit juices.

In agricultural sector, loads and loads of waste are generated. It becomes a difficult task to clear this waste due to lack of skilled hands or of mechanization. Nano bioengineering can be used in such cases. Efficient

enzymes are manufactured through nano science technology. It engineers certain atoms of amino acid or the amino acid themselves at nanoscale. It makes the enzyme more efficient and it degrades the agricultural waste more rapidly. It is being used in countries like Japan, Israel, and USA.

Few of the most common usage of Nanobiotechnology in quality monitoring of food products may be enumerated as Nanosensors, Electronic tongue, Bacteria identification.

Nanosensors can provide quality assurance by tracking food contaminants throughout the food processing chain. The Canadian Wheat Board Centre for Grain Research, University of Manitoba, Canada, has developed a grain quality monitoring Nanosensors, which consists of nanoparticles polymers responding to analytes and volatiles in food storage environment and hence detects the source and type of spoilage[30]. The Nanosensors can be utilised to detect the presence of insects or fungus accurately inside the stored grain bulk in storage rooms. Also, because of the low power consumption and smaller size, the Nanosensors can be placed in the grain bulk crevices, the place where pests often hide[31].

An electronic tongue has been developed which is included in food packaging and comprises of Nanosensors. These are extremely sensitive to gases released by food during spoilage and the sensor strip changes colour, signalling the freshness of food products[32].

Reflective interferometry, an analytical technology, has been developed by Horner et al[33]. This Nanobiotechnology makes rapid and specific optical detection of biomolecules in any complex mixtures. This makes the detection of *Escherichia coli* possible in food sample by detecting and measuring light scattered by *E. coli* cell's mitochondria. Fu et al has developed a biosensor using fluorescent dye attached to anti – *Salmonella* antibodies on a gold or silver nanorod array. The nanosized dye particle on the sensor becomes visible during the test of salmonella present in food. This is very instant test, unlike the traditional tests for bacterial cultures in food products[34]. Stutzenberger et al have developed a nanotechnology to eliminate *Campylobacter jejuni* bacterium from the poultry meats. It consists of antibiotic functioning nanocarbohydrate particles mixed in the chicken feed which binds to the campylobacter surface biomolecules and eliminates it through the bird's faeces. *Campylobacter jejuni* causes diarrhoea and abdominal cramps in human beings[35]. A nanobioluminiscent spray has been developed by Agromicron Ltd., Hong Kong. The pathogen strain on the food reacts with this spray and produces a visual glow which detects the contamination. This spray can be used to detect a number of microbes such as *Salmonella* and *E. Coli*[36,37].

Health risks due to nano-foods

Food and beverages holds one of the topmost ranks to be the cause of animal diseases. Since, the increasing applications of nanotechnology in food processing industries, there has been a subsequent increase in the research works to find the potential risks due to the usage of nano materials in food processing industries and the toxicity of nano foods. Till now, the researchers are mainly inclined to the inhalation exposure of the Nanomaterials. These research works has lead to the fact that the nano particles can cross the cellular barriers, and the exposure to these nanoparticles leads to an exaggerated population of free radicals and hence the increased oxidative damage to the cell[38-40].

The processing of food ingredients in order to obtain nanoparticulate food products may bring about any unnecessary and harmful change in the animal physiological conditions. The nanoparticle can easily cross the gut wall, which leads to an increased bioavailability and absorption leading to higher plasma concentration. This may implicate a higher risk of diseases, due to change in the nutrient profile of the body or due to introduction of foreign particles in the blood as a dietary supplement in food products. Nanoparticles cannot remain in free form in the gut but it aggregates or agglomerates. This may also prove harmful for the physiology of human body[41].

It has been shown in an *in vitro* study on human epithelial cell cultures that a nanoparticle can enter into the cell nuclei and leads to impairment of DNA replication as well as transcription. The study was performed using SiO_2 nanoparticles, which is generally used as a food additive[42] and also in food packaging. It may lead to similar effects *in vivo*[43].

Table 1: Various applications of Nanobiotechnology in Food Science and engineering

Nanotechnology Applications	Benefits
Smart packaging	Improves barrier properties, flexibility, and temperature & moisture stability along with durability.
Nano – biosensors	Helpful to detect the spoilage of food products as well as contamination by the foreign particles.
Nano – encapsulations	Targeted delivery of nutrient and hence increased bioavailability of the nutrients.
Nano – biotracers	Useful to trace the food particles during shipment to long distances.
Nano – emulsions	Maintains the texture and appearance for a better consumer appeal.
Nano – composites	Maintains the structure of the food component and helps to keep the product at a steady sate which gives a better shelf life to the product.

CONCLUSION

Applications of nanotechnology in food industry and its advantages are tabulated below (Table 1). There are certain limitations for which nanotechnology is not widely used in food industries till date. These limitations include the cost factor, facilities availability, training of man power or better handling of nanotechnology equipments and efficient production, and the acceptability of the food products in market.

REFERENCES

1. Scrinis G, Lyons K. The emerging nano-corporate paradigm: Nanotechnology and the transformation of nature, food and Agri-food systems. Int. J. Sociol Food Agric. 5(2), 2007, 22 – 44.
2. Morris VJ, Parker R. Natural and Designed self – assembled nanostructures in foods. The world of food science: Food Nanotechnology, 2008, 4.
3. Bugusu B, Mejia C, Magnuson B, Tafazoli s. Global regulatory food policies on nanotechnology. Food Technol. 63(5), 2009, 24 – 29.
4. Semo E, Kesselman E, Danino D, Livney YD. Casein micelle as a natural nano-capsular vehicle for nutraceuticals. Food Hydrocolloids. 21, 2007, 936 – 942.
5. Weber, C.J., Haugaard, V., Festersen, R., & Bertelsen, G. Production and application of biobased packaging materials for the food industry. Food Additives and Contaminants, 19 (Suppl.), 2002, 172 – 177.
6. Garlotta, D. A literature review of Poly (Lacticacid). Journal of Polymers and the environment, 9(2), 2001, 63 – 84.
7. Cabedo, L., Feijo, J.L., Villanueva, M.P., Lagaron, J.M., & Glinenez, E. Optimisation of Biodegradable Nanocomposites based on PLA/PCL blends for food packaging applications. Macromolecular Symposia, 233, 2006, 191 – 197.
8. Alexandre, M., & Dubois, P. Polymer-layered silicate nanocomposites: Preparation, Properties and use of a new class of materials. Material Science and Engineering, 28, 2000, 1 – 63.
9. Brody, A. Nanocomposite technology in food packaging. Food Technology, 61 (10), 2003, 80 – 83.
10. Pandey, J.K., Kumar, A.P., Misra, M., Mohanty, A.K., Drzal, L.T., & Singh, R.P. Recent advances in Biodegradable nanocomposites. Journal of Nanoscience and Nanotechnology, 5, 2005, 497 – 526.
11. Sinha Ray, S., & Okamoto, M. Biodegradable Polylactide and its Nanocomposites: Opening a new dimension for Plastics and Composites. Macromolecular Rapid Communications, 24, 2003, 815 – 840.
12. Rhim JW, Hong SI, Ha CS. Tensile water vapour barrier and antimicrobial properties of PLA/ Nanoclay composite films. LWT – Food Science and Technology, 42, 2009, 612 – 617.
13. S. Silver, FEMS Microbiol. Rev. 27, 2003, 341.
14. US Food and Drug Administration, Fed. Regist. 74, 2009, 11476.
15. Coma, V. Bioactive Packaging Technologies for Extended Shelf Life of Meat – Based Products. Meat Science, 78(2), 2008, 90 – 103.
16. Moore, S. Nanocomposites achieves exceptional barrier in films. Modern Plastics, 76, 1999, 31 – 32.
17. Quarmley, J., Rossi, A. Nonoclays. Opportunities in polymer compounds. Industrial Minerals, 400, 2001, 47 – 49.
18. Moraru, C. I., Panchapakesan, C.P., Huang, Q.R., Takhistov, P. Liu, S. and Kokini, J.L. Nanotechnology: A new frontier in food science. Food Technol., 57, 2003, 24 – 29.
19. Lauge, J., Wyser, Y. Recent Innovations in barrier technologies for plastic packaging – a review. Packaging Technol. And Sci., 16, 2003, 149 – 158.
20. Ranade, A., D'souza, N.A. Gnade, B., Dharia, A. Nylon – 6 and montmorillonite – layered silicate (MLS) nanocomposites. J. Plastic film and Sheeting, 19, 2003, 271 – 285.
21. Rodriguez, A., Nerin, C., & Batlle, R. New Cinnamon – based active paper packaging against *Rhizopusstolonifer* food spoilage. Journal of Agriculture and food Chemistry. 56 (15), 2008, 6364 – 6369.
22. Rojas – Grau, M. A., Bustillos, A.R.D., Friedman, M., Henika, P.R., Martin – Belloso, O., & Mc Hugh, T.H. Mechanical, barrier and antimicrobial properties of Apple Puree edible films containing plant essential oils. Journal of Agriculture and Food Chemistry, 54, 2006, 9262 – 9267.
23. A.J.Ruys, Y.W. Mai, The nanoparticle – coating process: a potential sol – gel route to homogenous nanocomposites, Mater. Sci. Eng. A 265, 1999, 202.
24. J.X. Zhang, L.Q. Gao, Nanocomposites powders from coating with heterogeneous nucleation processing, Ceram. Int. 27, 2001, 143.
25. S.Y. Chang, L. Liu, S.A. Asher. Preparation and properties of Tailored morphology, monodisperse colloidal silica – cadmium sulphide nanocomposites. J. Am. Chem. Soc. 116, 1994, 6739.
26. J.C. Leroux, E. Allemann, F.D. Jaeghere, E. Doelker, R. Gutny. Biodegradable nanoparticles – from sustained release formulations to improved site specific drug delivery. J. Control. Rel. 39, 1996, 339.
27. H.Cohen, R.J. Levy, J. Gao, V. Kousaev, S. Sosnowski, S. Slomkowski, G. Golomb,. Sustained delivery and expression of DNA encapsulated in polymeric nanoparticles. Gene Ther. 7, 2000, 1986.
28. Yuhu Wang, Rajesh N. Dave, Robert pfeffer. Polymer coating/encapsulation of nanoparticles using a supercrtitical anti – solvent process. J. of Supercritical fluids 28, 2004, 85 – 99.
29. Li N, Siontas C, Cho A, Schmitz D, Misra C, Sempf J, Wang M, Oberley T, Froines J, Nel A. Ultrafine particulate pollutants Induce oxidative stress and mitochondrial damage. Environmental Health Perspectives. 111(4), 2003, 455 – 460.
30. Neethirajan, S., Gordon, r., & Wang, L. Potential of Silica bodies (phytoliths) for nanotechnology. Trends in Biotechnology. 27 (8), 2009, 461 – 467.

31. Neethirajan, s., & Jayas, D.S. Sensors for grain storage. In: 2007 ASABE Annual International meeting, 2007, 17 – 20.
32. Ruengruglikil, c., Kim, H., Miller, r.D., & Huang, Q. Fabriction of nanoporous oligonucliotide microarrays for pathogen detection and identification. Polymer preprints, 45, 2004, 526.
33. Horner, S. R., Mace, c.R., Rothberg, L. J., & Miller, B. L. A proteomic biosensor for enteropathogenic E. Coli. Biosensors and Bioelectronics, 21 (8), 2006, 1659 – 1663.
34. Fu, J., Park, B., Siragusa, G., Jones, L., Tripp, R., zhao, Y., et al. An Au/ Si hetero – nanorod based biosensor for salmonella detection. Nanotechnology, 19, 2008, 1 – 7.
35. Stutzenberger, F. J., Latour, R. A., Sun, Y., & Tzeng, T. Adhesin – specific nanoparticles and process for using same. US Patent No. 20070184120 (in English), 2007.
36. Cheng, Y., Liua, Y., Huanga, J., Lia, K., Zhang, W., Xiana, Y., et al. Combining biofunctional magnetic nanoparticles and ATP bioluminescence for rapid detection of Escherichia coli. Talanta, 77 (4), 2009, 1332 – 1336.
37. Zhao, X., Hilliard, L. R., Mechrey, S. J., Wang, Y., Bague, R. P., Jin, S., et al. A rapid bioassay for single bacterial cell quantitation using bioconjugated nanoparticles. Proceedings of the National Academy of Sciences, 101, 2004, 15027 – 15032.
38. Donaldson K, Stone V, Tran CL, Kreyling W, Borm PJ. Nanotoxicology. Occupational and Environmental Medicine. 619, 2004, 727 – 8.
39. Oberdorster E. Manufactured Nanoaterials Fullerens C_{60} Induce Oxidative Stress in the Brain of Juvenile Largemouth Bass. Environmental Health Perspectives. 112 (10), 2004, 1058 – 1062.
40. Alok Prakash, Kanupriya Mathur, Ankita Vishwakarma, Suneetha Vuppu, Bishwambhar Mishra. Comparative Assay of Antioxidant and Antibacterial Properties of Indian Culinary Seasonal Fruit Peel Extracts obtained from Vellore, Tamilnadu. Int. J. Pharm. Sci. Rev. Res., 19(1), Mar – Apr 2013, no. 25, 131 – 135.
41. Chen MA, Von Mikecz. Formation of Nucleoplasmic Protein Aggregates Impairs Nuclear Function in Response to SiO_2 Nanoparticles. Experimental Cell Research. 305, 2005, 51 – 62.
42. Ramalingam C, Harshita Jain, Kirti Vatsa, Nausin Akhtar, Bhaskar Mitra, D.Vishnudas, Sharad Yadav, Kunal Garg, Alok Prakash, Amit Rai. Detection and Biochemical Characterisation of Microorganisms in Milk and Cocoa powder samples by FTIR and subsequent production of Bacteriocin from Lactobacillus. Int J. Drug Dev. & Res., 5(1), January-March 2013, 310 – 320.
43. Qasim Chaudhry, Robert Aitken, Michael Scotter, James Blackburn, Bryony Ross, Alistair Boxxall, Laurence Castle, Ricjhard Watkins. Application and Implications of Nanotechnologies for the Food Sector. Food Additives and Contaminants. 2007, 1 – 34.

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Corresponding Author's Biography: Dr. Shampa Sen

Dr. Shampa Sen, graduated at Indira Gandhi Institute of Technology, Sarang, Orissa, India, Post graduated at Jadavpur University, Calcutta, and Doctor in Philosophy at *Indian Institute of Technology*, Guwahati, currently serving as The Associate Professor at *Vellore Institute of Technology*, Vellore, since 2010, in the Industrial Biotechnology Division. Her research interest includes Bioprocess Engineering, Enzyme Engineering, and Biosynthesis of Silver and Magnetic Nanoparticles.