International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.12 No.04, pp 07-14, 2019

Application of Nanotechnology in Packaging of Foods : A Review

S.Sujithra[1]*, T.R.Manikkandan[2]

[1]Research Scholar and [2]Assistant Professor
Food technology laboratory, Department of Chemical Engineering, Annamalai University, Chidambaram-608002, Tamil Nadu, India.

Abstract : Nano packaging has received considerable attention in recent years because of their advantages such as used to increase shelf life and to protect the packed material. By functioning as barriers, such edible films and coatings can feasibly reduce the complexity and thus improve the recyclability of packaging materials, compared to the more traditional non-environmental friendly packaging materials, and may be able to substitute such synthetic polymer films. New materials are developed and characterized by scientist and several from natural resources that have historically been considered as waste materials. The objective of this review is to provide a comprehensive introduction to nano packaging in foods, nano materials, various techniques used in nano packaging such as chemical release nano packaging, nano sensors and track packaging, nano antimicrobial packaging, nano biodegradable packaging and their applications and potential uses in foods.
Keywords : Chemical release nano packaging, Nano sensors and track packaging, Nano antimicrobial packaging, Nano biodegradable packaging.

Introduction

Nanotechnology is the study and use of structures between 1 nanometre and 100 nanometres in size[1]. The definition of nano technology is based on the prefix "***nano***" which is from the Greek word meaning "***dwarf***". In more technical terms the word ***"nano***" means ***10^{-9}***or one billionth of something. The word nano technology is generally used when referring to materials with the size of 0.1 to 100 nanometres[2]. The novel properties of nano materials offer many new opportunities for food and agricultural industries, for example more potent food colouring, flavouring, nutritional additives, antibacterial ingredients for food packaging, more agro chemicals and fertilizers.

What Is Nano packaging?

Nano packaging is defined as the process of interconnecting, powering, cooling, and protecting the nanocomponents made of nonmaterial to form electronic and bioelectronics systems for improved functionality and cost[3]. Nano packaging is already making an impact in the development of functional or interactive foods,

DOI= http://dx.doi.org/10.20902/IJCTR.2019.120402

which respond to the body's requirement and deliver nutrients more efficiently[4]. Addition of nanoparticleshelps in production of bottles and packages with more light and fire resistance, stronger mechanical and thermal performance, and less gas absorption. These properties can significantly increase the shelf life, efficiently preserve flavor&color, and facilitate transportation & usage. Further, nanostructure film can effectively prevent the food from the invasion of bacteria and microorganism and ensure food safety. With embedded nanosensors in the packaging, consumers will be able to "read" the food inside. Sensors can alarm us before the food goes rotten or inform us the exact nutrition status contained in the contents[5.]

Nano Materials

Use of nanomaterials in food packaging is already a reality. One example is bottles made with nanocomposites that minimize the leakage of carbon dioxide out of the bottle; this increases the shelf life of carbonated beverages without having to use heavier glass bottles or more expensive cans. Another example is food storage bins with silver nanoparticles embedded in the plastic. The silver nanoparticles kill bacteria from any food previously stored in the bins, minimizing harmful bacteria.

There are other food packaging products currently under development. For example nanosensors in plastic packaging can detect gases given off by food when it spoils and the packaging itself changes color to alert you to food gone bad. Plastic films are being developed that will allow the food to stay fresher longer. These films are packed with silicate nanoparticles to reduce the flow of oxygen into the package and the leaking of moisture out of the package.

Nanosensors are being developed that can detect bacteria and other contaminates such as salmonella on the surface of food at a packaging plant. This will allow for frequent testing at a much lower cost than is incurred by sending samples to a lab for analysis. This point-of-packaging testing, if conducted properly, has the potential to dramatically reduce the chance of contaminated food reaching grocery store shelves[6].

Nano Particles

In nanotechnology, a particle is defined as a small object that behaves as a whole unit in terms of its transport and properties. Particles are further classified according to size: in terms of diameter, fine particles cover a range between 100 and 2500 nanometers. On the other hand, ultrafine particles are sized between 1 and 100 nanometers. Similar to ultrafine particles, **nanoparticles** are sized between 1 and 100 nanometers. The reason for this double name of the same object is that, during the 1970-80's, when the first thorough fundamental studies were running with "nanoparticles" in the USA (by Granqvist and Buhrman)[34] and Japan, (within an ERATO Project)[35] they were called "ultrafine particles" (UFP). However, during the 1990s before the National Nanotechnology Initiative was launched in the USA, the new name, "nanoparticle" had become fashionable [36]. Nanoparticles may or may not exhibit size-related properties that differ significantly from those observed in fine particles or bulk materials.[37 38] Although the size of most molecules would fit into the above outline, individual molecules are usually not referred to as nanoparticles.

Nanoclusters have at least one dimension between 1 and 10 nanometers and a narrow size distribution. Nanopowders[39] are agglomerates of ultrafine particles, nanoparticles, or nanoclusters. Nanometer-sized single crystals, or single-domain ultrafine particles, are often referred to as nanocrystals.

Chemical giant Bayer produces a transparent plastic film (called Durethan) containing nanoparticles of clay. The nanoparticles are dispersed throughout the plastic and are able to block oxygen, carbon dioxide and moisture from reaching fresh meats or other foods. The nanoclay also makes the plastic lighter, stronger and more heat-resistant.

Until recently, industry's quest to package beer in plastic bottles (for cheaper transport) was unsuccessful because of spoilage and flavour problems. Today, Nanocor, a subsidiary of Amcol International Corp., is producing nanocomposites for use in plastic beer bottles that give the brew a six-month shelf-life. By embedding nanocrystals in plastic, researchers have created a molecular barrier that helps prevent the escape of oxygen. Nanocor and Southern Clay Products are now working on a plastic beer bottle that may increase shelf-life to 18 months[7].

Nano Composites in Food Packaging

Nanotechnology has the potential to generate new food packaging. Nanocomposites can improve mechanical strength, reduce weight, increase heat resistance; and improve barrier against oxygen, carbon dioxide, ultraviolet radiation, moisture,and volatiles of food package materials. The main kinds of nanoparticles have been studied for use in food packaging systems; as well, their effects and applications were overviewed[8,9]. Fine nano particulates (100 nm or less) are incorporated into plastics to improve the properties over those of conventional counterparts. Polymer nanocomposites are thermoplastic polymers that have nanoscale inclusions of 2%–8% by weight. Nanoscale inclusions consist of nanoclays, carbon nanoparticles, nanoscale metals and oxides,and polymeric resins. Nanocomposites are characterized by extremely high surface-to-volume ratio,making them highly reactive in comparison to their macroscale counterparts, and thus presenting fundamentally different properties[10].Food and beverage packaging comprises 55% to 65% of the $130 billion value of packaging in the United States[11]. Moreover, nanocomposites could also be characterized by an antimicrobial activity. Packages containing nanosensors give information about enzymes produced in the breakdown of food molecules making them unsafe for human consumption. The packages could also be used to let air and other enzymes out but not in, thus increasing shelf life, as well as the reduction of man-made preservatives in our foods[12].

Applications of Nanopackaging in Foods

Nano packaging for Choclates

Already in use in brewing and dairy production are nano-filters - screens so small they can filter out micro-organisms and even viruses. In lab experiments, the colour has been removed from beetroot juice, leaving the flavour; and red wine turned into white. Lactose can now be filtered from milk, and replaced with another sugar - making all milk suitable for the lactose-intolerant. This could mean less use of chemicals and heat treatments in food processing.

When it comes to chewing gum, nano-particles will shortly be able to carry teeth-cleaning chemicals that you won't be able to taste. Pleasing to the lazy, as will be self-cleansing cutlery, an advance made possible by the engineering, at atomic level, of hydrophobic surfaces that allow substances to break down and drop off. This is already in use with industrial glass products. Nano-filters will allow you to choose the amount of caffeine you want to remove from your coffee. Making tap water sterile should be possible too[13].

Nano packaging for Chicken and Spinach

Nano-scale sensors are in development that will monitor toxins and bacteria at all stages of food processing. This will help producer's spot salmonella in chickens, or E-coli in spinach, long before the products reach the shops. Self-monitoring food packaging will mature into technology like the nano-tongue. Wired into your fridge, it will detect and warn you of a whole range of chemicals given off by rotting food, or the presence of bacteria. And then clean them[13].

Nano Packaging for Beverages

Nanotechnology, the science of very small materials, is poised to have a big impact in food and beverage packaging. Due to very large aspect ratios, a relatively low level of nanoparticle is sufficient to change the properties of packaging materials without significant changes in density, transparency and processing characteristics. The addition of certain nanoparticles into shaped objects and films has been shown to render them light, fire-resistant and stronger in terms of mechanical and thermal performance, as well as less permeable to gases. New packaging solutions will focus more on food safety by controlling microbial growth, delaying oxidation, improving tamper visibility, and convenience. Three basic categories of nanotechnology applications and functionalities appear to be in development for food packaging: enhancement of plastic materials barriers; incorporation of active components that can deliver functional attributes beyond those of conventional active packaging; and sensing and signalling of relevant information[14].

Nano Packaging for Fruits

A novel nano-packing material with lower relative humidity, oxygen transmission rate and high longitudinal strength was synthesized by blending polyethylene with nano-powder (nano-Ag, kaolin, anatase TiO_2, rutile TiO_2), and its effect on preservation quality of strawberry fruits (Fragaria ananassa Duch. cv Fengxiang) was investigated during storage at 4^0C. Results showed that nano-packaging was able to maintain the sensory, physicochemical, and physiological quality of strawberry fruits at a higher level compared with the normal packing (polyethylene bags). After 12-days storage, decreases in the contents of total soluble solids, titratable acidity, and ascorbic acid of nano-packing were significantly inhibited. Meanwhile, decay rate, anthocyanin, and malondialdehyde contents were decreased to 16.7%, 26.3 mg/100g, 66.3 micromol/g for nano-packing and 26.8%, 31.9 mg/100g, 75.4 micromol/g for normal packing; polyphenoloxidase (PPO) and pyrogallol peroxidase (POD) activities were significantly lower in nano-packing than the control. These data indicated that the nano-packaging might provide an attractive alternative to improve preservation quality of the strawberry fruits during extended storage[15].

Apples in the US come with a waxy coating to stop the fruit from losing moisture and shriveling. Now nanotechnology provides edible coatings as thin as 5nm for use in meats, cheese, fruit and vegetables, as well as confectionery and baked goods. These coatings provide a barrier to moisture and gas exchange, and can deliver colours, flavours, and antioxidants to preserve the appearance of the products even after the packaging has been opened. Edible antibacterial nano coatings have been developed, which can be applied directly to bakery goods to increase their shelf life[33].

Practical Application

Nano-packing exhibited identified quality benefits applicable to the preservation of fresh strawberry. Furthermore, nano-packing has the advantages of simple processing and feasibility to be industrialized in contrast with other storages. Thus, the utilization of nano-packing will likely assist commercial producers and retailers in extending the shelf life of products over a broader range in the future[15].

Nano packaging of Cheese

Waxy coating is used widely for some foods such as apples and cheeses. Recently, nanotechnology has enabled the development of nanoscale edible coatings as thin as 5 nm wide, which are invisible to the human eye. These edible nano-coatings could be used on meats, cheese, fruits, vegetables, confectionery, bakery goods and fast foods. They could provide a barrier to moisture and gas exchange, act as a vehicle to deliver colours, flavours, antioxidants, enzymes and anti-browning agents and could also increase the shelf life of manufactured foods, even after the packaging is opened.The U.S. Company SonoTec Corporation announced in early 2007 that it has developed an edible antibacterial nano-coating, which can be applied directly to bakery goods. It is currently testing the process with its clients [52].

Various Technologies in Nanopackaging

Chemical Release Nanopackaging

Chemical release nano packaging enables food packaging to interact with the food it contains. The exchange can proceed in both directions. Packaging can release nanoscale antimicrobials, antioxidants, flavors, fragrances or nutraceuticals into the food or beverage to extend its shelf life or to improve its taste or smell (del Nobile et al. 2004; LaCoste et al. 2005; Lopez-Rubio et al. 2006; Nachay 2007)[16,17,18,19]. In many instances chemical release packaging also incorporates surveillance elements, that is, the release of nano-chemicals will occur in response to a particular trigger event (Gander 2007)[20]. Conversely, nanopackaging using carbon nanotubes is being developed with the ability to 'pump'out oxygen or carbon dioxide that wouldotherwise result in food or beverage deterioration (FoodQualitynews.com 2005)[21].Nano packaging that can absorbundesirable flavors is also in development. nano zinc oxide or nano chlorine dioxide(AzoNano 2007; LeGood and Clarke 2006;Table 4)[22,23]. Nano magnesium oxide, nanocopper oxide, nano titanium dioxide and carbon nano tubes are also predicted for future use in antimicrobial food packaging(El Amin 2007c)[24].

Nano Based Antimicrobial Packaging

Food packaging and containers are also made incorporating antimicrobial nanomaterials, to prevent or slow down the decay of food due to microbial action. These products commonly use nanoparticles of silver but also nano zinc oxide and nano chlorine dioxide. Packaging materials using magnesium oxide, copper oxide and titanium dioxide in nano form as well as carbon nanotubes are also being developed for use in antimicrobial food packaging[25].

Silver nanoparticles have been incorporated in a wide variety of consumer goods including clothing, electrical goods, kitchenware, and wound dressings[44]. Nanoparticulate silver releases ions more efficiently than bulk metal, and it is the silver ions that have a bactericidal due to the inhibition of a wide variety of biological processes within the bacteria[45]. As the levels of silver ions liberated are too low to have toxic effects in humans; it is likely that nanoparticulate silver will be included in further composite materials. However, there is some concern over the effects of large amounts of silver ions being discharged into the environment and accumulating in ecosystems, as silver ions are known to be toxic to aquatic life.

Zinc oxide exhibits antibacterial activity that increases with decreasing particle size[46]. This activity does not require the presence of UV light (unlike titanium dioxide) but is stimulated by visible light[47]. The exact mechanism(s) of action is still unknown. Zinc oxide nanoparticles have been incorporated in a number of different polymers including polypropylene[47].In addition zinc oxide effectively absorbs UV light, without re-emitting as heat, and therefore improves the stability of polymer composites.

Chitosan is a biopolymer derived from chitin (a polysaccharide constituent of crustacean shells). It has seen much interest in recent years as a material for the encapsulation of nutraceutical (see report 'Food Processing and Functional Food'). In addition, to its utility as a packaging material, it also exhibits antimicrobial properties[48]. This has led a number of groups to investigate its incorporation into different composite materials which could have applications in healthcare and food packaging, including using it as a 'green' reagent to reduce and stabilise silver ions[49], in combination with clays such as rectorite which could then be used in polymer composites[50].[51]

Nano-Sensor and Track and Trace Packaging

Packaging equipped with nano sensors is designed to track either the internal or the external conditions of food products, pellets and containers throughout the supply chain. For example, such packaging can monitor temperature or humidity over time and then provide relevant information on these conditions, for example by changing colour (Food Production Daily 2006a; Gander 2007; El Amin 2006a, Table 5)[20,26,27]. Companies as diverse as Nestlé, British Airways, MonoPrix Supermarkets, 3M and many others are already using packaging equipped with chemical sensors, and nanotechnology is offering new and more sophisticated tools to extend these capabilities and to reduce costs (LeGood and Clarke 2006)[23]. Nanotechnology is also enabling sensor packaging to incorporate cheap radio frequency identification (RFID) tags (Nachay 2007; Pehanich 2006)[19, 28]. Unlike earlier RFID tags, nano-enabled RFID tags are much smaller, can be flexible and are printed on thin labels. This increases the tags' versatility (for example by enabling the use of labels which are effectively invisible) and thus enables much cheaper production. Other varieties of nano-based track and trace packaging technologies are also in development. For instance, United States Company OxonicaInc has developed nano barcodes to be used for individual items or pellets, which must be read with a modified microscope. These have been developed primarily for anti-counterfeiting purposes (Roberts 2007)[29]. An ingestible nano-based track and trace technology is promised by pSiNutria, a spin out of nanobiotechnology company pSivida. Potential pSiNutria products include: "products to detect pathogens in food,for food tracing, for food preservation, and temperature measurements in food storage" (pSivida 2006)[30].

Nano Biodegradable Packaging

The use of nano materials to strengthen bioplastics (plant-based plastics) may enable bio plastics to be used instead of fossil-fuel based plastics for food packaging and carry bags[24].When bioplastics are mixed with nanoclay particles, the resulting nanocomposites exhibit improvedbarrier properties compared with the purebioplastic, and after their useful life can be compostedand returned to the soil . Other nanomaterials can be utilized including nanoparticles, nanofibers and nanowhiskers[40 41].

Many biopolymers such as chitosan, cellulose, collagenand zinc (derived from corn) have been synthesized as nanofibers from various biopolymers using the electrospinning technique. In some casesthese have superior properties to the traditionallycast polymer, including increased heat resistance.In addition, mats of such nanofibers possess a highly nanoporous structure and can be used assupport matrixes for additional functionality possessingas they do the lowest thermal conductanceof all solids[41 42].

Applications

Applications in this area already support development of improved tastes, color, flavor, texture and consistency of foodstuffs, increased absorption and bioavailability of nutrients and health supplements, new food packaging materials with improved mechanical, barrier and antimicrobial properties, and nano-sensors for traceability and monitoring the condition of food during transport and storage[14].

Conclusion

Globally, many countries have identified the potential of nanotechnology in the food sectors and are investigating a significant amount in it. Equal importance has been given to the social issues associated with nanotechnology and to improve public awareness. Many agencies have commissioned studies to access new and potential applications of nanotechnology in food, especially on packaging. At the same time more money has been given by the government departments towards research and development which includes the developments of functional foods, nutrient delivery system and method for optimizing food appearance, such as color, flavor and consistency.

Whatever the impacts of nanotechnology on the food industry and product entering the market, the safety of food will remain the prime concern. This need will strengthen the adoption of nanotechnology in sensing application, which will ensure food safety and security, as well as technology which alerts customers and shopkeepers when the food is nearing the end of its shelf life. New antimicrobial coating and dirt repellent plastic bags are remarkable improvement in ensuring the safety and security of packed foods[32].

It is expected that nanotechnology could allow a more efficient and sustainable food production process to be developed where less raw material are consumed and food with higher nutritional quality is obtained.

References

1. Present Hawk's Perch Technical Writing., 2007
   Available at http://www.understandingnano.com/introduction.html.
2. Nano science and engineering for agriculture and food systems, Department of agriculture US.,2003.
3. RaoTummala, Wong C P, and Markondeya P. IEEE nano technology magazine,nanopackaging research at Georgia tech., 2009.
4. http://www.foodscience.afisc.csiro.au/foodfacts/foodfacts11-fishoil.html.
5. http://www.prlog.org/10016688-nanopackaging-is-intelligent-smart-and-safe-life-new-world-study-by-hkc22-com-beijing-office.html.
6. Hawk's Perch Technical Writing., 2008, Available at: http://www.understandingnano.com/column-food.html.
7. AZoNano-The AtoZ of Nanotechnology., 2011,
   Available at:http://www.azonano.com/article.aspx?ArticleID=1317.
8. Costa C. “Nanocomposites to extend the shelf life of ready to use fruit and vegetables”, 14th Workshop on the Developments in the ItalianPhD Research on Food Science Technology and BiotechnologyUniversity of Sassari, Oristano., 2010; 16–18.
9. De Azeredo HM C. “Nanocomposites for food packaging applications”, Food Res Int,.2009; 42(9):1240–1253.
10. Brody A. “Nano and food packaging technologies converge”, Food Technol., 2006;60(3):92–94.
11. Brody A. “Packaging by the numbers”. Food Technol., 2008; 62(2):89–91.

12. Sondi I and Salopek-Sondi B. “Silver nanoparticles as antimicrobial agent: A case study on E. coli as a model for Gram-negative bacteria”, J ColloidInterface Sci., 2004;275:177–182.
13. Guardian.co. “Guardian News and Media Limited”., 2011,
Available at http://observer.guardian.co.uk/foodmonthly/futureoffood/story/0,1971266,00.html.
14. http://www.innoresearch.net/report_summary.aspx?id=68&pg=107&rcd=FT102&pd=7/1/2009@iRAP 2011. All Rights Reserved
15. **15.**ChinaYang FM, Li HM, Li F, Xin ZH, Zhao LY, Zheng YH, Hu QH. “Key Lab. of Food Processing and Quality Control, College of Food Science and Technology”, Nanjing Agricultural Univ., 2010.
16. Del Nobile M, Cannarsi M, Altieri C, Sinigaglia M, Favia P,Lacoviello G, D’Agostino R.. “Effect of Ag-containing Nano-composite Active Packaging System on Survival of Alicyclobacillus acidoterrestris”, Journal of Food Science., 2004; 69(8):379.
17. LaCoste A, Schaich K, Zumbrunnen D, Yam K. “Advanced controlled releasepackaging through smart blending”, PackagTechnol Sci., 2005;18:77-87.
18. Lopez-Rubio A, Gavara R, Lagaron J. “Bioactive packaging: turning foods into healthier foods through biomaterials”, Trends Food Sci Technol., 2006;17:567-575.
19. 19.Lovern B andKlaper R.. “Daphnia magna mortality when exposed to titanium dioxide and fullerene (c60) nanoparticles”, Environ Toxicol Chem., 2006;25(4):1132-1137
20. Nachay K. “Analyzing Nanotechnology”, Food Technol., 2007:34-36.
21. Gander P. “The smart money is on intelligent design”, Food Manufacture UK ., 2007.
22. FoodQualityNews.com. CNI ushers in future with 30 nanotech patents., 2005
23. AzoNano. “Advanced Nanotechnology gets grant for food packaging”, Nanotechnology News Archive., 2008.
24. LeGood P and Clarke A. “Smart and active materials to reduce food waste”, SMART.mat.,2008.
25. ElAmin A. “Carbon nanotubes could be new pathogen weapon”, FoodProduction Daily., 2007.
26. GeneCampaign.,2010,Availableat:http://www.genecampaign.org/Publication/Article/nanotech/nanotechnology-in-food-is-it-safe-p2=ID1.htm.
27. ElAmin A. “Nano ink indicates safety breach in food packaging”, FoodNavigator., 2006.
28. Biosensor uses nanotechnology to spot the right smell., 2006, FoodProductionDaily.com Available at: http://www.foodproductiondaily.com/ news/67830.
29. Pehanich M.“Small gains in processing, packaging”, FoodProcessing.com., 2006.
30. Roberts R. “The role of nanotechnology in brand protection”, Packaging Digest., 2007.
31. pSivida launches pSiNutria in the Food Industry, Applications in food quality, safety,authentication and detection of bio terrorism.,2005.
32. Iran agro sector developing nanotech, Available at:http://www.iranmania.com/News.
33. http://www.ifst.org/uploadedfiles/cms/store/ATTACHEMENTS/nanotechnology.pdf
34. Gene Campaign., 2010,
Available at :http://www.genecampaign.org/Publication/Article/nanotech/nanotechnology-in-food-is-it-safe-p2=ID1.htm
35. Granqvist C G, Buhrman R A, Wyns J, SieversA J. "Far-Infrared Absorption in Ultrafine Al Particles". Phys.Rev.Lett., 1976;**37**: 625–629.
36. Ch. Hayashi, RyoziUyeda, A, Tasaki. “Ultra-fine particles: exploratory science and technology”, Noyes Publications.,1997 ;1981-86
37. Kiss L B ,Söderlund J, Niklasson, G A, Granqvist C G. "New approach to the origin of lognormal size distributions of nanoparticles". Nanotechnology., 1999;**10**: 25–28.
38. Cristina Buzea, Ivan Pacheco and Kevin Robbie. "Nanomaterials and Nanoparticles: Sources and Toxicity". Biointerphases., 2007;**2** (4): 17–71..
39. ASTM E 2456 – 06, Standard Terminology Relating to Nanotechnology.
40. Fahlman, B. D. “*Materials Chemistry*”, Springer., 2007;pp. 282–283.
41. Sorrentino A, Gorrasi G. and Vittoria V. “Nanotechnology”, Trends in Food Science & Technology., 2007; 18(2), 84–95
42. Robinson D. K. R. &Salejova-Zadrazilova G. “Nanotechnology for Biodegradable and Edible Food Packaging”, Working Paper ., 2010.
43. De Azeredo HMC.“Nanocomposites for food packaging applications”, Food Research International., 2009;42 :1240–1253.
44. The Project on Emerging Nanotechnology, Consumer Product Inventory
http://www.nanotechproject.org/inventories/consumer/

45. Sondi I andSalopek-Sondi B. “Silver nanoparticles as antimicrobial agent: a case study on E-coli as a model for Gram-negative bacteria”, Journal of Colloid and Interface Science., 2004; 275, 177-182.
46. Yamamoto O. “Influence of particle size on the antibacterial activity of zinc oxide”, International Journal of Inorganic Materials., 2001; 3:643-646.
47. Jones N, Ray B, Ranjit, K T and Manna A C. “Antibacterial activity of ZnO nanoparticle suspensions on a broad spectrum of microorganisms”, FEMS Microbiology Letters., 2008; 279:71-76.
48. Chandramouleeswaran S,Mhaske S T, Kathe A A, Varadarajan P V, Prasad V and Vigneshwaran N. “Functional behaviour of polypropylene/ZnO-soluble starch nanocomposites”, Nanotechnology., 2007; 18: 8.
49. Qi L F, Xu Z R., Jiang X, Hu C H andZou X F. “ Preparation and antibacterial activity of chitosan nanoparticles”, Carbohydrate Research., 2004; 339:2693-2700.
50. Sanpui P, Murugadoss A, Prasad P V D, Ghosh S SandChattopadhyay A. “The antibacterial properties of a novel chitosan-Ag-nanoparticle composite”, International Journal of Food Microbiology., 2008;124:142-146.
51. Wang X Y,Du Y M.,Yang H H, Wang X H, Shi X W and Hu Y. “Preparation, characterization and antimicrobial activity of chitosan/layered silicate nanocomposites”, Polymer., 2006; 47: 6738-6744.
52. Wang X Y, Du Y M.,Luo J W, Lin B F and Kennedy J F “Chitosan/organic rectorite nanocomposite films: Structure, characteristic and drug delivery behaviour”, Carbohydrate Polymers., 2007; 69:41-49.
53. Alfadul S M and Elneshwy A A.“Use of nanotechnology in food processing, packaging and safety review”,African Journal of Food, Agriculture, Nutrition and Development., 2010**.**

****