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Research Article,

Nanotechnology awareness, Knowledge and risks in the modern era

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Abstract:

Nanotechnology is described as the control and perception of material at dimensions amid one and hundred nanometer where distinctive phenomena facilitate new applications. The word "Nano" in Nanotechnology appears from the Greek expression "Nanos" that signifies dwarf. Researchers make use of this prefix to signify 10-9 meter or one billionth; 1 One billionth fraction of a meter; a nanometer or lesser 10,000 times than the diameter of a single human hair. A substance that is that has diameter between the range of 1 to 100 nanometer is recognized as nanoparticle or ultrafine particle. Nanotechnology is amalgamation of the nanostructures into better systems for actual-world applications and Nanotechnology is a rising interdisciplinary technology that has been flourishing in lots of regions during the past ten years, counting medicine, material science, energy electronics, electronics, optics, mechanics, plastics, and aerospace. The key prospective applications of Nanotechnology to many fields of research are summarized in this context.

Keywords: Nanotechnology; Nanoparticle; Nanostructures; Nanobiotechnology; Nanoscience.

Introduction:

The Nanotechnology, a border line of twenty first-century, was born out of such visions. It is described as the control and perception of material at dimensions amid one and hundred nanometer where distinctive phenomena facilitate new applications. (NNI, 2011) Though human contact to nanoparticles (NPs) has happened all the way through the human history, it has remarkably accelerated during the industrial era. The study of NPs is not something new. The idea of a ‘‘nanometer’’ was 1st suggested by Richard Zsigmondy, the Nobel award Laureate of 1925 in the subject of chemistry. He invented the word nanometer clearly to distinguish the size of particle and he was the first to microscopically describe particles, such as gold colloids. Contemporary nanotechnology was invented by Richard Feynman, the Nobel award Laureate of 1965 in physics. Throughout the American Physical Society meeting at Caltech in year 1959, he offered a lecture named, ‘‘There’s Plenty of Room at the Bottom’’, in which he established the proposal of influencing matter at the level of atoms. This innovative idea revealed novel ways of thinking about matter and Feynman’s hypotheses have been confirmed. It is for these reasons that he is regarded as the father of contemporary nanotechnology. Feynman illustrated how substantial phenomena alter their manifestations depending on the scale and caused two challenges: manufacturing at a nanometer scale and reducing the size of letters to the extent that the entire Encyclopedia Britannica could fit on the top of a needle. At that time, Feynman’s concepts were accepted as mere science fiction. In contrast, nowadays, modern tools permit us to accurately assess Feynman theoretical expectations: moving atoms independently and generate physical structures. The word 'nanotechnology' was coined by Norio Taniguchi (1912-1999), a Japanese researcher who in a 1974 technology paper described operations at nanometer scale.

In 1986, Drexler co-established The Institute of Foresight to increase public acceptance of nanotechnology concepts, contributing to the inception of nanotechnology. Dressler’s academic and community work became accepted by the public at large, leading to significant progress in working at atomic level. Drexler’s vision in nanotechnology is also known as ‘‘molecular nanotechnology.’’ In 1991, Iijima, (Iijima et al., 1991), another Japanese researcher, developed carbon nanotubes, allowing researchers to discern materials at the atomic level. This resolution scale led to the 1986 awarding of Nobel Prize in physics to Heinrich Rohrer and Gerd Binnig of Zurich IBM Research Laboratory (Binning et al., 1986, nobelprize.org, 1986). Another development took place in1985 when the structure of carbon atom was identified as a bucky ball, consisting of a circular structure comprised of sixty particles. This constituted the avant-gard which preceded the 1991 discovery of carbon nanotube. Carbon nanotubes remain the nanotechnology area in which most progress was accomplished as these structures are nearly a hundred times stronger, while weighing 1/6 of the steel weight.

Today, nanotechnology is a growing interdisciplinary field that has been flourishing in many regions of the world during the past ten years, contributing to the development of various disciplines, including medicine, material science, energy electronics, optics, mechanics, plastics, and aerospace industry. Researchers make use of this prefix nano to denote a length of 10-9 meter or one billionth part of a meter. This size is one billionth of a meter or about ten thousand times smaller than the diameter of a human hair (Qian et al., 2004). A length in the range of 1 and 100 nanometer in diameter is defined as ultrafilne particle or nanoparticle (Vertet al., 2012).

Nanotechnology in Biology:

Nanotechnology is the amalgamation of the nanostructures into better systems for actual-world applications. NPs are around thousand times smaller than the regular human cells. It is this minute size and other distinctive physiochemical properties that make them exceptionally attractive for therapeutic applications (Dasilva et al., 2017; Wen et al., 2016, Pathak et al., 2015; Barua et al., 2014) Over the past two decades, nanotechnology has become significant for contemporary biology and medicine and is currently the top developing field (Barua et al., 2014). Nanoparticles allow the delivery of therapeutics with utmost precision and comprise vehicles for intracellular administration (JM et al., 2009). Currently, enormous progress has been made in the utilization of micelles, carbons, artificial polymers, liposomes, and medicine–polymer polysaccharide linkages, to name a few (Ding et al., 2017, Kermanizadeh et al., 2018, Lanone et al., 2013, Vega et al., 2008) Additional benefits of nanoparticles include drug stability and extended shelf-life (Vega et al., 2008). The biomedical implementation of nanotechnology and nanoscience has enormous potential in development of new therapeutics and promises better cure for various diseases. The nanomedicine and nanobiotechnology makes use of chemistry, biology, technology, medical science and clinical sciences at nanomolecular level towards development of new therapeutic possibilities.

Miniaturized robotics, proposed in 1980s, boosted research and development of new drugs, delivery methods and advanced therapeutics at nanometer scale. Since then the field of nanomedicine has grown exponentially and many new drugs are currently administred vis nanocarriers (Pelaz et al., 2017).

Other applications of Nanotechnology

Contemporary models of economic growth are also operated by nanoscience and nanotechnologies which correspond to a novel “Technological System” (Freeman and Soete, 1987, p. 67). Studies of nanoscience are flourishing in a number of countries and researchers publish more and more on this topic (Islam et al., 2010; Bainbridge et al., 2006). The significance of nanoscience and nanotechnologies is going beyond the exposed associates of research centers and laboratories and is currently well represented in multiple domains of industrial innovation (Goddard et al., 2007). Nanoscience is the consequence of interdisciplinary collaboration of biotechnology, physics, material sciences, chemistry, and engineering in the direction of studying assemblies of atoms and molecules (Renn and Roco, 2006). The field of Nanotechnology has lots of novel potential uses (Danie et al., 2013; Ranjan et al., 2014; Dasgupta et al., 2015).

1.-Delivery of Drugs and Role of Nanotechnology

The recent ways of medicine delivery pose definite dilemmas that can be resolved by nanotechnology. Medicines are introduced into the human body by many routes such as parenteral and enteral, inhalation and topical application. Often the efficacy of many drugs is lowered due to enzymatic degradation that takes place between the administration and efficacy site. For instance, an oral preparation may undergo acidic environment-associated alterations. Parenteral drugs undergo first-pass metabolism in the liver or gut, frequently diminishing the efficacy of active ingredients (Thummel et al., 1997).

Nanotechnology provides the potential of direct intracellular administration of therapeutics, bypassing multiple barriers, including the liver, gut, or circulatory system, facilitating the treatment of chronic diseases, such as diabetes, carcinoma, asthma, eye diseases, and genetical conditions. Several studies for these disorders are ongoing throughout the world, making use of nanotechnology to improve outcomes (Singh et al., 2005, John et al., 2003, Bourges et al., 2003, Dobson et al., 2006). Furthermore, nanoparticles can offer the possibility of encapsulation and slow release from the administration site, lowering the dosage frequencies (Hu et al., 2012). For example, utilization of nanoparticles for chemotherapeutics, have the ability to lower adverse effects by targeting selectively the malignant cells, while at the same time, achieving higher concentration in target cells. In addition, nanocrystals were demonstrated to achieve maximal drug concentration in malignant cells alone, minimizing the adverse effect of collateral damage on healthy cells (Liu et al., 2010) along this line, magnetic NPs, ferro fluids withiron oxide nanoparticles (IONPs), have been assessed for potential application in both treatment and imaging of colorectal carcinoma (Jordan et al., 1999). IONPs had focused the attention of researchers and clinicians due to their target selectivity on damaged or cancerous cells only. In this regard, superparamagnetic iron oxide nanoparticles (SPIONs) have been studied due to their selective affinity for human malignant cells (petri-fink et al., 2005). For example, “hiding” IONPs within amino acid moieties was shown to increase the selectivity and intake in malignant cells. Indeed, dextran-covered IONPs demonstrated superior results in the management of breast carcinoma by magnetic heating (Hilger et al., 2005).

2.-Nanotechnology in Food Industry

Aside from physics and medicine, nanotechnology has found usefulness in food processing (Doyle et al., 2006). Indeed, nanotechnology has the capability of positively impacting alimentary industry and agriculture. Nanoscale foods can increase effectiveness, protection, absorption, and dietary value, while decreasing the odds of metabolic syndrome by lowering the glycemic index (Blundell et al., 1987; Aguilera et al., 2005). The application of this field in industries of food and agriculture was first communicated in 2003 by the by US Department of Agriculture (USDA) roadmap. Modern researches have started to address the utilization of nanoencapsulation of dynamic complexes for instance vitamins, flavors, minerals, anti-bacterial, medicines, antioxidants, colorants, microorganisms of probiotic, and micronutrients (Chen et al., 2006; Hsieh and Ofori, 2007). To keep active substances at optimal range for extended time periods, a variety of delivery systems, including biopolymer matrix, emulsions, simple solutions, and linking colloids have been created. (Jelinski et al., 2002). The toxicity and effectiveness of dispersion are reduced when tailored nanocarriers are used. (Ravi,2000; Khosravi-Darani et al., 2007). NPs outperform conventional encapsulation techniques in terms of release and encapsulation efficiency. (Roy et al., 1999). Foods can be encapsulated in NPs and released upon contact with specific atmospheric activators. For example, modifying the solution states can increase or decrease permeability or particle dissolution (Weiss et al., 2006; Chang et al., 2005; Gupta et al., 2005; Oppenheim et al., 1981). Emulsifying, mixing, as well as making inks, paints, and coatings can be done with a watery solution of starch-dependent NPs that operate in colloid-like manner (Dziechciarek et al., 2003). Enzymes can be used in food processing for altering constituents and increase nutritional value, flavor, or nutritional value. Because of their assistance in distribution via food matrix and its greater surface-to-volume proportions compared with conventional foods (Yu et al., 2005). In this regard, silicon dioxide (SiO_2) nanoparticles, are efficiently hydrolyzed the olive oil with customized flexibility, steadiness, and reuse capability (Bai et al., 2006).

3.-Nanotechnology in Agriculture and Forestry

An extensive application of nanotechnology in agriculture has been proposed, including the 'sector of agrifood', utilization of tracking devices, nanosensors, and targeted delivery (McClements et al., 2009; Huang et al., 2010; Ranjan et al., 2014; Dasgupta et al., 2015). Agriculture productivity can be improved through nano-material-induced genetically improved animals and plants for better nutrition (Pramanik et al., 2020). This field can also contribute to the solubility of water, heat or temperature constancy and improved biological absorption of the useful food complexes (McClements et al., 2009; McClements and Li, 2010). Utilization of nanosensors hold considerable promises as they could analyze signaling pathways, metabolisms, exposure of crop and/or soil to diseases, pollutants and pesticides (Shang et al., 2019; Husen and Jawaid, 2020). Moreover this technology can be an optional fertilizer source. In a trial, it was detected that SiO_2 nanoparticles improved seed germination of Lycopersicum esculentum/tomato (Siddiqui and Al- Whaibi, 2014). These progressions will assist in escalating the bioavailability of dynamic constituents, thus minimizing the quantity of efforts to be applied as well as the amount of dissipation. Cai et al. (2014) developed nanoclays, nanoparticles of layered mineral silicates, which can be included in conventional fertilizer to advance the fertilizing capability of nitrogen. This modality minimizes loss of nitrogen and improves crop nutrition. Nanoemulsions have been utilized to enhance the biological absorption of pesticides and herbicides, minimizing crop losses (Lim et al., 2012; Jiang et al., 2013; Pant et al., 2014). Using nanotechnology many of the forest materials can be converted into valuable substances, including smart paper, nano-packaging, material to coat with, structure build up and for biomedical uses (Jasmani et al., 2020).

4.-Nanotechnology in Textile Industry

Several progresses in nanotechnology and its applications have the potential to optimize the textile industry. The customer-oriented applications in textile industry is among the leading beneficiaries of progresses in nanotechnology. Being one of the major customer-assisted industries, with considerable influence on a country's financial system, progresses in applications of nanotechnology to advance the offer of textile properties noticeable, elevate the economic prospective for the growth of industry. It was revealed in current years that nanotechnology can be applied to improve the attributes of textile, for instance breathability, softness of fabric, permanence, and fire retardancy, repellency of water, anti-bacterial properties and the like in textiles, fabrics and yarns (Paul et al., 2004). Researchers have used a plant enzyme to synthesize gold nanoparticles (GNPs) that boost immune response in Bombax mori, an economically important silkworm

(Govindaraju et al., 2011). This not only improves the survival rate of silkworm but also promote its growth and development along with the quality of silk fiber. The eco-friendly way of making GNPs may further be very useful in medical and biotechnological applications. It is anticipated that in the next decade, the development of textile industry by nanotechnology may grow into a multi-billion $ endeavor with related ecologic and monetary benefits to the consumers of textile and the public in general (Li et al., 2003). It was determined that distinctive compound fibers were manufactured from artificial nano-fibers acquired through an advanced process of electro-spinning, for instance the coagulation-based revolving method of carbon-nano-tube (Dalton et al., 2002, Schreuder et al., 2002).

Conclusion:

Nanotechnology constitutes the amalgamation of the nanostructures into better systems for real-world applications. Nanotechnology is a growing interdisciplinary field that has been flourishing in many regions during the past ten years, including medicine, material science, energy electronics, optics, mechanics, plastics, and aerospace industry. Nanotechnology applications in biology, medicine, drug delivery, food, textile industry, agriculture and forestry, are producing i promising and encouraging results that bode well for the future. Research should strive to improve and deepen these techniques to enable further progress in certain sectors of vital importance for economic development, for the common well-being and for the health of all.

References:

[1] National Nanotechnology Initiative (NNI). (2011). National Science and Technology Council. Committee on Technology, Subcommittee on Nanoscale Science, National Technology Initiative Strategic Plan, www.nano.gov, (accessed 25 August 2015).

[2] Iijima S. (1991). Helical microtubules of graphitic carbon. Nature 354: 56–58.

[3] G. Binnig and H. Rohrer; (1986). IBM Journal of Research and Development, 30355

[4] Press Released: The 1986 Nobel Prize in Physics, Nobelprize.org, 15 October1986

[5] L. Qian and P. Juan, (2004) Application of Nanotechnology for high performance textiles, Journal. 4

[6] Vert, M.; Doi, Y.; Hellwich, K. H.; Hess, M.; Hodge, P.; et al. (2012). "Terminology for biorelated polymers and applications (IUPAC Recommendations 2012)". Pure and Applied Chemistry. 84 (2): 377 410.

[7] Da Silva AL, Cruz FF, Rocco PRM, Morales MM. (2017). New perspectives in nanotherapeutics for chronic respiratory diseases. Biophys Rev.9(5):793–803.

[8] Wen R, Banik B, Pathak RK, Kumar A, Kolishetti N, Dhar S. (2016). Nanotechnology inspired tools for mitochondrial dysfunction related diseases. Adv Drug Deliv Rev. 99(Pt A):52–69.

[9] Pathak K, Raghuvanshi S. (2015). Oral bioavailability: issues and solutions via nanoformulations. Clin Pharmacokinet.54(4):325–357.

[10] Barua S, Mitragotri S. (2014). Challenges associated with penetration of nanoparticles across cell and tissue barriers: A review of current status and future prospects. Nano Today.9 (2):223–243.

[11] Jm Y, Yj L, Qiu LY, Jin Y. (2009). Polymeric nanoparticles of cholesterol-modified glycol chitosan for doxorubicin delivery: preparation and in-vitro and in-vivo characterization. J Pharm Pharmacol.61:713–719.

[12] Ding C, Li Z. (2017). A review of drug release mechanisms from nanocarrier systems. Mater Sci Eng C Mater Biol Appl.76:1440–1453.

[13] Kermanizadeh A, Jantzen K, Brown DM, Møller P, Loft S. (2018). A flow cytometry-based method for the screening of nanomaterial-induced reactive oxygen species production in leukocytes subpopulations in whole blood. Basic Clin Pharmacol Toxicol.122(1):149–156.

[14] Lanone S, Andujar P, Kermanizadeh A, Boczkowski J. (2013). Determinants of carbon nanotube toxicity. Adv Drug Deliv Rev.65 (15):2063–2069.

[15] Vega-Vila KR, Takemoto JK, Yanez JA, Remsberg CM, Forrest ML, Davies NM. (2008). Clinical toxicities of nanocarrier systems. Adv Drug Deliv Rev.60:929–938.

[16] Routes of Drug Administration, http://www.boomer.org/c/p2/Ch16W.pdf
[17] Thummel, K.E., Kunze, K.L. and Shen, D.D. (1997). ‘Enzyme-catalyzed processes of first-pass hepatic and intestinal drug extraction’, Adv. Drug. Deliver. Rev., 27 (2-3): 99–127.
[18] Hu K, Cao S, Hu F, Feng J. (2012). Enhanced oral bioavailability of docetaxel by lecithin nanoparticles: preparation, in vitro, and in vivo evaluation. Int J Nanomedicine.7:3537–3545
[19] Liu F, Park JY, Zhang Y, et al. (2010). Targeted cancer therapy with novel high drug-loading nanocrystals. J Pharm Sci.99(8):3542–3551.
[20] Singh, K.K. (2005). ‘Nanotechnology in cancer detection and treatment’, Technol. Cancer. Res. T., 4(6):.583.
[21] John, A.E., Lukacs, N.W., Berlin, A.A., Palecanda, A., Bargatze, R.F., et al. (2003). ‘Discovery of a potent nanoparticle P-selectin antagonist with anti-inflammatory effects in allergic airway disease’, Fed. Amer. Soc. Exp. Biol. J., 17 (15):.2296–2298.
[22] Bourges, J.L., Gautier, S.E., Delie, F., Bejjani, R.A., Jeanny, J.C., et al. (2003) ‘Ocular drug delivery targeting the retina and retinal pigment epithelium using polylactide nanoparticles’, Invest. Ophth. Vis. Sci., 44(8): 3562–3569.
[23] Dobson, J. (2006). ‘Gene therapy progress and prospects: magnetic nanoparticle-based gene delivery’, Gene Ther., 13(4): .283–287.
[24] Jordan, A., Scholz, R., Wust, P., Fähling, H. and Felix, R. (1999). ‘Magnetic fluid hyperthermia (MFH): cancer treatment with AC magnetic field induced excitation of biocompatible superparamagnetic nanoparticles’, J. Magn. Magn. Part.,. 201:.413–416.
[25] Petri-Fink, A., Chastellain, M., Juillerat-Jeanneret, L., Ferrari, A. and Hofmann, H. (2005). ‘Development of functionalized superparamagnetic iron oxide nanoparticles for interaction with human cancer cells’, Biomaterials, 26:2685–2694.
[26] Hilger, I., Hergt, R. and Kaiser, W.A. (2005) ‘Towards breast cancer treatment by magneticheating’, J. Magn. Magn. Mater. 293:314–319.
[27] B. Pelaz, C. Alexiou, R.A. Alvarez-Puebla, F. Alves, A.M. Andrews, et. al. (2017). Diverse Applications of Nanomedicine. ACS Nano. 11:, 2313-2381.
[28] McClements DJ, Decker EA, Park Y, Weiss J (2009). Structural design principles for delivery of bioactive components in nutraceuticals and functional foods. Crit Rev Food Sci Nutr 49:577–606.
[29] Huang Q, Yu H, Ru Q (2010). Bioavailability and delivery of nutraceuticals using nanotechnology. J Food Sci; 75:R50–R57.
[30] Ranjan S, Dasgupta N, Chakraborty AR et al (2014). Nanoscience and nanotechnologies in food industries: opportunities and research trends. J Nanoparticle Res 2014; 16:2464.
[31] Dasgupta N, Ranjan S, Mundekkad D et al (2015) Nanotechnology in agro-food: from field to plate. Food Res Int 69:381–400
[32] McClements DJ, Li Y (2010). Structured emulsion-based delivery systems: controlling the digestion and release of lipophilic food components. Advances in Colloid and Interface Science, 159(2): 213-228.
[33] Siddiqui MH, Al-Whaibi MH (2014) Role of nano-SiO2 in germination of tomato (Lycopersicum esculentum seeds Mill.). Saudi J Biol Sci 21:13–17.
[34] Cai D, Wu Z, Jiang J et al.(2014). Controlling nitrogen migration through micro-nano networks. Sci Rep. 4:3665.
[35] Lim CJ, Basri M, Omar D et al. (2012). Green nano-emulsion intervention for water-soluble glyphosate isopropylamine (IPA) formulations in controlling Eleusine indica (E. indica). Pestic Biochem Physiol; 102:19–29.
[36] Jiang LC, Basri M, Omar D et al. (2013). Green nanoemulsion-laden glyphosate isopropylamine formulation in suppressing creeping foxglove (A. gangetica), slender button weed (D. ocimifolia) and buffalo grass (P. conjugatum). Pest Manag Sci. 69:104–111.
[37] Pant M, Dubey S, Patanjali PK et al. (2014). Insecticidal activity of eucalyptus oil nanoemulsion with karanja and jatropha aqueous filtrates. Int Biodeterior Biodegrad 91:119–127.

[38] Doyle, M.E... (2006). Nanotechnology:A Brief Literature Review. Food Research Institute Briefings, University ofWisconsin-Madison.; 10 pages. Available at: http: //www.wisc.edu/fri

[39] Blundell, J.E. and Thurlby, P.L. (1987). Experimental manipulations of eating advances in animal models for studying anorectic agents. Pharmacol. Ther.34(3): 349–401.

[40] Aguilera, J.M. (2005). Why food microstructure? J. Food Eng. 67(1–2): 3–11.

[41] Yu, L.T., Banerjee, I.A., Gao, X.Y., Nuraje, N., and Matsui, H. (2005). Fabrication and application of enzyme-incorporated peptide nanotubes. Bioconj. Chem. 16: 1484–1487.

[42] Bai, Y.X., Li, Y.F., Yang, Y., and Yi, L.X. (2006). Covalent immobilization of triacylglycerol lipase onto functionalized nanoscale SiO2 spheres. Proc. Biochem. 41: 770–777.

[43] Chen, H., Weiss, J., and Shahidi, F. (2006). Nanotechnology in nutraceuticals and functional foods. J. Food Tech. 60(3): 30–36.

[44] Hsieh, Y.H.P. and Ofori, J.A. (2007). Innovations in food technology for health. Asia. Pac. J. Clin. Nut. 16: 65–73.

[45] Jelinski, L. (2002). Biologically related aspects of nanoparticles, nanostructured materials, and nanodevices. In: Nanostructure Science & Technology. Siegel, R.W., Hu, E., and Roco, M.C., Eds. A worldwide study, prepared under the guidance of National Science and Technology Council and the Interagency Working Group on NanoScience, Engineering, and Technology, May 2002. Available online at www.wtec.org/loyola/nano/toc.htm.

[46] Ravi Kumar, M.N.V. (2000). Nano and microparticles as controlled drug delivery devices. J. Pharm. Sci. 3(2): 234–258.

[47] Khosravi-Darani, K., Pardakhty, A., Honarpisheh, H., Rao, V.S.M., and Mozafari, M.R. (2007). The role of high-resolution imaging in the evaluation of nanosystems for bioactive encapsulation and targeted nanotherapy. MICRON. 38: 804–818.

[48] Roy, K., Mao, H.Q., Huang, S.K., and Leong, K.W. (1999). Oral gene delivery with chitosan-DNA nanoparticles generates immunologic protection in a murine model of peanut allergy. Nature Med. 5: 387–391.

[49] Weiss, J., Takhistov, P., and McClements, D.J. (2006). Functional materials in food nanotechnology. J. Food Sci. 71(9): R107–R116.

[50] Chang,Y.C. and Chen, D.G.H. (2005).Adsorption kinetics and thermodynamics of acid dyes on a carboxymethylated chitosan-conjugated magnetic nanoadsorbent. Macromol. Biosci. 5(3): 254–261.

[51] Gupta, A.K. and Gupta, M. (2005). Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications. Biomaterials. 26(18): 3995–4021.

[52] Oppenheim, R.C. (1981). Solid colloidal drug delivery systems: Nanoparticles. Int. J. Pharm. 8: 217–234

[53] Dziechciarek, Y., Van Schijndel, R.J.G., Gotlieb, K.F., Feil, H., and Van Soest, J.J. G. (2003).Development of starch-based nanoparticles: Structure colloidal and rheological properties. Presented at the Meeting of the Dutch Society of Rheology, Oct. 22, (accessed June 2003). Abstract available online at: http: //www.mate.tue.nl/nrv/ede/dziech%20ciarek.html.

[54] Paul, J., Galvin, L., (2004).Intern. Fiber J., 19, T316

[55] Li, Y., Lo, L., Hu, J., (2003).Text Asia, November, 29

[56] Dalton, A., Collins, S., Muñoz, E., Razal, J., Ebron, V. H., et al. (2002).Nature, 423, 703

[57] Schreuder, G., Gibson, P., Senecal, K., Sennett, M., Walker, J.,et al.(2002).J. Adv. Mat., 34, 44

[58] Freeman C., Soete L. (1987), Technical Change and Full Employment, Basil Blackwell, Oxford (UK).

[59] Islam N., Miyazaki K. (2010), “An empirical analysis of nanotechnology research domains”, Technovation, vol. 30, n. 4, pp. 229-237.

[60] Bainbridge W.S., Roco M.C. (Eds.) (2006), Managing nano-bio-info-cogno innovations, converging technologies in society, Springer, Berlin.

[61] Goddard III W., Brenner D., Lyshevski S., Iafrate G. (Eds.) (2007), Handbook of

Nanoscience, Engineering and Technology, Second Edition, Taylor and Francis Group.
[62] Renn O., Roco M.C. (2006), “Nanotechnology and the need for risk governance”, Journal of Nanoparticle Research, vol. 8, n. 2, pp. 153-191.
[63] Danie Kingsley J, Ranjan S, Dasgupta N, Saha P (2013). Nanotechnology for tissue engineering: need, techniques and applications. J Pharm Res. doi:10.1016/j.jopr.2013.02.021
[64] Ranjan S, Dasgupta N, Chakraborty AR et al., (2014). Nanoscience and nanotechnologies in food industries: opportunities and research trends. J Nanoparticle Res 16:2464.
[65] Dasgupta N, Ranjan S, Mundekkad D et al., (2015). Nanotechnology in agro-food: from field to plate. Food Res Int; 69:381–400.