Nanotechnology: a future tool to improve quality and safety in meat industry

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Abstract Nanotechnology refers to the new aspect of science modifies its physical, chemical and biological properties leading to new applications or enhanced utility. Keeping the pace with other industries, the meat industry has adopted the new technology in a range of applications to improve the quality and safety of products. The potential applications include the improvement in the tastes, texture, flavor, production of low fat and salt products, enhanced nutrient absorption, improved packaging techniques and better pathogen detection system. However some safety issues need to be addressed before taking a ride on the technology at the full throttle.

Keywords Nanotechnology · Packaging · Meat products · Nanosensors · Nanocomposites

Introduction

Meat has been processed since time immemorial to improve its quality and shelf life. The processing techniques like drying, salting, smoking are one of the oldest practices employed to enhance the texture, flavor, taste and microbial safety of meat products. Meat just like other foods is a complex biological system that is governed by many of the same basic mechanisms and principles as in biology and biochemistry. Therefore, the discoveries made in nanotechnology with respect to biological sciences will also impact the meat industry.

Nanotechnology has its roots in a talk delivered in 1959 by physicist Richard Feynman to the American Physical Society (Ozimek et al. 2010). Nanotechnology involves the characterization, fabrication and/or manipulation of structures, devices or materials that have at least one dimension (or contain components with at least one dimension) that is approximately 1–100 nm in length (Duncan 2011; Coles and Frewer 2013). We can classify a product with nanotechnology only when following approaches have been used in the production system (Table 1).

- When any of the food ingredients have been processed to form nanostructures e.g. nanosized nutrients to enhance the bioavailability of nutrients and improve sensory properties of product.
- Where nanosized or nanoencapsulated additives and supplements have been incorporated in a product.
- If the packaging materials utilize nano-particles to improve their quality.
- When nanotechnology based device have been used in the processing or packaging of a product e.g. nanosensors.

The major areas of nanotechnology application to the meat industry are improving security level and processing; flavor and nutrition, delivery methods, pathogen detection, functionality of foods, protection of the environment, and the cost-effectiveness of storage and distribution. With the advent of time there has been drastic improvement in the processing practices both at domestic level and industrial as well to obtain products with better attributes. The driving force behind the adoption of newer techniques is obviously the profitability in the industry which is based on the consumer acceptance of the products. The consumer acceptance of a product depends on the value addition in terms of nutritional value, taste, texture, shelf life, safety etc. The nanoscale level of foods can affect

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Table 1 Applications of nanotechnology in meat industry: A glimpse

S.No.	Subject of study	Main results	References
1.	Industrial sausage and cured meat production requires the addition of many additives to speed up the production process, stabilize colour and improve taste.	Aquanova, a German Company, has developed a nanotechnology based carrier system using 30 nm micelles to encapsulate active ingredients such as vitamins C & E and fatty acids.	Alfadul and Elneshwy (2010)
2.	Nanoscale edible coatings which can act as a vehicle to deliver colours, flavours, antioxidants, enzymes.	Coatings developed as thin as 5 nm wide, which are invisible to the human eye and could be used on meats, cheese etc.	Weiss et al. (2006)
3.	Effective deliver of nutrients like protein and antioxidants for precisely targeted nutritional and health benefits.	Shefer developed the encapsulated system, which resulted in nanospheres for processed meat products, seasonal confectionery, specialty products etc.	Shefer and Shefer (2003)
4.	The use of nanoparticle paprika oleoresin as an ingredient to enhance the quality.	Enhanced the effects of marination and the sensory qualities of the chicken breast fillets.	Yusop et al. (2012)
5.	Determination of hypoxanthine in tuna fish samples.	A glassy carbon paste electrode based on xanthine oxidase (XOD) and gold nanoparticles was prepared for the chronoamperometric detection, where the analytical characteristics were determined, but no LOD was reported.	Cubukcu et al. (2007)
6.	To detect presence of gases, that may indicate of fish and meat spoilage.	Nanotechnology based sensors that can detect gaseous amines even in very low concentrations were developed.	Mills and Hazafy (2009); Duncan (2011)
7.	The effects of antimicrobial chitosan nanoparticles on the growth of microorganisms in fish fingers.	Fish fingers with chitosan or chitosan edible coating showed decreased bacterial counts.	Abdou et al. (2012)
8.	A nanoemulsion prepared with sunflower oil was used in the processing of Indo-Pacific king mackerel steaks.	Decrease in the initial microbial growth up to 12 h except for the control and an increase in the shelf life of 48 h, determined organoleptically, indicating its potential use in the short-term storage of fish products.	Joe et al. (2012)
9.	To develop a meat packaging material with efficient barrier properties.	Durethan, a meat-packaging product of Bayer, consists of a polyamide plastic film reinforced with clay nanoparticles and is able to act as an oxygen, moisture and carbon dioxide barrier.	Brody et al. (2008)
10.	Antimicrobial application of cellulose pads containing Ag nanoparticles generated from silver ions in situ.	Reduces the microbial levels of exudates from beef meat stored in modified atmosphere packaging.	Fernandez et al. (2010)
11.	Zinc oxide (ZnO) can be a potent antimicrobial along with silver (Ag) in a nanocomposite with low density polyethylene.	Pathogens in meat, such as <i>E. coli</i> , <i>P. aeruginosa</i> and <i>L. monocytogenes</i> , were inhibited by this type of packaging in a study on chicken breasts.	Panea et al. (2013)
12.	Antimicrobial activity of absorbent pads containing Ag nanoparticles.	Effect against <i>E. coli</i> and <i>Staph. aureus</i> was confirmed.	Fernandez et al. (2009)
13.	To develop biosensor for detection of <i>Salmonella Infantis</i> , associated with the egg and especially the chicken meat industry.	A network of single walled carbon nanotubes has been used for the construction of a field effect transistor (FET) biosensor for <i>Salmonella Infantis</i> detection and the device could detect at least 100 cfu mL ⁻¹ of the pathogen in 1 h.	Villamizar et al. (2008)
14.	Food contact materials, in which the nanoparticles are located on the material surface, may come into direct contact with the food matrix.	Detectable levels of silver ions leached into the meat exudates (though not into the meat itself).	Fernandez et al. (2010)

the safety, efficiency, bioavailability, and nutritional value properties as well as the molecular synthesis of new products and ingredients (Aguilera 2005).

As we have reached to a status where almost all the permutations and combinations at gross level have been explored to improve the quality of products, hence the nanotechnology is the answer to manipulate the food ingredients at nanoscale where handling of ingredients approaches the molecular level. We are at the beginning of the immense growth potential the nanotechnology is going to offer in the near future. Nanotechnologies are

projected to impact at least \$3 trillion across the global economy by 2020, and nanotechnology industries worldwide may require at least 6 million workers to support them by the end of the decade (Roco et al. 2010).

The small particle size and increased surface area give nanoparticle its unique feature and wide applications in different fields. It offers a wide range of opportunities for the development of innovative products with wide applications in the industry. Nanomaterials and nanoparticles may include any of the following nano forms: nanoparticles, nanotubes, fullerenes, nanofibres,

nanowhiskers, nanosheets (Cushen et al. 2012). Many of these different nano forms are either in use or under investigation for use within the industry.

Manufacture of nanomaterials and their possible effects

Manufacture of nanomaterial involves the approaches like ‘top down’ or ‘bottom up’. Where top down manufacturing of nanomaterials involves breaking down larger particles of matter to particles of only nanometers in dimension by physical or chemical means. Mechanical milling or grinding is an important method to convert the macro sized particles to the nanoscale. This technique is commonly used in the enhancement of binding ability of product ingredients like wheat flour. Some researchers have also indicated it as a method to enhance the antioxidant properties of ingredients by increasing the surface area, where reduction in size increases the active sites as well as the surface area of active principles present in the materials. As the powder size of green tea is reduced to 1000 nm by dry milling, the high ratio of nutrient digestion and absorption resulted in an increase in the activity of an oxygen-eliminating enzyme (Shibata 2002). The process of homogenization used in the milk industry is a common technique to reduce the fat particle size subjecting it to high pressure and there by application of shearing and shattering forces. The use of lasers and vaporization followed by cooling are other top down methods of nanomaterial manufacture reported by Brody et al. (2008).

However self assembly and self organization are concepts derived from biology that has inspired a bottom-up technique in nanotechnology. The organization of casein micelles or starch and the folding of globular proteins and protein aggregates are examples of self-assembly structures that create stable entities (Sozer and Kokini 2009). Self organization on the nanometer scale can be achieved by setting a balance between the different non-covalent forces (Dickinson and Van Vliet 2003).

Nanotechnology allows to measure, control, and manipulate matter at the nanoscale level to change those properties and functions in a beneficial way. Most materials have different properties when they are nanostructured and these properties depend on the designed location of every atom or molecule (Roco et al. 2010). Ozimek et al. (2010) stated that nanostructures or nanomaterials exhibit properties different from their macroscale counterparts (their “big brothers”) such as mechanical strength (how hard they are to break), electrical conductivity (how fast electrons flow through them), thermal conductivity (how fast heat flows through them), chemical reactivity (how well/fast they react with other chemicals), transparency (how well you can see through them) and magnetism (whether or not they are magnetic).

Protocol for preparation of nanoparticles, nanocarriers or other nanomaterials

There can be a variety of nanomaterials depending on their source and application, however those having relevance to meat industry are being discussed here.

Preparation of metal nanoparticles

Metal nanoparticles are used as various types of catalysts, adsorbents and sensors. They have applications in different devices used for the safety and quality of products. Most of these applications critically depend on the size and shape of the nanoparticles. Hence, the synthesis of well-controlled size and shape of these particles is critical for their applications. There are several methods like chemical reduction, spray pyrolysis etc. for preparation of these metal nanoparticles.

The metal nanoparticles with spherical shape and sharp size distribution such as Au were produced continuously by the chemical reduction method assisted by ultrasonic device where by changing the amount of tannin acid into the mixture of AuCl_4H and sodium citrate dihydrate, particle diameter of Au nanoparticles can be controlled between 5 and 17 nm (Kikuo and Wuled 2004). The mono-dispersed Ag nanoparticles ranging below 10 nm in diameter have been obtained in more than 100 mM of Ag concentration of precursor liquid.

Another type of most common nanoparticles are magnetic one, used in the industry. FePt nanoparticles are the material for developing ultra high density magnetic media. Here the FePt nanoparticles have been synthesized by mixing two precursor liquids: ferric acetyl acetonate, $\text{Fe}(\text{acac})_3$, and platinum acetyl acetonate, $\text{Pt}(\text{acac})_2$ in polyol solution of sodium hydroxide at high temperatures (Iwaki et al. 2003). The FePt nanoparticles have been extensively used in sensitive applications like biosensor development.

Preparation of nanocarriers

The selection of appropriate method for the preparation of nanocarriers depends on the physicochemical character of the polymer and the ingredient to be carried. For example, industrial sausage and cured meat production requires the addition of many additives to speed up the production process, stabilize colour and improve taste. Aquanova, a German company, has developed a nanotechnology based on carrier system using 30 nm micelles to encapsulate active ingredients such as vitamins C & E and fatty acids, which can be used as preservatives. Aquanova markets these micelles as “NovaSol”. The German industry magazine “Fleischwirtschaft” claims that NovaSol offers considerable advantages of faster meat processing, cheaper ingredients and higher colour stability (Alfadul and Elneshwy 2010). There are

several techniques to develop the nanocarriers, some are as follows.

- *Emulsion-solvent evaporation method*: It is one of the most common methods used for the preparation of nanoparticles. It has basically two steps, where the first step involves preparation of an aqueous phase by emulsification of the polymer and in the second step, nanospheres are formed by inducing polymer precipitation and subsequently solvent is evaporated. The nano particles are harvested by ultracentrifugation technique where washing is done with distilled water to remove impurity (Song et al. 1997). The size can be controlled by adjusting the stirring rate, type and amount of dispersing agent, viscosity of organic and aqueous phases and temperature (Tice and Gilley 1985).
- *Double emulsion and evaporation method*: The above method has the limitation of poor entrapment of hydrophilic materials. Hence, to encapsulate hydrophilic agent, the double emulsion technique is used. In this method, aqueous material solutions are added to organic polymer solution with vigorous stirring to form w/o (water in oil) emulsions and this w/o emulsion formed is again added into second aqueous phase with vigorous stirring to form the w/o/w emulsion (Pal et al. 2011). The emulsion formed is then subjected to solvent removal by evaporation and nano particles can be isolated by centrifugation.
- *Salting out method*: In this method, the polymer and material to be carried are initially dissolved in a solvent and subsequently emulsified into an aqueous gel, containing the salting out agent. The salting out agent here are an electrolyte or a non-electrolyte and a colloidal stabilizer. Sufficient volume of water or aqueous solution is used to dilute the oil/water emulsion formed to enhance the diffusion of solvent into the aqueous phase. This results in induced formation of nanospheres. Salting out does not require an increase of temperature and hence can be useful for heat sensitive substances (Lambert et al. 2001).

Applications of nanotechnology

Nanostructured ingredients or carriers

The first and the foremost role of nanotechnology in the processing sector of meat industry could be the enhancement of sensory characteristics of a product. Nanostructuring of natural food materials can potentially enable the reduced level of fat in a product having the same rich flavor of a full fat product. Nanoemulsions are produced by high-pressure value homogenizers or microfluidizers with a droplet diameter less

than 100–500 nm (McClements 2005). Using nanoemulsions in food products can facilitate the use of less fat without a compromise in creaminess, thus offering the consumer a healthier option; examples include low fat nanostructured mayonnaise and spreads (Chaudhry et al. 2008). As the size of the droplets in an emulsion is reduced, the less likely the emulsion will break down and separate. In this way nanoemulsification may reduce the need for certain stabilizers in a product (Cushen et al. 2012). Functional food components can be incorporated within the droplets, the interfacial region, or the continuous phase of the nano-emulsions (Jasinska et al. 2010). Hence the low fat meat products can be produced without using fat replacers or compromising with the flavor of the products. Similarly the nano-structuring can be used to reduce salt level in a meat product or for production of low sodium products. Reducing the salt level is especially important and presents a great challenge for meat industry because in spite of advantages, use of salt has shortcomings since it is linked to hypertension and consequently increased risk of cardiovascular disease (Boskovic et al. 2013). There is a wide range of additives and supplements available in the market to enhance the sensory properties of meat products. The colour, flavor and texture of a product can be enhanced by nanoencapsulation of active compounds responsible for the sensory attributes of a product.

Nanocarriers are also available for nutrients and supplements having an important role in the increase of uptake and bioavailability. They are based on the nanoencapsulated substances in structures like liposomes, micelle etc. Micelles are spherical particles (5–100 nm diameters) and have the ability to encapsulate nonpolar molecules including lipids, flavorants, antimicrobials, antioxidants, and vitamins (Weiss and McClements 2002). Liposomes are closed, continuous bilayered structures made mainly of lipid and/or phospholipid molecules and can be prepared by the heating method in which no harmful chemical or procedure is involved (Khosravi-Darani et al. 2007). Liposome encapsulated antimicrobials peptides showed advantages in comparison with free bacteriocin (nisin) and improved food shelf life, showing to be an interesting delivery system to food products (Malheiros et al., 2010). Encapsulation is applied in food technology to mask odors or tastes, control interactions of active ingredients with the food matrix, control the release of the active agents, ensure availability at a target time and specific rate, and protect them from moisture, heat, chemical, or biological degradation during processing, storage, and utilization, and also compatibility with other compounds in the system (Weiss et al. 2006). The nano-carrier systems are also used for taste masking of certain ingredients and additives, or to protect them from degradation during processing where additives include synthetic form of the tomato carotenoid lycopene, benzoic acid, citric acid, ascorbic acid, and supplements such

as vitamins A and E, isoflavones, β -carotene, lutein and omega-3 fatty acids (Chaudhry and Castle 2011). Nanomaterials can be used as bioactives in functional foods (Chau et al. 2007). Nanoencapsulated substances are also being developed as part of interactive foods, which will allow consumers to modify the food depending on their own nutritional needs or tastes where nanoencapsulated ingredients or additives could be activated by consumer at a particular microwave frequency (Chaudhry et al. 2008). Reducing the particle size of bioactives may improve the availability, delivery properties and solubility of the bioactives and thus their biological activity because the biological activity of a substance depends on its ability to be transferred across intestinal membranes into the blood (Chen et al. 2006; Shegokar and Muller 2010).

Nanotubes can be obtained from milk protein α -lactalbumin by partial hydrolysis having cavities of 8 nm in diameter, which might enable the binding of food components, such as vitamins or enzymes and these cavities could also be used to encapsulate and protect nutraceuticals or to mask undesirable flavor or aroma compounds (Graveland-Bikker and de Kruif 2006).

Packaging

Muscle foods are generally high value, perishable goods and because of this they are an ideal target for value nanotechnology-assisted packaging. It has been estimated that nanotechnology-derived packaging (including food packaging) will make up to 19 % of the share of nanotechnology-enabled products and applications in the global consumer goods industry by 2015 (Nanoposts Report, 2008). Nanotechnology in the packaging industry can have following approaches (Chaudhry et al. 2008):

- a. Incorporation of nanoparticles in the packaging materials to improve the properties like flexibility, barrier, strength etc.
- b. Active packaging; incorporation of nanoparticles having antimicrobial or oxygen scavenging properties.
- c. Intelligent packaging; incorporation of nanoparticle devices like nanosensors.
- d. Biodegradable polymer–nanomaterial composites.

Nanocomposites

Polymer nanocomposites (PNCs) are the latest materials aimed at solving the permeability and barrier related problems of the packaging industry in addition to mechanical strength. PNCs are created by dispersing an inert, nanoscale filler throughout a polymeric matrix where the filler materials can include clay and silicate nanoplatelets, silica (SiO_2) nanoparticles, carbon nanotubes, graphene, starch nanocrystals,

cellulose-based nanofibers or nanowhiskers, chitin or chitosan nanoparticles and other inorganics (Duncan 2011). The use of nanoparticles can improve the mechanical and heat resistance properties of packaging materials and increase shelf life, by affecting gas or water vapor permeability; as polymers are not inherently impermeable to gases or water vapor, but polymer silicate nanocomposites have improved gas barrier, the mechanical strength, and the heat resistance properties (Schaefer 2005; Brody 2006). The use of nanoscale fillers in composite films represents a radical, promising alternative to conventional polymer composites (Alexandre and Dubois 2000; Sinha et al. 2002). The dispersal of nano-sized fillers into the polymer matrix affects the barrier properties of a homogeneous polymer film by creating a tortuous path for gas diffusion as the filler materials are essentially impermeable inorganic crystals, gas molecules must diffuse around them rather than taking a straight line path. Montmorillonite (MMT) has been widely studied and is of particular interest due to its successful incorporation into composite materials and the advantageous properties which the reinforced films exhibit, which are attributed to the high aspect ratio (Rhim and Ng 2007). MMT is not the only layer silicate material utilized in nanocomposite materials, other related clays such as kaolinite, hectrite and saponite can also be used in PNC applications and the natural structure of these various clays can play an important role in PNC properties (Duncan 2011).

Active packaging

Despite efforts and improvements in slaughter hygiene and food production techniques, food-borne pathogens found in meat, such as *Salmonella spp.*, *Campylobacter spp.* and *E. coli*, still present a cause of millions episodes of illness annually all over the World (Burt 2004; Sofos 2008; Newell et al. 2010; Duncan 2011; Linscott 2011; Boskovic et al. 2013). Looking to the demand of meat industry it is important here to discuss the antimicrobial properties associated with nanoparticles and their possible use. Polymer nanocomposites incorporating metal or metal oxide nanoparticles have been developed for antimicrobial “active” packaging, abrasion resistance, UV absorption and/or strength (Chaudhry et al., 2008). Duncan 2011 described the metal nanomaterials commonly used for antibacterial activity are silver (Ag), zinc (Zn), Magnesium(Mg),Copper(Cu) and titanium (Ti).

There are many components which are used as antimicrobial films for food packaging, but the most used is silver because of its activity against Gram-negative and Gram-positive bacteria, fungi, protozoa, and certain viruses (Azeredo 2009; Velebit and Petrovic 2012; Azeredo 2013; Loncina et al. 2013). Silver has long history of being used as an antimicrobial agent in the food. In spite of the long history of silver as an antimicrobial, the mechanism of its activity is not well understood. The general explanation offered is that

silver kills by at least one of the following mechanisms: (a) interference with vital cellular processes by binding to sulfhydryl or disulfide functional groups on the surfaces of membrane proteins and other enzymes; (b) disruption of DNA replication; and (c) oxidative stress through the catalysis of reactive oxygen species (ROS) formation (Luoma 2008). One of the biggest advantages of inorganic nanoparticles over molecular antimicrobials is the ease with which the former can be incorporated into polymers to form functional antimicrobial materials due to the controlled release properties of silver nanoparticles which can be engineered to remain potent antimicrobial agents for long periods of time (Duncan 2011). Other metal oxide materials most used as inorganic nanomaterials are titanium dioxide (TiO₂), zinc oxide (ZnO) and magnesium oxide (MgO), they also exhibit antibacterial activity, which may be attributed to the generation of ROS (Azeredo 2013). Recent studies in the area of muscle foods include the study of antimicrobial activity of absorbent pads containing Ag nanoparticles by Fernandez et al. (2009); the antimicrobial effect against *E. coli* and *Staph. aureus* was confirmed during the modified atmosphere packaging preservation of poultry meat. In another kind of application, cellulose pads containing AgNPs generated from silver ions in situ have been shown to reduce the microbial levels of exudates from beef meat stored in modified atmosphere packaging (Fernandez et al. 2010).

Intelligent packaging

The premature deterioration of the product can occur if there is any deviation from the recommended storage conditions which may even cause harm to the consumer due to the presence of toxins or pathogens. Using nanobiosensors have been reported for the detection of pathogens in processing plants or alerting consumers, producers and distributors on the safety status of product (Cheng et al. 2006; Helmke and Minerick 2006). When integrated into packaging, nanosensors can detect specific indicators of pathogen metabolism or can alert or inform the consumer about a product's temperature, light or O₂ exposure (tampering) history (Cushen et al. 2012). Different devices have been developed to detect numerous toxins, pathogens and chemicals in food packaging such as nanowires and antibodies (Dingman 2008).

It also empowers the manufacturers to check the malhandling of product in the transit from the manufacturing unit to the consumers. Nanoparticles used as nanosensors are able to detect the presence of gasses, aromas, chemical contaminants or respond to changes in environmental conditions (Azeredo 2009; Duncan 2011). Nanosensors enable easy monitoring of the gases like oxygen in a headspace without destruction of package. One of these methods is photo activated indicator ink for in-package oxygen detection which is based upon nanosized TiO₂ or SnO₂ particles and a methylene

blue where the colour of the films varies according to O₂ exposure— it is bleached when there is no exposition and blue when film is exposed (Milan et al. 2013). Sensors may detect presence of some other gases such as gaseous amines, which are indicators of fish and meat spoilage, in very low concentrations (Mills and Hazafy 2009; Duncan 2011). Similar to gas sensors, the moisture sensors can denote the moisture level without destruction of the packaging of a product. This sensor allows quick and accurate determination of package moisture levels without invasive sampling; under the influence of humidity polymer-matrix of the packaging swells, which results in larger degrees of inter-nanoparticle separation and these changes cause sensor strips to reflect or absorb different colours of light which can be monitored (Duncan 2011). In another study, a xanthine amperometric sensor was developed based on calcium carbonate nanoparticles which can determine the freshness of fish samples (Shan et al. 2009).

Bionanocomposites

The use of nanocomposite with biopolymers is expected to rise because they offer possibility for carbon-neutral biodegradable materials for packaging and this will offer opportunities for developing countries to utilise their agricultural and forestry resources, by-products and wastes for development of biopolymer nanocomposites (Chaudhry and Castle 2011). The use of nanoclays into a poly lactic acid biopolymer increases barrier properties to oxygen and water vapor and extends the shelf life of food products (Lagaron et al. 2005).

Bionanocomposites use biodegradable materials and incorporate nanomaterial fillers to minimise the disadvantages of not using traditional packaging materials (Sorrentino et al. 2007). Not only do they protect the food which they surround and prolong its shelf life with the aid of nanofillers, but the use of nanocomposite reduces the use of plastics as packaging materials, require less fossil fuel in production and biodegradation, making them more environmental friendly (Sozer and Kokini 2009). Zein, a major component of corn protein, has been an important material in food industry owing to its unique properties and molecular structure. Nanotechnology approaches are expected to yield new applications for zein in specialty foods and in the biodegradable plastics industry. Zein can form a meshwork consisting of tubular structures, which can be microbiologically resistant and inert, for example, after treatment with formaldehyde (Lawton 2002). Controlling the uniformity and organization of zein films at the nanolevel are crucial in terms of mechanical and tensile properties. Starch and its derivatives are other important natural polymers that could be further improved through nanotechnology approaches. When hybrids of thermoplastic starch (TPS) with nanoclay were investigated, the resulting properties indicated that the strong interaction between the TPS and the nanoclay improved tensile strength and lowered water-

vapor permeability compared with native TPS matrix (Lopez-Rubio et al. 2006).

Biopolyesters are another group of biodegradable polymers formed from biological monomers, including polylactic acid (PLA), polyhydroxybutyrate (PHB) and polycaprolacton (PCL). Biopolyesters are biodegradable and biocompatible and can be formed into films or molded into objects (Tharanathan 2003). However, biopolyester applications in the food-packaging industry have some important limitations that are caused by their relatively poor gas-barrier properties and brittleness. Cabedo et al. (2006) showed that the addition of nanoclays, in this case kaolinite nanofillers, to PLA films improved both thermal stability and mechanical properties without decreasing barrier properties.

Nanotechnological based detection methods

Nanosensors are an important tool in the meat industry because these devices may be able to detect and quantify the most common health hazards present in the products; pathogens, toxins and chemical residues. These devices exhibit high sensitivity, fast response and a potential for integration in massive scale screening systems. Electrochemical detection is a popular method by which nanomaterial-based sensors with applications in the food industry function; compared to optical (colorimetric or fluorimetric) methods, electrochemical approaches may be more useful for food matrices because the problem of light scattering and absorption from the various food components can be avoided where electrochemical sensors operate by binding selective antibodies to a conductive nanomaterial (e.g., carbon nanotube) and then monitoring changes to the material's conductivity when the target analyte binds to the antibodies (Duncan 2011).

Often, a technique known as immunomagnetic separation (IMS) is used to isolate target organisms from food to avoid hindrances from food particles, prior to detection and nanoscale magnetic particles are especially useful in this regard due to their extremely high surface-to-volume ratios, which facilitate large analyte capture efficiencies (Duncan 2011). Using universal protein G-liposomal nanovesicles and an immunomagnetic bead sandwich assay can simultaneously detect *E.coli* O157:H7, *Salmonella* spp. and *Listeria monocytogenes* (Chen et al. 2006). A quartz crystal microbalance based biosensor has been reported using 50 nm gold nanoparticles as amplification probes for DNA detection (Zhao et al. 2001). A gold nano-particle coated quartz crystal microbalance based DNA sensor has been reported for the detection of *E. coli* O157:H7 synthesized oligonucleotides (Rashidi and Kashravi-Darani, 2011). The use of nanoparticles amplifies the signals and improves the detection limit for pathogenic bacteria detection (Mao et al. 2006).

Nanocantilevers are another innovative class of biosensors. Their detection principle is based on their ability to detect

biological-binding interactions, such as between antigen and antibody, enzyme and substrate or cofactor and receptor and ligand, through physical and/or electromechanical signaling (Hall 2002). They consist of tiny pieces of silicon-based materials that have the capability of recognizing proteins and detecting pathogenic bacteria and viruses (Kumar 2006). Pathogen detection here is based on their ability to vibrate at different frequencies which in turn depends on the biomass of the pathogen under scrutiny. Nanosensors using novel methods, such as amperometry and magnetic relaxation by gold nanoparticles, plasmonic shifts in iron oxide nanoparticles and changes in magnetic properties to detect pathogens, toxins, antigens and nucleic acids with a great sensitivity have also been described (Kaittanis et al. 2010; Duncan 2011).

Safety issues

As the technique is new and the materials used have unexplored perspective, hence there are many unanswered questions, regarding its safety and potential risk to human population as well as environment. Properties like solubility, bioavailability, biopersistence, aggregation, and adsorption are very important in determining their potential ill effects on the human health. There are a lot of factors that affect dissolution including concentration, surface area, surface energy, surface morphology, aggregation, dissolution layer properties, and adsorbing species (Doyle 2006; Borm et al. 2006). The consumer-safety implications from nanotechnology applications in food are intrinsically linked to the physicochemical nature of the nanoparticles, and the likelihood and extent of exposure through consumption of nanofoods (Chaudhry et al. 2008). As nanoparticles have high aspect ratio hence their behavior may change contrary to the conventional forms. The potential routes of human exposure to nanoparticles are dermal contact, inhalation and ingestion. In the food industry, the inhalation and the introduction by dermal contact and through skin penetration is almost exclusively related to workers in the nanomaterials handling units which is why use of protective equipment is required there (Silvestre et al. 2011). Cushen et al. (2012) found that the main exposure of concern in the food industry occurs via ingestion (nanofoods and nano-related Food Contact Materials). Chaudhry et al. (2008) described that as nano-sized food ingredients and additives are likely to have a greater ability to cross the gut wall, their enhanced absorption and bioavailability would give rise to higher internal exposure, with higher plasma concentrations (from higher absorption rate). It is unclear to what extent the biochemical pathways which facilitate processing of silver ions apply to silver nanoparticles (AgNPs), to what extent AgNPs pass through the intestinal lining intact or are dissolved into silver ions in the highly acidic environment of the stomach, and to what extent AgNPs can pass through

natural biological barriers such as the blood–brain barrier, the placenta or into breast milk (Duncan 2011). Depending on the nature of nanoparticles, Chaudhry and Castle (2011) have classified them as follows:

- a. Areas of least concern: where food products contain processed (natural) food nano-structures, which are either digested or solubilised in the gastrointestinal (GI) tract, and are not biopersistent.
- b. Areas of some concern: where food products contain encapsulated food additives in nano-sized carriers which may not be biopersistent but may carry the encapsulated substances across the GI tract. A greater uptake of food colours or preservatives could take the application outside of the conditions under which the ADI (acceptable daily intake value) was set for the additive.
- c. Areas of major concern: where food products contain insoluble, indigestible, and potentially biopersistent nano-additives (e.g. metals or metal oxides), or functionalized nanomaterials.
- d. ADME profile (adsorption, distribution, metabolism and elimination) and toxicological properties of which are not fully known at present. Some of the projected applications in the agricultural sector (e.g. nanopesticides) will also fall in this category.

By the addition of nanostructured materials to food, water, and drugs, nanoparticles can be absorbed from the intestine and enter the circulatory system but there is not much research focused on this potential route of entry (Maynard 2006). In an *in vitro* study on human epithelial cell cultures using fluorescence-labelled SiO₂ nanoparticles, Chen and von Mikecz (2005) have shown that particles smaller than 70 nm could enter cell nuclei where the study also revealed the protein accumulation in the nuclei and indication for impairment of DNA replication and transcription. In another research it has been showed that AgNPs are not toxic under strict anaerobic conditions, and that Ag ions are only released from AgNPs under aerobic conditions demonstrating that the antimicrobial activity of AgNPs is not particle-specific but due only to the release of Ag ions (Xiu et al. 2012).

Ingestion of foods previously in contact with nanopackaging presents an exposure route due to weakness in packaging performance and subsequent transfer of particulate nanomaterials from the packaging into the food (Cushen et al. 2012). Hence a more pressing concern, however, may be food contact materials in which the nanoparticles are located on the material surface, such that they come into direct contact with the food matrix, where Fernandez et al. (2010) in a study on packaging borne nanoparticle, AgNPs being incorporated into cellulose pads for use in modified atmosphere packaging of fresh beef, found that detectable levels of silver ions leached into the meat exudates (though not into the meat itself). The

few experimental and modelling studies reported so far (Avella et al. 2005; EFSA 2008) suggest that the likelihood of nanoparticle migration from polymer packaging to be either nil or very low. Moreover a model put forward by Simon et al. (2008), predicts migration and quantifies nanoparticles migrating from nanopackaging, requires information about the packaging matrix and about the nanoparticles themselves; rate of migration of a system increases with decreasing polymer dynamic viscosity and nanoparticle size.

Animal feeds, medicines or vaccines if used in the farm practices, toxicological information on any possible accumulation of drug/feed nanocomponents in food animals must be established and metabolism of such materials and clearance times would need to be determined to ensure safe levels at time of slaughter (Cushen et al. 2012). Nanoparticles can have unpredictable impact not only on humans and animals but on the environment, as well (Azeredo 2013). During waste disposal of AgNPs, Ag ions could be released and may accumulate in the environment, where they would continue to kill micro-organisms resulting in disturbed balance in natural microflora, especially in aquatic system. In this context Maynard (2010) put forward a view that an integrated system of research is required to fully understand the implications of nanotechnologies on human health, to pre-empt adverse health effects and to proactively minimize them where the ideal research team includes risk assessors, toxicologists and food technologists among others.

Future aspects of nanotechnology in meat food

Nanotechnology is going to impact each and every aspect of the food sector. The first and the foremost opportunity it is going to offer is in the production system. With the development of more efficient delivery system by incorporating nanocarriers, it is going to be an age of least use of chemicals like antibiotics and other veterinary drugs and consequently less carryover over of these residues in the meat produced. Food borne organisms will no longer be a threat in meat industry with better detection system (nanosensors) having improved efficiency in terms of limit and time of detection. The application of nonmaterial in biosensors provided opportunities to generate a new aspect of biosensor technologies having importance in food analysis (Rai et al. 2012). The concept of nanotechnology has not touched the different aspects of food industry and it needs to be explored at all facets of the industry. Nanotechnology with advanced nanosensors as tool has great scope in residue detection system. In the bulk handling of products like meat, timely detection of contaminants becomes a crucial issue. Moreover a safer and hygienic product will lead to the confidence build up of the industry as well as consumer. The nanotechnology based newer and more advanced techniques of the packaging will help in better

communication between producer and consumer in addition to addressing the safety and shelf life issues. The packaging innovations are bound to travel a long distance, as the nanomaterials are going to produce more stronger and lighter materials in future, with additional features which we have not even thought of today. Security inks and nanobarcodes will become a common practice to protect against counterfeiting or preserve the product identity (Duncan 2011). Hence the nano-based smart labels will in fact become a trade mark for the authenticity, traceability and safety of products (Chaudhry and Castle 2011).

Conclusions

Nanotechnology has a potential to offer benefits to the meat industry in the complete chain from the improvement of taste, odour and texture to the production of low fat and salt products and enhancing the bioavailability of nutrients and supplements, protection of products with the use of advance packaging materials and ensuring the safety of products employing biosensor. Functionalized preparations with nanoparticles as flavor and nutrient carriers ensure a high quality products. Nanotechnology in product packaging is currently the most promising future in the industry and the next important avenue is the microbial as well as sensory quality of products. Manufacturers have the benefit to go on a long stride in safety of products by taking the harness of this new technique. Integration of nanotechnology with other related sciences like biotechnology is leading to innovations that are going to produce a major impact on the production, processing, storage, transportation, traceability and safety of meat products. A large number of industries as well as institutional research is now days focused for the better utilization of this recent technique in the food industry. In addition to the scientific and technical input needed for the growth of nanotechnology based industries, a great deal of research is needed to fulfill the knowledge gap to address important issues like properties of nanoparticles and their behavior and toxic effects on the human life as well as environment. Some of the applications of nanotechnology cited in the literature are still in infancy or at the research level only. Hence a great deal of research work and regulatory norms are required to address the consumer safety issues and establish a positive public perception for the nanotechnology based products. Uncertainties and lack of knowledge in the application of the technique to the industry will attract considerable public concern. Existing uncertainties for risk assessment of nanomaterials arise due to limited information on several aspects including toxicity, behavior and bioaccumulation.

In order to utilize nanotechnology to the full potential, its acceptance by the consumer is a vital issue. Consumer needed to know the advantages of this new technique over the

conventional methods in use. For a technology to be acceptable it should outweigh the risks associated with it, where risks should be in permissible limit.

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