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NANOTECHNOLOGY CONSIDERATIONS FOR POULTRY AND LIVESTOCK PRODUCTION SYSTEMS – A REVIEW

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Abstract

The global animal productivity should proportionally increase to meet the food needs of a growing population. This article presents an overview of the current and promising nano-applications in poultry and livestock production systems that could offer opportunities for improved efficiencies and productivity. Some basic information on nanotechnology and the economics of nanotechnology is provided. Poultry and animal production systems, current situation and available tools and techniques are presented in parallel with animal health care, animal nutrition, animal shelter and food processing nano-applications and their advantages. These applications are directly or indirectly related to the human food chain and may affect the food safety and food quality. Lastly, the expected risks and hazards related to nano-application in poultry and livestock production systems that can affect animal, human and environment are described. It is concluded that nano-applications have the potential to provide smarter solutions for various applications in the poultry and livestock production systems, which can help in reducing costs and enhancing the final product quality. However, concerns over safety of some nano-applications hamper their immediate implementation. Extensive risk assessments should be conducted to ensure the safety of the nano-products before making them available for animal or human use.

Key words: nano-application, animal feed, health applications, food processing, housing, environmental hazard

Nano-materials with at least one dimension in the 1–100 nm range (National Nanotechnology Initiative, 2011) may have different physical and chemical characteristics compared to the bulk material (Scott, 2005; Duncan, 2011; The Scientific Committees, 2013; Hartemann et al., 2015). Because of the novel properties of nano-particles, vast socio-economic and environmental benefits have been envisioned for nanotechnology (National Nanotechnology Initiative, 2011). However, concerns have been raised about the safety and the regulation of nano-materials due to uncertainty regarding their adverse effects to the consumer and the environment. Nonetheless, research in nano-enabled technologies increased over the past decade, and numerous companies specialized in the fabrication of new forms of nano-sized materials developed applications for medical therapeutics and diagnostics (Duncan, 2011). Developments in these fields can be transferred to the poultry and livestock production systems with the goal of increasing animal welfare, enhancing production systems efficacy and meeting the need of the humans for high quality poultry and animal products. In this article, some current applications, opportunities and risks of using nanotechnology in the poultry and livestock production systems are discussed. This may help the researchers and producers in the fields of poultry and animal production to take safer decisions about using nanotechnologies as well as increase the awareness of public community toward nano-enabled applications in the field of poultry and livestock production systems.

Nanotechnology basics

Materials, structures, devices and systems of controlled shape, size and morphology at the nanometer scale have been developed purposely for medical, food, and military applications. Nano-particles can be divided into three categories as a function of their size; big particles if their diameter is greater than 500 nm, medium size ranged from 100 nm to 500 nm, and ultrafine particles if their diameter is less than 100 nm, based on a document developed by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR, 2010). The material is considered a nano-material and nano-specific risk assessment has to be performed according to the Committee for nanoparticles with sizes smaller than 100 nm. A volume specific surface area (VSSA) above the threshold e.g. >60 m^2/cm^3 may be used as an additional qualifier to indicate a size below 100 nm. The most important properties of a nano-material to characterize, from a risk assessment European Commission Public Health viewpoint, are: the size, size distribution, surface area, stability in relevant media, surface adsorption properties and water solubility (SCENIHR, 2010; SCENIHR, 2016).

Nanotechnology from a socio-economic perspective

Research and development in the area of new nano-materials has been given high priority in the US, the EU, China, Sweden, Germany and Denmark (Zhao et al., 2008; de Wit, 2009; Kastenhofer, 2011). Zhao et al. (2008) and de Wit (2009) stated that nano-materials are an area of research that is having an enormous socio-economic potential for developing new medicines, electronics, pesticide and fertilizers and mitigation of environmental problems.

Roco et al. (2010) reported that in 2008, over 400,000 studies and more than \$15 billion were spent worldwide in research and development of nanotechnologies. For example, more than 30 research organizations in China have been founded for studying the toxicological and environmental effects of nanomaterials (Zhao et al., 2008). In terms of nanotechnology developments around the world, food related industries are considered as an active area in nanotechnology research and development (Roco et al., 2010). In this sector, the global nano-enabled food and beverage packaging market was around US$ 4 million in 2006 and increased to be about US$ 4.13 billion in 2008. It is expected that nano-products will reach at least $3 trillion of global economy and at least 6 million workers will be employed in the nanotechnology enabled industries by 2020 (Innovative Research and Products Inc., 2009).

According to the Helmut Kaiser Consultancy report about nanotechnology in the food industry (2010), USA, Japan, and China led the nano-food area, whereas Asian countries could be the biggest future market for nano-food products. The EU confirmed its full active support of nano-sciences and nanotechnologies because nanotechnology has promised to boost quality of life and industrial competitiveness in Europe. The EU plays important roles in support of nanotechnologies, as a policy maker and as a funding source for research and development (Sauer, 2009).

A number of R&D departments, between 200 and 400 of companies, were reported as actively working on food related applications in 2006 (Institute of Food Science and Technology Trust Fund, 2006). According to de Wit (2009) and FAO/WHO the availability of nanoproducts on the market increased from 600 to 800, but only around 10 percent of these are foods, beverages and food packaging products (FAO/WHO meeting report, 2010).

Due to the current socio-economic lifestyle and consumer demands for healthy and high-quality food as well as the need for availability of food at reasonable prices, producers have to be more consistent with regards to the quality of the food, by possibly using advanced nano-techniques, which will eventually lead to an increase in their revenues. Despite the enthusiasm surrounding the potential use of nanotechnology and the abundance of funds for improving its applications, the food industry has been slow to adapt to the new developments provided by nanotechnology. This is not surprising, as consumers' preferences for natural food products has slowed the growing of food technologies, and nanotechnology is not an exception. Public belief in nano-applications has ranged from neutral to slightly positive (Satterfield et al., 2009), which is encouraging. Consumers are more likely to embrace non-food nano-applications than direct addition of nano-particles to foods (Siegrist et al., 2007; Department of Innovation, Industry, Science and Research, 2011).

Still, poultry and livestock production systems can provide society with highly nutritious essential constituents such as proteins from meat, egg, milk and their processed products by using a nano-enabled technology, as described in the following sections.

Nanotechnologies in poultry and livestock production systems

Human population will grow to an estimated 8 billion people by 2025 and 9 billion by 2050, and it is well recognized that global agricultural productivity must increase to feed the growing world population (Sekhon, 2014). The following are some nano-applications that could give poultry and livestock production opportunities to continue to grow.

Animal health care applications

Diagnosis of diseases

Animal diseases are divided into groups based on the causative agents. Some causative agents of infectious diseases are common to humans and animals and others are pathogenic only for non-human animals or to specific species. Infectious diseases arise in the form of individual cases or assume a widespread distribution.

In general, the traditional approaches to detect the presence of pathogens have several limitations: 1) working with samples directly, 2) time consuming 3) some microorganisms cannot grow easily, and 4) significant limitations in the identification of viruses due to their small size (Kaittanis et al., 2010; Mungroo and Neethirajan, 2014). In spite of high sensitivity and accuracy in detection of pathogen of the advanced techniques e.g. PCR and ELISA, these procedures have limitations of needing undamaged microbial DNA, being affected by the clinical sample nature and requiring experience and expensive facilities (Kaittanis et al., 2010).

Nanotechnology presents great opportunities to develop fast, accurate and cost-effective tools for pathogen detection. In 2006, avian influenza viral diseases (H5N1) led to a global epidemic, increased mortality rate and economic losses (El Sabry et al., 2012). Unique properties of nano-materials could allow advanced devices that are able to detect pathogenic agents and predict the outbreaks such as those due to avian influenza virus. For example, Emami et al. (2012) tried to enhance the ability of Western blot technique to detect small molecules of proteins or peptides. They used nanotechnology to develop a sensitive and accurate technique for detecting avian flu antibodies in poultry serum by coating the immobilin-polyvinylidene difluoride membrane with gold nanoparticles. They found that the presence of the gold nanoparticles prevented diffusion of the peptides from the membrane after applying the voltage, which enhanced the accuracy of the test.

Also, researchers from Guelph University in Canada announced the creation of a portable nano-detector for avian flu (H1N1 and H5N1) outbreaks in the farms that uses gold nanoparticles and glowing quantum dots. The advantages of this new device are less volume of blood, less chemicals, shorter time, cheaper and more accuracy compared to the current laboratory methods. Also, with some modifications, this bio-sensing technique has the potential to detect other avian influenza strains (Researchers Guelph University, 2015).

Bovine tuberculosis is a chronic bacterial disease of cattle that occasionally affects other mammal species. It causes severe economic losses due to livestock deaths, low productivity and trade restrictions. This disease can be spread to humans through air or unpasteurized milk. In developed countries, control of this disease in domestic livestock and humans has succeeded through different approaches such as milk pasteurization and intensive eradication programs (De La Rua-Domenech, 2006; LoBue et al., 2010). However, there is still a challenge to completely eradicate diseases because of the unauthorized movement of infected animals and uncontrolled herds, and the presence of wildlife reservoirs of the disease (Humblet et al., 2009).

In 2012, Peled et al. reported a new methodology in detecting *Mycobacterium bovis* infection in cattle based on identifying unique volatile organic compound profiles in the breath of cattle. A custom-made nanotechnology-based array of sensors were inserted into a nano artificial nose (NA-NOSE) to detect the volatile organic compound patterns linked with the disease conditions. "NA-NOSE is an artificial olfactory system based on an array of cross-reactive, nanomaterials-based, chemical gas sensors which can identify and separate gaseous mixtures, even if their constituent analytes are present at very low concentrations and their differences are very subtle" (Peled et al., 2012). Their results showed that NA-NOSE successfully detected *Mycobacterium bovis*-infected cattle via breath analysis.

In the category of pathogen detection, an example of a nanosensor is that developed by Illuminaria, an engineering consulting company that specializes in nanofabrication and optomechanical design. The Illuminaria team with their collaborators at Cornell University developed a nano DETECT system for the rapid and on-site detection. This system is based on nanotechnology and uses the polymerase chain reaction (PCR) in a microchip format to detect *L. monocytogenes*, *S. typhimuruim* and *B. anthracis* cells in an hour. The company is targeting the food industry as a marketing niche for this system (Illuminaria, 2016).

These recently developed nano-detectors represent opportunities for faster, cheaper, portable and easier to use tools as screening techniques for different pathogens in poultry and animal stocks. This will allow prevention of the spread of diseases, which is vital for disease control worldwide.

Veterinary medicines and vaccines

Nano-medicine is defined as the application of nanotechnology in making a medical diagnosis or the treatment or prevention of diseases (The Scientific Committees, 2013). Nano-medicine consists of 'smart drug' delivery systems used in animals to deliver the drug to the target tissue while providing a drug-release profile that would insure that the drug is delivered as needed (Scott, 2005). Drug substances entrapped by biodegradable nano-particles can be protected against degradation by gastrointestinal fluids and for improved absorption of the drug across the intestinal mucosa (Des Rieux et al., 2006; Cai et al., 2010; Simon et al., 2016). Also, more uniform drug absorption and lower risks of local irritation could be achieved through formulations based on polymeric nano-particles administered by oral delivery (Galindo-Rodriguez et al., 2005; Feng et al., 2009).

Pathogens are considered one of the important challenges in animal production sector because they can be transferred easily from infected individuals to healthy ones (El Sabry et al., 2012). The ordinary treatments for controlling diseases include the combined use of vaccines and/or antibiotics. However, the disadvantages of live vaccines include the instability and the risk of reverting the pathogenic strain back to their virulent form (Lowenthal et al., 2005; Peek et al., 2008). Moreover, use of antibiotics and chemicals has resulted in the emergence of resistant strains of pathogens, as well as the potential for increasing environmental contamination and residual content in meat or eggs. Furthermore, a consideration in the food chain is the risk of transferring antibiotic resistance from animal production to humans, which represents a public health challenge (Hilton et al., 2002; Cummings, 2006).

Nano-particles showed a potential to provide novel alternatives for development of a new generation of drugs, including vaccines. They work as delivery carriers for vaccines and new adjuvants to enhance the immune response because in many cases the antigen itself is very weakly immunogenic (Zhao et al., 2014). Recent investigations have revealed higher efficiency of nano-vaccines and nano-antibiotics. Biodegradable nano-particles in vaccine formulations showed advantages such as improved antigen stability and immunogenicity, targeted delivery and slow release (Sekhon, 2014). Therefore, it is concluded that nano-medicines could be very beneficial in disease prevention and treatment for animals.

Also, the routes of vaccine administration have been developed from intravenous and muscular injection to oral, nasal and transdermal nano delivery systems. Although some vaccines are successfully commercialized products through an oral route delivery system, such as Polio vaccine, the progress in commercialization of nano-medicine still faces technical challenges related to the mechanism of cellular entry and toxicity for various nano-materials (Jain et al., 2014). For example, in humans, despite the lack of knowledge on the mode of action of nano-aluminum salt adjuvants, vaccines containing aluminum salts have been shown to produce higher and longer lasting antibody titers after a single immunization (Simon and Edelman, 2006; Peek et al., 2008).

In a FDA report, unfortunately, it was mentioned that manufacturers usually do not have to submit a food additive petition if their food additive is generally recognized as safe (GRAS). However, FDA is not aware of any nano-animal food ingredient for which there is generally available safety data sufficient to serve as the foundation for determining that the use of such an animal food ingredient is GRAS (FDA report, 2016). Even though there are biological and technical challenges that face the nano-medicines, the nano-particles could be very helpful in delivering medicines efficiently by all different routes and in increasing the efficacy of vaccines especially during bird and animal epidemics such as avian flu.

Animal feeding nano-applications

Nutrition represents a major portion (≈60–65%) of poultry and animal production systems inputs. Nano-feed additives could help in improving the feed efficiency, reducing feed cost, and increasing the yield and quality of animal products. Concerning the quality and safety of feedstuffs, nano-biosensors could be used for detection of the presence of toxin-producing insects or fungi inside bulk grain storage silos. Also, nano-particles engineered to protect fats in ruminant diets to minimize fermentation disruption in the rumen and to protect essential amino acids and make them more available for the host animal might be advantageous in the future. In the present time, there are many successful and promising examples about the use of different nano-materials in poultry and livestock feeding (Table 1).

It is expected that in intensive production of poultry or ruminants, nano-feed additives and novel detoxifying nano-materials could provide added value in feeding practices because of their positive effect on stimulating productivity and livability. In addition, *in ovo* feeding may be considered as a future safe nano-application for poultry industry.

Table 1. Potential use of nano-materials in poultry and livestock feeding

Nano-material	Use	Animal	Action	Reference
Selenium	Feed additive	Sheep	Decreasing ammonia concentration Increasing total volatile fatty acids concentration Enhancing the digestibility Stimulating rumen microbial activity, digestive microorganisms or enzyme activity	Shi et al., 2011; Xun et al., 2012
		Chicken	Increasing productive and reproductive performance Enhancing immune response	Cai et al., 2013
		Goat	Enhancing semen quality	Shi et al., 2010
Zinc		Ruminants Chicken Pig	Encouraging growth and improving feed conversion ratio Enhancing the immune response	Swain et al., 2015
Chromium		Pig	Anti-diarrheal	
			Improving carcass characteristics. Enhancing antibody production	Wang and Xu, 2004; Wang et al., 2007
Montmorillonite – composite		Chicken	Reducing aflatoxin toxicity	Shi et al., 2006
Nano-Polystyrene with polyethylene glycol linkers and mannose targeting biomolecules		All animals	Binding and removing food-borne pathogens in animal feed	Sekhon, 2014
Bio complex of glutamine and nano-diamond	In ovo feeding	Chicken	Enhancing the differentiation and proliferation of pectoral muscle at the end of the embryonic life	Grodzik et al., 2013
Copper			Stimulating the metabolic rate in broilers during embryonic development Strengthening immunological biocompatibility	Scott et al., 2016

Poultry and animal shelter nano-applications

Different studies showed that nano-materials have a specific characteristic that may enable them to be used in farm constructions and equipment manufacture. For instance, Jelle (2011) and Pacheco-Torgal et al. (2016) suggested nano-materials to be used as efficient thermal insulation materials. In the future, this could be beneficial for intensive poultry and animal production in tropical and sub-tropical areas. Another promising application is paints that contain a nano-photocatalyst e.g. TiO2. These photocatalyst materials are capable of oxidizing organic and inorganic substances and micro-organisms under the influence of light (Chen and Poon, 2009; Pacheco-Torgal and Labrincha, 2013). The decontamination function may be a future application for providing a solution to achieve a micro-organism free environment, which meets the high standard hygiene needs in hatchery.

Food processing nano-applications

Processing is an essential part of both poultry and livestock production systems because processing adds value to the product and various products are created to meet consumer demands. In the food processing industries, most common uses of nanotechnology involve nano-enabled water treatment technologies, novel antimicrobial surfaces and quality monitoring of food products in the form of nano-sensors.

Water is considered the foremost nutrient for all animal species as well as a significant commodity in food processing. Water purification using nano-filtration is relatively recent. A filtration membrane was developed to remove solids, bacteria and parasites from surface and fresh groundwater (Sekhon, 2014). This application could be very useful in providing a high-quality water and recycling water wastes of processing plants, especially in areas with limited water resources.

Nano-sensors can accurately detect the presence of antibiotic residues in meats (Sekhon, 2014; Mungroo and Neethirajan, 2014). This application is very important for protecting live birds and animals on the farms as well as production lines from contamination from residues during the different phases of processing that help to ensure the safety and quality of the products for consumers.

Currently, engineered nano-materials have been introduced to food packaging including nano-silver, nano-zinc oxide and nano-titanium dioxide because of their functional properties such as lighter weight with stronger packaging barriers (Bumbudsanpharoke and Ko, 2015). Antimicrobial materials are playing a key role in preserving meats or poultry from pathogens by providing safe products and increasing shelf life. Several researchers suggested that nano-sized materials could result in new horizons in the fields of food preservation and packaging (Cruz-Romero et al., 2013; Bumbudsanpharoke and Ko, 2015). Cruz-Romero et al. (2013) showed that low- and medium-molecular weight chitosan had higher antimicrobial activity than normal chitosan on *E. coli*: (NCIMB 11943), *Staphylococcus aureus*: (NCIMB 13062), *Bacillus cereus*: (NCIMB 9373) and *P. fluorescens*: (NCIMB 9046) isolated from raw chicken fillets. They suggested that nano-sized materials could result in novel applications in the fields of food preservation and packaging.

Nano-medicinal risks

Scientific uncertainty about the harmful properties of nano-particles complicates and hampers the implementation of regulative measures by legislators. The European Commission has adopted an "incremental approach", which focuses on adapting existing laws to regulate nanotechnologies. Chaudhry and Castle (2011) stated that humans can be at risk due to nano-particles exposure. The literature indicates that orally delivered nano-particles have the ability to be absorbed through the intestine and translocated to different organs in the body (Navarro et al., 2014; Navarro et al., 2016). In spite of significant efforts by research groups and many companies to elucidate toxicity questions surrounding nano-particles, there are no confirmations about the safety of the products to become available on the market across the board.

The special physiochemical properties of nano-medicines raise several critical considerations: 1) nano-particles reverting live vaccines back to their virulent form and/ or making vaccines unstable; 2) potential transfer of antibiotic resistance to humans or animals via the food or feed supplies; 3) disposal procedures of the residual of nano-vaccine, bactericidal packages, vials and dead animals; 4) potential immune or other toxicity in consumers.

High doses of nano-particles could affect the organs and tissue of the animal; the effect is a function of nano-particle composition. For example, Loghman et al. (2012) showed harmful effects of high doses of nano-silver on the liver cells in broilers. However, it is not well known which portion of toxicity is due to the nano-form and what is resulting from the ionic form. So, nano-silver might be used as an antimicrobial agent or disinfectant in the poultry industry only with caution and under specific conditions to avoid toxic effects in animals. Moreover, toxicity studies on the long-term exposure to some nano-particles showed several effects on the immune system and that the nano-particles could be distributed in animal and human organs e.g. liver and spleen (Gatti and Montanari, 2008; Nel et al., 2009; Hartemann et al., 2015).

For improved safety and enhancing the use of nano-particles, biodegradable nano-particles should be designed and more effort dedicated to determining their intracellular fate and biological interaction and function in order to provide safe nano-particle drug delivery systems for use in animal systems (Nel et al., 2009).

Nano-hazards to animal-human food chain

Scientists, stakeholders and manufacturers have already identified potential uses of nanotechnology in every segment of the food chain, particularly in food processing. For instance, The Organization for Economic Co-operation and Development (OECD) reported that notifications for food nano-applications had been received by the Food Packaging Materials and Incidental Additives Section of Health Canada (OECD, 2010). On the other hand, there may be potential risks to consumers due to consumption of animal products nano-materials in their food (Chaudhry and Castle, 2011; Hartemann et al., 2015). From a physiological perspective, new properties of nano-particles may enable them to reach those parts of the body which are protected from entry of any exogenous materials (Chaudhry and Castle, 2011). Liu et al. (2010) found a relationship between the size of nano-particles and its effect on the human cell. They reported that smaller silver nano-particles (5 and 20 nm) have a deleterious effect on the human cell morphology and its membrane integrity. Moreover, ultrastructural observations confirmed the presence of silver nano-particles in the cells. Wijnhoven et al. (2009) mentioned that when nano-silver particles pass the physiological barriers and reach the systemic circulation, the particles can interact with plasma proteins and other blood components such as red and white blood cells. Moreover, they may be distributed into organs such as liver, kidney, heart, brain, lung and testicles via the systemic circulation. Poly lactic-co-glycolic acid (PLGA) nano-particles have the ability to translocate from the intestine, especially to liver, kidney and spleen (Navarro et al., 2014) with minimum toxic effects in these organs, as determined by histological evaluations of this tissue (Navarro et al., 2016).

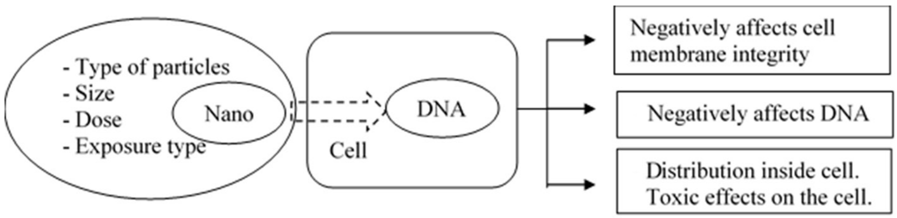

Figure 1. Summarizing the expected negative effects of nano-particles on the animal cell

Chaudhry and Castle (2011) categorized the concerns for nano-materials in feed and food products: The 1st area, of least concern, is for food nano-structures which are either digested or are not bio-persistent. The 2nd area, of some concern, is for products that contain encapsulated food/feed additives in nano-carriers, which may not be bio-persistent, but may carry the encapsulated substances across the gastrointestinal tract. The 3rd area, of major concern, is for food products that contain insoluble, indigestible, and potentially bio-persistent nano-particles. Therefore, the conventional tests are not enough to assess the solubility of silver-nanoparticles to reflect silver ion availability (Chaudhry and Castle, 2011; Huang et al., 2015; Hartemann et al., 2015).

There is a lack of information in the understanding of the properties, behavior and effects of nano-materials that may be used in food applications. Moreover, the tools and methodologies to assess the risk of using nano-particles are big challenges faced by the scientific community in this field. A careful consideration of the nature of nano-materials and nano-applications could provide a basis for a risk categorization on a case-by-case basis.

Environment related nano-hazards

Nano-materials will pass into the environment because of intentional or accidental releases such as emissions and solid or liquid waste from production facilities (Ray et al., 2009). These nano-materials have new hazard properties compared to their constituent parts because toxicity has been reported in multiple nano-particles due to size and dose, e.g. the cytotoxic effect of TiO_2 has been found to relay on crystalline structure, size of particles and purity (Hansen, 2009). The particle's size, shape and coating will influence particle's bio-distribution in an organism or an ecosystem (Ray et al., 2009; Huang et al., 2015).

The most important problem is insufficient information to prove that nano-materials are safe or hazardous. There is some evidence that some nano-materials are hazardous depending on their particle characteristics. Hansen (2009) and Ray et al. (2009) mentioned a number of examples about the environmental hazards of nanometals such as gold, silver, titanium dioxide, zinc, and iron oxide on human, rats, mice, zebrafish, juvenile largemouth and different strains of bacteria.

Therefore, nano-particles need different categories of investigation before certifying them for safe use. These investigations should comprehensively describe the hazards, find out potential concentrations, the effect threshold(s) and understand fate and behavior of nanomaterials case-by-case. It is important to note that in a limited number of previous studies, nano-particles showed a low eco-toxicity, but the majority of the studies demonstrated some degree of adverse effects on tested animals or cells.

Promising solution for nano-hazards

Biosynthesis of metal nanoparticle method is utilizing different biological natural substances such as leaf extract, fungi, algae and bacteria for the reduction and stabilization of nanoparticles (Allafchian et al., 2016; Li and Zhang, 2016). Biosynthesized nanomaterials showed superior characteristics compared to those of conventional physical and chemical methods, e.g. silver and gold (Allafchian et al., 2016; Li and Zhang, 2016). The advantages of the metal nanoparticle biosynthesis and conventional synthesis methods are included in Table 2.

Table 2. The main differences between biosynthesis and conventional methods of nanoparticles production

	Bio synthesis	Physical and chemical	Reference
Base	Utilize natural substances such as bacteria, fungi, plants (whole, tissues or extracts), marine algae and micro-fluids	Reduction of solutions, photochemical reactions, electrochemical reduction, heat evaporation and radiation assisted methods	Otari et al., 2012 Muthoosamy et al., 2015 Li and Zhang, 2016
Procedure	Could be produced in one step	Multi steps are needed	Otari et al., 2012
Production time	Rapid	Takes more time	Prakash et al., 2013
Cost	Less expensive	Expensive	Allafchian et al., 2016
Stability of products	High	Less	Muthoosamy et al., 2015
Biomedical application	More efficient More biocompatible	Efficient Biocompatibility concerns	Prakash et al., 2013 Muthoosamy et al., 2015
Eco-risk	Eco-friendly	A kind of risk may be found because of toxic and hazardous chemicals	Prakash et al., 2013 Allafchian et al., 2016

Soon, it seems that biosynthesis of nanoparticles method will be one of the foremost milestones in the nano-science, because of its potential to provide safer and more efficient metal nano-particles.

Conclusion

In poultry and animal production systems, nano-particle research and potential applications are increasing in scale and broadening in scope. Available data substantiates that different applications of nano-particles increased productivity, livability, and biological activities of the animal. Also, quality, processing, packaging and commercialization of poultry and animal products could be improved by using different nano-materials. On the other hand, the limited data on safety of the nano-materials to both animals and the environment is of concern to scientists, governments, non-governmental organizations, members of the public and stakeholders. Therefore, components of poultry and animal production chains such as: veterinary medicine, animal feed additives and packaging materials that include nano-particles should go through risk assessment and toxicology tests before commercial-scale use. This kind of assessment is important to ensure the efficiency and safety of the application of nano-enabled technology to poultry and animal production systems.

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Declaration of interest

To the best of our knowledge no conflict of interest exists.

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