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REVISÃO

Advances and concerns about nanotechnology in foods for humans and animals - a review

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PALAVRAS CHAVE ADICIONAIS

Alimento.
Nanocápsulas.
Nanodispersões.
Nutrição.
Riscos potenciais.

SUMMARY

Nanotechnology in food is relatively new compared to biomedical area and information technology industries. In this way, this science has aroused great interest in recent years mainly in developed countries, where industry has benefited from its use. Major uses include nanodispersions, nanocapsules, nanolaminates, nanofibers and nanotubes for food packaging, as well as nutritional utilization. In the animal area, the use of nanotechnology is present in vaccines, nutrition, genetics and medicines. However, potential risks must be considered, in addition to the need for specific legislation. Research on food nanotechnology is in progress, with nanoparticle-derived food products expected to be increasingly available to consumers and producers worldwide in the coming years. The present review aims to present the use of nanotechnology in the food industry, emphasizing the use of various nanomaterials for food packaging, as well as its nutritional application in animal diets, potential risks and existing legislation.

Avanços e preocupações sobre a nanotecnologia em alimentos para humanos e animais – uma revisão

RESUMO

A nanotecnologia em alimentos é relativamente nova em comparação com a área biomédica e as indústrias de tecnologia da informação. Desta forma, esta ciência tem despertado grande interesse nos últimos anos, principalmente nos países desenvolvidos, onde a indústria se beneficiou de seu uso. Os principais usos incluem nanodispersões, nanocápsulas, nanolaminatos, nanofibras e nanotubos para embalagens de alimentos, bem como a utilização nutricional. Já na área animal, o uso da nanotecnologia está presente em vacinas, nutrição, genética e medicamentos. No entanto, riscos potenciais devem ser considerados, além da necessidade de legislação específica. Pesquisas sobre nanotecnologia alimentar estão em andamento, com produtos alimentícios derivados de nanopartículas que devem estar cada vez mais disponíveis para consumidores e produtores em todo o mundo nos próximos anos. Esta revisão tem como objetivo apresentar o uso da nanotecnologia na indústria de alimentos, enfatizando o uso de vários nanomateriais para embalagens de alimentos, bem como sua aplicação nutricional em dietas animais, riscos potenciais e legislação vigente.

ADDITIONAL KEYWORDS

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INTRODUCTION

Nanotechnology is the study of the development of systems or structures in a nanometer scale. This technology uses particles of very small materials, measured in millionths of a millimeter. One nanometer equals one billionth of a meter, or 10^{-9}. Typical nanotechnology uses structures below 100 nanometers in size, more than 1000 times narrower than the diameter of a human hair (Pankaj, 2016). With this size, the particles acquire special properties and are being actively investigated how to apply them in different fields of science (Alves, 2010).

In the area of nutrition, nanotechnology has great potential, aiding in the discovery, development and intervention strategies to improve health and reduce the risk of numerous diseases. To do this, the study of materials used in food, such as coatings and/or packaging, is necessary because of its likely capacity in the food industry, such as improving product safety and quality, by changing the way food is produced, processed, packaged, transported and consumed (Miller & Senjen, 2008; Ross et al. 2004, p. 684).

There are two techniques to produce nanostructures, with varying levels of quality, speed and costs. They are known as Bottom-up and Top-down. The Bottom-up technique provides the construction of structures atom by atom or molecule by molecule, by means of three alternatives: the first one consists of the chemical synthesis, generally used to produce raw materials, in which molecules or nanoparticles are used; the second is self-organization, a technique in which atoms or molecules organize themselves autonomously by means of physical or chemical interactions, thus constructing ordered nanostructures; and, finally, the determined organization, in which atoms and molecules are intentionally manipulated and arranged in a certain order, one at a time (Scott 2007, p. 140). In turn, the Top-down technique aims to reproduce something, but on a smaller scale than the original and with greater information processing capacity, for example, on a chip (Martins 2008, p. 11).

Food packaging materials correspond to the largest category of uses of nanotechnology in the food sector. Because the surface-volume ratios are very large, a relatively low level of nanoparticles is sufficient to modify the properties of the packaging materials without significant changes in transparency, density and processing characteristics (Lei et al. 2006; Greiner 2009, p. 250). Polymer compounds containing nanoparticles of clay are among the first nanocomposites to emerge on the market as improved materials for packaging food. They demonstrate strength, thermal properties and durability (Hyun et al. 2003, p. 2134).

Thus, the use of nanoparticles for food packaging not only has the potential to protect them and increase their shelf life, but can also be more environmentally friendly, since such compounds can reduce the use of plastic packaging, minimizing environmental pollution, in addition to consuming less fossil fuel for production (Sozer & Kokini 2009, p. 87).

There are, however, some concerns about nanotechnology stemming mainly from the lack of information regarding the interactions of nanometer-scale materials, at the molecular or physiological level, and their effects and potential impacts on consumer health and the environment. Due to their larger contact surface, there is concern that they may promote toxic effects not apparent on bulk materials (Dowling 2004, p. 33).

Nevertheless, the benefits of nanotechnology have been recognized by many industries, and commercial products are already being manufactured, such as in the microelectronics, aerospace and pharmaceutics fields. Nanoparticles, have been used in industries such as physics, chemistry, biology, engineering and materials science. In contrast, their uses in the food industry, in turn, are rather limited. However, findings in the field of nanotechnology are beginning to impact this industry for both humans and animals, affecting important aspects of food safety for the molecular synthesis of new products and ingredients (Chen 2006, p. 189).

Copper nanoparticles, for example, have been tested as a new way of using the mineral in animal diets. Thus, the use of nanoparticles has become an interesting and widely used subject in dietary supplements (El Basuini et al. 2016, p. 38; Chen et al. 2015, p. 435; Gopinger et al. 2016a; Gopinger et al. 2016b).

According to Mura et al. (2014, p. 93), there are not many studies that show the potential use of nanotechnologies in the field of animal husbandry, and these have been focused on animal health, more specifically. Based on what is known about nanocomposites, these could play important roles in animal production, such as being added to diets in order to avoid the proliferation of fungi and their consequent mycotoxins, in addition to enhancing the nutrients utilization by the animal, reducing its excretion in the environment (Manuja et al. 2012, p. 25).

The present review aimed to present the use of nanotechnology in the food industry, emphasizing the use of nanodispersions, nanocapsules, nanolaminates, nanofibers, nanominerals, nanotubes for food packaging, as well as their nutritional application in animal diets, potential risks and existing legislation.

MATERIALS USED IN NANOFOODS

The potential benefits of nanotechnology have been recognized by many industries and commercial products are already being manufactured, especially in the microelectronics, aerospace and pharmaceutical industries (Chen 2006, p. 189). Around the world, there are currently more than 200 companies conducting research on the use of nanotechnology in agriculture or in the engineering, processing, packaging or distribution of food and nutritional supplements (Chaudhry et al. 2008, p. 250). The materials used in nanofoods that will be addressed in this review are: nanodispersions and nanocapsules, nanolaminates, nanofibers, nanotubes and nanominerals.

Nanodispersions and nanocapsules

Functional ingredients of foods, such as vitamins, antimicrobials, antioxidants, flavorings and preservatives are in various physical and molecular forms and, since they are hardly used in their purest form, are part of a delivery system. The ideal mechanisms for delivering these ingredients are nanodispersions and nanocapsules. Nanoencapsulation involves the incorporation, absorption or dispersion of bioactive compounds into small vesicles with nanodiameter (Weiss et al. 2006, p. 110). These types of nanostructures include colloidal associations, nanoemulsions and nanoparticles of biopolymers.

Colloidal associations are thermodynamically favorable systems, whose formation is normally conducted by hydrophobic effect, that is, it reduces the contact area between the apolar groups that comprise the association colloid and water (Weiss et al. 2006, p. 110). Surfactant micelles, vesicles, bilayers, reverse micelles and liquid crystals are examples of colloidal associations. A colloid is a stable system of a substance containing small dispersed particles (Tarver 2006, p. 24). The dimensions of the colloidal associations are in the range of 5 to 100 nm and these structures are therefore considered nanoparticles. For example, a non-polar functional ingredient may be solubilized within the hydrophobic core of a surfactant micelle or as part of the micellar membrane structure. Thus, it can be delivered in an aqueous solution, depending on the specific application requirements (Flanagan & Singh 2006, p. 225). The major advantages of colloidal associations are that they are formed spontaneously, are thermodynamically favorable and typically transparent solutions. On the other hand, the major disadvantage is that a large amount of surfactant is required to form them, which can lead to problems with flavor, regulation or economic drawbacks (Weiss et al. 2006, p. 110).

Emulsion, in turn, is a mixture of two or more liquids (such as oil and water) that do not mix easily. Therefore, a nanoemulsion is an emulsion in which the diameters of the dispersed droplets have on average 500 nm or less. Nanoemulsions may encapsulate functional ingredients within their droplets, which may facilitate a decrease in chemical degradation (McClements & Decker 2000, p. 1277). In fact, different types of nanoemulsions with more complex properties, such as multi-emulsion nanostructures or multilayer emulsion nanostructures, offer various encapsulation possibilities for a single delivery system, which can carry various functional components (Tarver 2006, p. 24). This form has been developed for use in decontamination of food packaging equipment and for food packaging. Nanoemulsions have recently received much attention from the food industry because of their high clarity as they allow the addition of bioactive substances and nanoemulsifying flavors to a beverage without changing the product's appearance. In addition, they are effective against a variety of foodborne pathogens, including Gram-negative bacteria, and may also be used for decontaminating the surface of plants in food processing and for reducing the skin surface contamination of marketed poultry.

Nanoparticles of biopolymers, or nanometric particles, are highly bioactive solid particles with a diameter equal to or less than 100 nm. Food grade biopolymers, such as proteins or polysaccharides, can be used to produce nanometric particles (Chang & Chen 2005, p. 260). These particles may be formed by self-association or aggregation of individual biopolymers, or by inducing phase separation in mixed biopolymer systems. For example, using aggregating (attractive) or segregative (repulsive) interactions, a single biopolymer is separated into smaller nanoparticles. One of the most common components of nanoparticles consisting of biodegradable biopolymers is polylactic acid (PLA), which has some limitations because it is rapidly withdrawn from the bloodstream, remaining isolated in the liver and kidneys. Thus, it is necessary to associate with other compounds, such as polyethylene glycol, to be successful in this regard (Riley et al. 1999, p. 151).

Nanolaminates

They consist of two or more layers of nanometer-sized materials that are physically or chemically bound to each other (Weiss et al. 2006, p. 110). One of the most accurate methods is based on the LbL (Layer-by-Layer) deposition technique, in which the charged surfaces are coated with films consisting of several different materials of nanolayers (Decher & Schlenoff 2003, p. 543). The LbL technology allows greater control over the thickness and properties of the films, which, in this case, allows the creation of thin films (1 to 100 nm per layer) (Weiss et al. 2006, p. 110). Nanolaminates may assist in food surveys for the preparation of edible coatings and films relative to conventional technologies and may therefore have a significant number of uses in the food industry. Edible coatings and films, for example, have already been used in a wide variety of foods, including fruits, vegetables, meats, chocolate and candies (Morillon et al. 2002, p. 70; Cagri et al. 2004 p. 833).

The main materials used for the formation of these edible coatings and films are polysaccharides, proteins and lipids (Weiss et al. 2006, p. 110). Generally they promote a moisture barrier, but offer little resistance to gas transfer as well as poor mechanical strength. In contrast, films based on biopolymers often provide good oxygenation and good barrier to carbon dioxide, but offer little protection to moisture migration (Park 1999, p. 256).

Nanofibers

Nanofibers offer small pore sizes and large surface area, significantly improving the physical, chemical and biological properties, decreasing the fiber diameter (Wei 2012, p. 39). Typically, polymer fibers range from 1 to 10 nm in diameter and may exhibit unusual functionalities with respect to their mechanical, electrical and thermal properties. Although the use of these fibers is increasing at an exponential rate, in the area of foods and agricultural systems are relatively few, which is probably because the fibers are not typically composed of biopolymers used in food, being made mainly from synthetic polymers (Weiss et al. 2006, p. 110).

Nanotubes

A nanotube is a nanometric structure in tubes that is often composed of carbons (Elkin et al. 2005, p. 245). Particularly relevant for the food industry is the possibility of obtaining nanotubes of milk proteins from lactalbumin by means of partial hydrolysis (Sozer & Kokini 2009, p. 87) and it has been demonstrated that certain milk globular proteins can be made to organize structures in nanotubes under appropriate environmental conditions (Graveland-Bikker & Kruif 2005, p. 550).

APPLICATION OF NANOTECHNOLOGY IN NUTRITION AND FOOD

Due to significant investments made, involving several billion dollars, nanotechnology has been considered as a new industrial revolution, not only in developed countries, but also developing countries (Martins 2008 p. 11).

Nanotechnology offers a wide range of opportunities for product development and uses in innovative food systems. Nanotechnology and nanomaterials are a natural part of food processing, because the characteristic properties of many of them rely on nanometer sized components, such as nanoemulsions and foams (Ozimek et al. 2010, p. 409).

The benefits of nanotechnology have been recognized by many industries, such as microelectronics, aerospace, pharmaceutics, and commercial products have been produced for several years. The use of nanoparticles in industries involves physics, chemistry, biology, engineering and materials science. In contrast, its use in the food industry is quite limited. However, discoveries in the field of nanotechnology are beginning to impact this and also associated industries, affecting important aspects of food safety for the molecular synthesis of new products and ingredients (Chen 2006, p. 189).

This new technology has the potential of transforming the entire food industry by changing the way they are produced, processed, packaged, transported and consumed. The uses in food packaging are also very promising, and may improve both their safety and quality (Sozer & Kokini 2009, p. 87).

Systems with nanoscale structural features have substantially different physical, chemical and biological properties from their macroscopic counterparts, and are changing the understanding of biological and physical phenomena in food systems. Because foods are complex biological systems, studies and discoveries made in nanotechnology can also impact on this particular industry (Weiss et al. 2006, p. 110). An example is mayonnaise composed of nanomicelles that contain nanodrops of water inside. It has similar taste and texture attributes to the equivalent, but with a substantial reduction in the amount of fat ingested by the consumer (Chaudhry et al. 2008, p. 250). The Australian company Weston Foods has developed a bread with tuna oil microcapsules, rich in omega-3, but with a pleasant taste, which are programmed to release the component only in contact with the stomach. In turn, Unilever has developed an ice cream with a low fat content by reducing the particle size of the emulsion. With this, the company estimates to use 90% less emulsion and reduce the fat content from 16% to 1%. The North American Oilfresh Corporation has a nanoceramic product that allows halving the use of cooking oil in restaurants and fast food chains. The larger surface area prevents oxidation and agglomeration of fats, extending the shelf life of the cooking oil. In addition, there is a faster heating of the oil, reducing the energy expenditure for the preparation of the food (Martins 2008, p. 10).

Examples of food additives currently available include the synthetic form of the tomato carotenoid, Lycopene®, with a particle size in the range of 100 nm. Its main uses in food include soft drinks, cooking mixes and puddings (BASF 2003).

BioDelivery Sciences International (BDSI) has developed nanoparticles derived from non-transgenic soybeans, which, when associated with calcium, carry and deliver pharmaceutical components as well as nutrients, lycopene and omega-3 directly to the body's cells (ETC Group 2005). The content of flavonoids present in the soybean grain could be increased, allowing to obtain derivatives with lower costs and greater efficiency in their use, improving feed conversion in proteins, in the case of animals, and functional foods and nutraceuticals (Martins 2008, p. 11).

The low bioavailability of minerals such as iron, zinc and copper in conventional diets has become a major problem in animal nutrition. Besides that, high content of Fe in mineral supplementation, for example, may inhibit the absorption of Zn. The inclusion of Zn in the diet to correct its deficiency is a promising strategy and available compounds of the mineral proposed for use as a supplement have small absorptions in the order of 10 to 25% (Zimmermann & Florentine 2011). Although nanotechnology is not widely used in nutrition, potential nutritional uses for nanomaterials would include new systems that allow the targeted delivery of substances, such as Zn, increasing permeability and/or retention.

Food packaging materials constitute the largest category of uses of nanotechnology in the food industry. Because the surface-volume ratios are very high, a relatively low level of nanoparticle is sufficient to modify the properties of the packaging materials without significant changes in transparence, density and processing characteristics (Lei et al. 2006; Greiner 2009, p. 250). Polymeric compounds, containing clay nanoparticles, are among the first nanocomposites to emerge on the market as improved materials for food packaging. They demonstrate higher strength, thermal properties and durability (Hyun et al. 2003, p. 2133).

The use of nanoparticles for food packaging has not only the potential to protect food and increase shelf life, but it can also be more environmentally friendly, since such compounds can reduce the use of plastic packaging materials, minimizing pollution, in addition to consuming less fossil fuel for production (Sozer & Kokini 2009, p.88).

Bayer Polymers has developed a packaging film, the DurethanKU2-2601, which is more transparent and resistant than those in the market. This product is known as a "hybrid system" because it is enriched with an enormous number of silicate nanoparticles that significantly reduces the entry of oxygen and other gases, as well as the exit of the moisture, preventing the deterioration of the food. Also, Kodak has developed a special antimicrobial film, which has the capacity to absorb oxygen from the food, preventing it from deteriorating (Martins 2008, p. 10).

A nanocomposite with antimicrobial properties, using nano-zinc oxide and magnesium oxide, was designed at the University of Leeds. Compared to silver nanoparticles, zinc oxide and magnesium oxide particles must provide solutions for more affordable and safe food packaging in the future because they improve the properties of packaging materials, such as flexibility, temperature, moisture, stability, fire resistance and lower gas permeability, and help in the elimination of microorganisms (Chaudhry et al. 2008, p. 251). The addition of nanosensors to food packaging is also expected in the future, where they would be used to detect chemicals, pathogens and toxins in food (Brody et al. 2008, p. 110). Taking into account the importance of time in food microbiology, the main goal of nanosensors is to reduce the time required for the detection of pathogens, from days to hours or even minutes. Nanosensors could be added directly to packaging material, where they would serve as an "electronic tongue" or "nose" for the detection of chemicals released during food spoilage (Sozer & Kokini 2009, p. 86).

APPLICATION OF NANOTECHNOLOGY IN ANIMAL NUTRITION

In the last decades, it was possible to observe significant changes in the eating habits of the population of several countries, which reflects the complexity of consumption models and the factors that determine them (Pinheiro et al. 2013, p. 23). Such changes affect the quality of food produced and industrialized, and an alternative to improve the food supply chain is in nanotechnology.

In the animal area, the use of nanotechnology is mainly present in vaccines and medicines and, more recently, studies have been carried out to apply this technology also in animal nutrition, with the aim of improving the zootechnical performance of the production animals. It is believed that nanotubes linked to nutrients and administered to animals can be released at specific sites, thus allowing the maintenance of high levels over a long period of time. This approach should avoid nutrient degradation and increase its availability (Ross et al. 2004, p 682).

As this action should be greater in the intestine, the studies have shown that the microencapsulated form becomes a competitive advantage over the direct use in the diet given to production animals. Research has shown that the additives are absorbed and metabolized almost immediately upon entering the animal duodenum, improving intestinal digestion of food. Therefore, nanotechnology protects the additives from this rapid absorption and metabolization through microencapsulation, increasing the efficiency and consequently the performance of animals (Cho & Kim 2015, p. 232).

Due to the restriction on the use of antibiotics as growth promoters in animal feed, several studies have been carried out with alternative additives that present similar results to the antibiotics, but with beneficial antibacterial action in the intestinal microbiota. Copper is one of those additives used with growth promoting function in poultry and swines. Studies with Cu nanoparticles have shown an improvement in piglet growth performance, as well as improved yield, protein synthesis and broiler immunity (Gonzales-Enguia et al. 2009, p. 128; Wang et al. 2016, p. 2227). It is further believed that nanometal copper, as dietary supplementation could, for example, improve the ability of fish to absorb medications such as vaccines, hormones and nutrients (El Basuini et al. 2016, p. 37).

Nanocomposites are also being used in adsorbents of mycotoxins added to animal diets, being effective in removing aflatoxins from grains, such as corn (Gaonkar et al. 2014, p. 425). This new technology also helps in the efficiency of the production of animal diets, presenting a high recovery rate of enzymes that are subjected to the extrusion process. In addition, the release of these enzymes can be controlled, being released only in the place of the organism where its action is most effective. Moreover, the cost of the diet may decrease because there is no need for excess doses of the enzymes in the formulations (Mascarenhas 2010).

A study evaluated the effects of the use of copper nanoparticles as growth promoters in pig diets, with a positive effect on the performance of these animals. In addition, there was a greater absorption of Cu and, consequently, lower mineral excretion in the feces, representing an environmental advantage (Gonzales-Eguia et al. 2009, p. 125). The same researchers attributed these results to the smaller particle size in nano form, agreeing with Win and Feng (2005, p. 2721) that indicated that the absorption depends on the particle size and smaller particles have higher overall absorption.

Several researches have been done with the use of nanominerals in diets of production animals. Fondevila et al. (2009, p. 267) suggest that silver nanoparticles as food additives offered to weaned piglets improve their intake and growth. Broiler chickens receiving nanozinc and nanoselium administered *in ovo* showed improvement in feed efficiency (Joshua et al., 2016, p.292).

Selenium in the nano form was also tested in works with other species, such as fish (*Carassius gibelio*) and sheep. In the first case there was an improvement in the final weight, the relative gain rate and the concentration of Se in the musculature of the fish that received diets supplemented with nanoSe, whereas in the other, the sheep presented increase of the concentration of VFA (volatile fatty acids) in the rumen and alteration of the ruminal fermentation pattern (Zhou et al, 2009, p.81; Shi et al, 2011, p.141).

The low bioavailability of minerals such as iron, zinc and copper in conventional diets has become a major problem in animal nutrition. Besides that, high content of Fe in mineral supplementation, for example, may inhibit the absorption of Zn. The inclusion of Zn in the diet to correct its deficiency is a promising strategy and available compounds of the mineral proposed for use as a supplement have small absorptions in the order of 10 to 25% (Zimmermann & Florentine 2011). Although nanotechnology is not widely used in nutrition, potential nutritional uses for nanomaterials would include new systems that allow the targeted delivery of substances, such as Zn, increasing permeability and/or retention.

The development of this technology in the area of feed is very recent and to boost this process, it is necessary more investment, from the training of specialized professionals, research projects and the animal production chain. In addition to these factors, legislation must also follow this process, since many materials and final products are still limited, making it difficult to develop this technology in the market. As this is a new concept, further research is required to prove safety to consumers, animals and the environment.

POTENTIAL RISKS OF NANOTECHNOLOGY

If, on the one hand, nanotechnologies have the potential to promote improvements in industrial performance, nutritional quality and efficiency of food packaging, on the other hand, they can also bring greater risks to health and the environment (Martins 2008, p. 11).

The main concerns regarding nanotechnology stem from the lack of knowledge regarding the interactions of nanometer-scale materials, at the molecular or physiological level, and their effects and potential impacts on consumer health and the environment. Due to their larger contact surface, they may present stronger toxic effects that are not apparent in bulk materials (Dowling 2004, p. 33).

There are studies that report that nanoparticles ingested, inhaled or absorbed through the skin are able to move between cells with greater ease than larger particles (Semo et al. 2007, p. 939). In this sense, toxicological studies evaluated nanoparticles of low solubility and surface activity, such as nanotubes. Such long particles, fine fibers, such as asbestos (narrower than about 3 µm and more than about 15 mm), should be treated with greater care (Mossman et al. 1990, p. 296). These particles have aerodynamic properties which enable them to reach the gas exchange of the lung, when inhaled, taking a long time to be removed by macrophages, lung's scavengers. Once at the bottom of the lungs, tissue inflammation can occur and eventually lead to lesions and cancer (Dowling 2004, p. 34).

REGULATION OF NANOTECHNOLOGY

Despite progress in the development of food nanotechnology, little is known about the occurrence, fate and toxicity of nanoparticles. Food ingredients, food additives and materials derived from nanotechnology have been reported as potential implications for consumer safety and control of it. A significiant percent of the population does not want their food to be composed of nanoparticles (Almeida 2009, p. 64). Regulatory bodies around the world have established rules and principles for nanoscale materials that have ramifications for use in food. There is uncertainty about the regulation of nanotechnology-based products and this is due to the lack of safety data needed to inform regulators (Batista & Pepe 2014, p. 2108). Therefore, there is a need to consider the entire life cycle of nanomaterials in agri-food uses and further improve their study.

In the United States of America, the Food and Drug Administration (FDA) is responsible for regulating medications. A Working Group was established in 2006 to identify ways to assess the risks and potential benefits of nanotechnology products that are regulated by the FDA and recommended the development of a guide to the industry (FDA 2012). The regulation of nanotechnology products follows a product-focused and science-based policy, in which technical analyses and legal norms are product-specific. Additionally, the FDA has provided guidance and technical assistance to industries as well as product control in post-marketing (Batista & Pepe 2014, p. 2107). Risk analysis varies according to the product class and takes into account the safety, efficacy and impact on public health. This is the same logic of analysis of other products, since it is considered that the security assessment is sufficiently robust. Nevertheless, the FDA is investing in a broad nanotechnology regulatory program to strengthen its scientific capabilities in assessing the properties of nanomaterials and the impact they can have on products (Batista & Pepe 2014, p. 2107). It has also sought data and orchestrated policy approaches to ensure the safety and efficacy of nanotechnology products through the National Nanotechnology Initiative (NNI), in collaboration with the White House, with other US government agencies and with International Regulatory agencies (FDA 2012).

In June 2014, the FDA issued three final guidance documents reflecting the institution's current thinking on certain issues related to the use of nanotechnology in regulated products. The FDA has prepared such guidelines after taking into account the public comments received on the corresponding guidance document previously published in 2011 and 2012. These guidance documents are being issued as part of the FDA's ongoing implementation of the recommendations of its 2007 Nanotechnology Task Force Report (FDA 2014).

In August 2015, the FDA issued a final guidance to address several issues related to the use of nanotechnology in food ingredients intended for use in animal feed. This and other guidance documents are also being issued as part of the ongoing implementation of the recommendations of its 2007 Nanotechnology Task Force Report (FDA 2015).

In the European Union, in turn, the regulation of nanotechnology drugs occurs similarly to the FDA. Several documents were published aiming to standardize the concepts and guide the industries and researchers to work with nanotechnology consciously. Some groups are organizing themselves to investigate the risks of nanotechnology and the ways to evaluate them. The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) identified the need for a case-by-case analysis of nanomaterial risk assessment (EU 2012). Since 2006, they have analyzed the approval of nanotechnology drugs and by 2012 have already been approved 20 (EU 2012). These drugs are analyzed according to the current pharmaceutical legislation, which is based on the benefit / risk relationship, being monitored after commercialization (EU, 2008).

Since nanomaterials fall within the scope of the Council on the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) and the Regulation on Classification, Labeling and Packaging (CRE), the European Chemicals Agency (ECHA) must, in respect of these materials, perform the tasks incumbent upon within the various REACH proceedings (e.g. registration, evaluation, authorization and restrictions) and CRE processes (e.g. classification and labeling), as well as for any other substance, in any form, and have sufficient scientific and technical competence to do so. To this end, as from 2011, ECHA has progressively stepped up its activities in this field, in many areas, in particular the Nanomaterials Expert Group (ECHA-NMEG), which was set up in October 2012 with the support of the competent authorities for REACH and CRE (CARACAL) and biocidal products. This informal advisory group provides support for the implementation of the ECHA work plan on nanomaterials for the period 2016-2018, besides information and recommendations on scientific and technical issues relating to the implementation of REACH, CRE and the Biocidal Products Regulation (EU Regulation #528/2012 (BPR)) with regard to nanomaterials (ECHA 2016).

In Brazil, the National Health Surveillance Agency (ANVISA) also requires products that use nanotechnology to clearly inform, at the time of registration, the use of such technology. This may be the first step for the Agency to evaluate the new technology background in the country and discuss how these products should be monitored (Brasil 2014).

The results obtained with the lack of consensual standards (nanometrology) have allowed several international bodies, organizations and governments to elaborate recommendations, norms and procedures to address these issues. There has also been an important discussion concerning a better definition of nanotechnology within the scope of REACH, legislation that regulates the circulation of national and imported chemicals within the European Community territory (ABDI 2010). Legislation for nanotechnology is undergoing an inflection, in that it ceases to be voluntary to be mandatory. The United States and the European Community are working together to build harmonized legislation (ABDI 2010).

CONCLUSIONS

Nanotechnology has the potential to improve food, making it tastier, healthier and more nutritious, to generate new food products, new food packaging and storage. However, many of the uses are currently at an elementary stage, and most are intended for high value products. In addition to the scientific and technical advances required to continue the use of nanotechnology in the food sector, regulation, savings and the role of consumers in their acceptance will dictate their success in food uses.

With what was discussed it is clear that the use of nanotechnology in animal nutrition seems to bring benefit to the production and also to the environment. Therefore, new approaches and standardized testing procedures to investigate the impact of nanoparticles on living cells are urgently needed for the assessment of risks related to human and animal exposure to this new technology. It is widely expected that food products derived from nanotechnology will increasingly be available to consumers around the world in the coming years.

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