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Nanoparticles in food packaging: Biodegradability and potential migration to food—A review

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ABSTRACT

Lately, the appliance of nanotechnology into the food industry has been focused in the development of packaging material. Nanoparticles (NPs) are used as reinforcements to improve barrier and mechanical properties of polymers, resulting in packages with less demand for raw materials (more sustainable) and when are applied into biopolymers makes its production and use feasible, contributing to reduce the dependence on petroleum based materials. However, being a novel technology, there are gaps on its knowledge that pose questions to the scientific community, especially regarding its toxicity and ecotoxicity. Theoretically, the NPs have potential to migrate to the foodstuff packaged, but migration assays and risk assessment are still not conclusive. This critical review shows an overview of the actual state of the art demonstrating the urgent demand for research on this field.

1. Introduction

Protecting the food from tampering or contamination from physical, chemical and biological sources is the main goal of the food packaging (Prasad & Kochhar, 2014). Glass, metal, paper and paperboard, and plastics are the traditional materials used by this industry (Tang, Kumar, Alavi, & Sandeep, 2012). Due to its functional properties, convenience, resistance, low weight and costs, plastic emerged as the main material used in food packaging in the past decades (Accorsi, Cascini, Cholette, Manzini, & Mora, 2014; Shah, Hasan, Hameed, & Ahmed, 2008). According to PlasticsEurope (2015) report, the European plastic industry is responsible for more than 1.45 million direct employments distributed in more than 60 thousand companies, all over the 27 member States (Croatia was not accounted in this study), with a turnover of 320 billion euro in 2013. The sector include plastic raw material producers, plastic converters and plastic machinery manufacturers, being part of the most innovative sector in the EU representing 1 in every 25 patents submitted between 2002 and 2013.

Among the latest innovations in the food packaging industry, the use of biodegradable polymers reinforced with nanofillers is highlighted due to its sustainable appeal that matches with the actual consumers demand for more environmental friendly products (Abdollahi, Rezaei, & Farzi, 2012; Tang et al., 2012). Nano-biocomposites have shown improved technological properties, such as higher resistance and barrier against gases (Ghanbarzadeh, Oleyaei, & Almasi, 2014).

Regardless the improvement of the material properties, the incorporation of compounds at nanoscale level (particle size between 1 and 100 nm) into the food packaging has resulted in concerns among consumers about the effects derived from the ingestion of these nanocompounds. Therefore, it is crucial to determine the potential migration to food matrices and its toxicity by understanding the action dynamics of these nanoparticles (NPs) inside the human body as also their metabolization and elimination mechanisms, besides the definition of regulatory issues (Azeredo, Mattoso, & McHugh, 2011).

Another important concern when discussing the use of nanofillers into biodegradable polymers is the maintenance of its biodegradability (Paul et al., 2005), so appreciated nowadays and the effects on its deposition into the environment (Klaine et al., 2012). Scientists have started to address a large and growing number of questions regarding the human and environmental safety of nanomaterials (Klaine, 2009). Some studies have addressed this subject, but more research is still demanded, especially regarding the use of nanoparticles in the food packaging. Thus, the aim of this work was to present the current knowledge on the influence of the incorporation of nanocompounds on the

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biodegradability of plastic food packaging, as well as its potential migration from the polymers to the food. In this critical review benefits and constraints of this novel technology were pointed out.

2. Degradable polymers

The growing demand and use of plastic materials in recent years has resulted in a global waste disposal problem (Shah et al., 2008). Polymers cause serious damage to the environment since they remain undegraded for more than hundreds of years contaminating the wildlife in the ocean or land and also the food chain (Sadeghi & Mahsa, 2015). In order to minimize the environmental impact, materials with faster degradation process are being researched and developed as substitutes to the traditional polymers (Fernando, Duarte, Vatsanidou, & Alexopoulou, 2015,Imran et al., 2010). According to Avella, Bonadies, Martuscelli, and Rimedio (2001), degradable polymers can be divided in two main classes, photodegradable and biodegradable. The former, upon exposure to sunlight, suffer photooxidative degradation. The latter, by microbial activity in presence (aerobic degradation) or absence (anaerobic degradation) of oxygen, have its organic chemical compounds converted to carbon dioxide, water, inorganic compounds, methane and biomass (Avella et al., 2001; Lucas et al., 2008; Petersen et al., 1999). In this review, only the biodegradable materials will be described in detail.

To accomplish the biodegradation of polymers, the microorganisms first need to cleave the polymer chains in order to reduce its molecular weight making feasible its transportation into the cells, where most of the biochemical processes take place. To break down the polymeric materials, the microorganisms excrete extracellular enzymes which depolymerize the polymers outside the cells (Fig. 1). Then, the aerobic or anaerobic deterioration occur being the material biodegraded (Mueller, 2006).

2.1. Future generation of packaging materials—biopolymers

Since the end of the last century, environmental impacts have concerned the society. Regarding packaging, in 1996, a study conducted by Thøgersen (1996) in Germany concluded that consumers considered important not only the food origin and processing, but also the disposal of its packaging, and at least half of the surveyed were willing to pay more for an environmentally friendly packaging.

Biodegradable polymers derived from renewable resources are highlighted as the future generation of packaging materials (Petersen et al., 1999). Their origin can be either from raw materials or manufacturing processes which classifies them into three groups (Table 1), namely: directly extracted/removed from natural materials; produced by classical chemical synthesis from renewable bio-derived monomers; produced by microbial fermentation (Petersen et al., 1999; Rhim, Park, & Ha, 2013; Sadeghi & Mahsa, 2015). Poly(lactic acid) (PLA), starch, cellulose, chitosan, agar, alginate, proteins are some of the biopolymers that can be named in this large class of materials.

Despite its biodegradable characteristic, renewable biopolymers have three main problems: performance, processing and cost (Petersen et al., 1999). In special, their poor mechanical and barrier properties are limiting its use, particularly in food packaging, thus these characteristics may be modified by adding some reinforcing compounds, generally on nanoscale dimension, forming composites/nanocomposites (Sadeghi & Mahsa, 2015). The use of nanotechnology as reinforcement to these materials emerged as a solution, because the nanofillers are capable to improve barrier and mechanical properties by decreasing filler dimensions, and also reduce the production cost since less material is needed to obtain the desired properties (Rhim et al., 2013).

The use of nanotechnology into food contact materials (FCM) is the largest current application of this technology in the food sector, and was divided into four main categories by Chaudhry et al. (2008): (i) FCMs with improved packaging properties (gas barrier, mechanical, etc) due to incorporation of nanoparticles (NPs); (ii) "Active" FCMs that gain additional properties such as antimicrobial or oxygen scavenging through the incorporation of NPs; (iii) "Intelligent" FCMs as result of the incorporation of nanosensors; and (iv) Biodegradable polymer–nanomaterial composites – biopolymers with improved characteristics through the nanofillers.

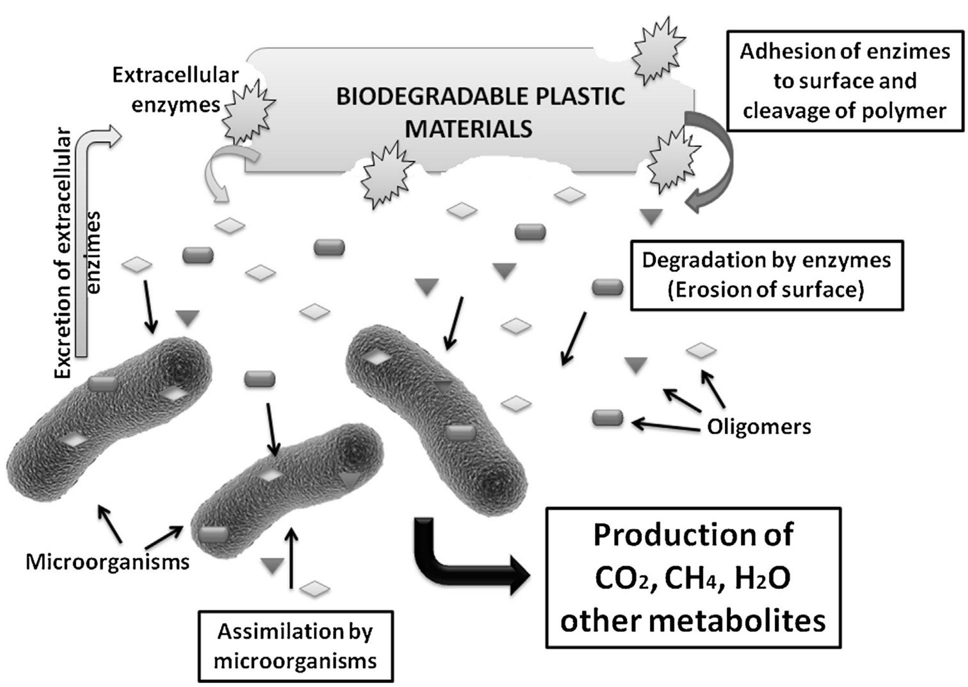

Fig. 1. General mechanism of plastic biodegradation (Souza, 2015).