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DEVELOPMENT OF RECYCLABLE AND BIODEGRADABLE FOOD PACKAGING MATERIALS – OPPORTUNITIES AND RISKS

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Abstract
In recent years the development of new recyclable and biodegradable food packaging systems has been greatly increased, because currently raw material used in the food packaging industry is mainly plastic, a non-biodegradable and not so easy recyclable material. The packaging industry is the largest single end-user for plastics globally, and about 100 million tons of plastic materials are used annually worldwide. Polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET) are the most used petrochemical-based plastic materials used in the food packaging industry, the main advantage of these being the low production price, however, the recycling and reuse rate being very low. Biodegradable polymer materials such as polylactic acid (PLA), polyhydroxyl alkanoate (PHA) and polyhydroxyl butyrate (PHB) are increasingly used in the food packaging industry due to their capability to biodegrade which leads to benefits for the environment preservation. This review will describe current status of existing petrochemical-based plastics and their capabilities to be recycled and the newly developed biodegradable food packaging materials explaining which are the opportunities and which are the risks of it for a better sustainability of our life.

Keywords: biodegradable, development, food packaging, recycle.

1. INTRODUCTION

Food packaging helps preserving the quality and safety through the distribution chain of various types of food products. Among the above, food packaging also has the role of keeping the food safe from outside influence, by providing gases and water barrier (Liu et al., 2020). Nutritional information and ingredient information of the packaged food product need to be displayed also on the package. Different types of plastics, glass, metals, paper and paperboard are commonly used in food packaging and, along with, inks, adhesives, coatings, may come in contact with food products, thus the possibility of unwanted chemical residues migrating into the food package exists (Kumar et al., 2020).

In the food industry, a large part of food packaging is made from petroleum-based polymers and many of these polymers are introduced into the ecosystem as industrial waste and, as they are not biodegradable, become an important problem for the environment (Priyadarshi and Rhim, 2020). In 2015, approximately 8.3 billion tons of petroleum based polymer products were produced in eight industry sectors worldwide, thus resulting approximately 6300 million tons of plastic waste, of which 12% were incinerated, 9% were recycled and the vast majority of them (79%) were collected

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in landfills or dumped in the environment. In this way, by 2050 approximately 12,000 million tons of plastic waste will exist in the environment, because there is no development of new recycling plans for non-biodegradable polymeric materials (Rabnawaz et al., 2017).
Petroleum resources are still widely used in the production of food packaging, leading to concerns for both industry and consumers about environmental sustainability, so the need to use biodegradable polymeric materials plays an important role in replacing conventional ones (Eubeler et al., 2010). The use of polymers from renewable resources for the development of new biopolymers is an innovative and promising alternative for reducing greenhouse gas emissions. Biopolymers are a variety of thermoplastic polymers that come from biological and fossil resources. Currently, the market for biopolymers is growing year by year, one of the major advantages of biopolymers being that they break down into simple molecules already present in the environment, such as CO_2, water or methane, under the enzymatic action of microorganisms, resulting in degradation through biodegradation processes (Rudnik, 2019).
Biodegradation is a process in which organic material is decomposed by natural biological activity. In this process, the biochemical decomposition of an organic compound leads to smaller compounds (oligomers or monomers) due to the action of microorganisms (bacteria, fungi, yeasts) or their hydrolytic enzymes (Poznyak et al., 2019).
This review studies both the considerations for sustainability and recycling of several petroleum-based food packaging materials that exist on the market, as well as the uses in the agri-food industry of newly developed biodegradable food packaging materials.

2. MATERIALS AND METHODS

For a better understanding of this topic better, a literature review was carried out in order to investigate the new research opportunities that emerged in the past 10 years in the agri-food packaging industry. The content analysis of the reviewed papers was aimed at defining the scope of analysis, evaluate the content and in the end to classify the content in two distinct topics – considerations for sustainability and recycling of food packaging and novel biodegradable food packaging uses. Web of Science, Elsevier, Wiley Online and Springer databases were electronically searched for articles published in the last 10 years. The literature search included as document type: research article and review, on the topics: „recycled packaging”, „composite materials biodegradability” „food packaging sustainability”, „food packaging challenges”. Also, we searched the following key phrases: biodegradable packaging materials, sustainability of packaging materials, biodegradation studies, recycling processes of petroleum-based packaging materials. Books, books chapters, research articles and reference lists of papers were retrieved in order to identify additional potentially relevant materials.

3. RESULTS AND DISCUSSIONS

Twenty-two relevant articles with a publish date not longer then 10 years were obtained from publisher databases. In recent years (from 2014), the distribution of articles shows a higher number of research studies related to novel biodegradable food packaging, which indicates that the sustainability topic has gradually received more and more attention. The obtained references were categorized into two distinct topics: considerations for sustainability and recycling of food packaging and novel biodegradable food packaging uses. The vast majority of research articles was found in publications devoted to environmental engineering, green chemistry and progress in

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polymer science. Most of articles were published in "Progress in Polymer Science", "Food Hydrocolloids" and "European Polymer Journal".

Considerations for sustainability and recycling of food packaging

Food packaging recycling process consists of three major steps: collecting, sorting and processing of different types of materials after they have been used for their initial purpose. Sustainability and recycling are two distinct concepts, and it is important to understand the differences between them. Sustainability of food packaging refers to the way that they are processed after their initial use, without impacting the future generations to meet their own needs (Wikström et al., 2016).

The whole life-cycle of the food packaging system has to be taken into consideration when the environmental impacts are evaluated. Because not all recyclable materials are suitable for recycling, there is a possibility that reducing the amount of those materials can be more beneficial to the sustainability aspect, that recycling them. For example, plastic food packaging uses less energy for production, thus lowering the environmental impact for plastic bottles over other materials.

When evaluating the sustainability of a food packaging material, is important to take into account the production impact, which can be greater than that of disposal one, so focusing on the end-of-life can be misleading when evaluating the sustainability aspects (Dhaliwal et al., 2014). A perfect example are plastic bottles, which use a lower quantity of energy for production then glass, the latter having more recyclable content.

In order to achieve a good recycling rate, the materials that undergo this process need to have the following attributes: same type or amounts of the same material and a low degree of contamination with other types of materials. If these criterions are not met, the recycling process will not be achieved, and so, it is important to take into consideration the following factors: the functionality, cost and availability of the recycling process (Geueke et al., 2018). The final step of the recycling process is the development of recycled materials through post-processing. In order to develop food-grade post-consumer recycled materials, the process needs to be closed monitored. A close control over the source materials and processing (high-temperature washing with detergent, vacuum treatment, and sometimes even depolymerization/repolymerization) need to be addressed (Eriksen et al., 2019).

Novel biodegradable food packaging uses

There are several types of biodegradable food packaging present in the market these days, the most common being the ones made from biopolymers resulting from plants (starch, cellulose, etc.), biopolymers produced by chemical polymerization that combine the use of renewable raw materials with industrial polymerization processes, biopolymers produced by genetically modified microorganisms and synthetic biopolymers (Etxabide et al., 2017).

The main problem for packaging is the elimination of harmful substances, reduction in volume and content, recyclability, safety and easy separation of materials, use of recycled resources, reusability, marking on packaging materials and handling precautions (Raquez et al., 2013).

Plastic waste is resistant to microbial attack and thus accumulates in large amounts in the soil. This waste does not help fertilize the soil. The best alternative for plastics waste is the synthesis of degradable plastics. Natural polymers such as starch or wood flour are biodegradable, while most synthetic polymers are not biodegradable. Additives in plastics with a molecular weight, such as plasticizers and reinforcing agents, are susceptible to microbial attack (Klaiman et al., 2016).

Arrieta et al. (2017) evaluated the proprieties of an active and biodegradable food packaging system made from a composite material: polyester-urethane (PU) loaded with catechin (Cat). The biodegradable polyester-urethane was composed with the help of tri-block copolymer of poly (L-

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lactic acid), poly(ε-caprolactone) and catechin agent as antioxidant, incorporated the structure. Fatty food stimulant was subjected to the developed food packaging material, and the catechin antioxidant effectiveness was proven after 10 days. As for the biodegradability of the developed food packaging material, it was shown that the catechin incorporation improved the disintegration process under composting conditions.
Bashira et al. (2018) carried out biodegradation studies on some biodegradable films made from chitosan, guar hum and polyvinyl alcohol with incorporated mint, grapefruit peel and nontoxic tetraethoxysilane. The biodegradation tests were made by soil buried method and the results obtained showed that the degradation process started rapidly, only after 6 days. The lower water vapor transmission rate and water vapor permeability showed better shelf life; hence, these biodegradable films are environmentally friendly and have potential for food and other packaging.
The structure and the properties of some biodegradable films used for food packaging materials were investigated by Saral Sarojini et al. (2019). The newly developed films were fabricated from Mahua oil-based polyurethane (PU) and chitosan (CS), with zinc oxide nanoparticles incorporated, in order to improve the shelf-life of food products. As a result of the incorporation of the zinc oxide nanoparticles in the film, the antibacterial proprieties were enhanced, and the barrier and hydrophobicity properties were improved. As for the biodegradation studies, the sample PU/CS/5% nano ZnO lost 86% of its initial weight after 28 days in the soil.
Hai et al. (2020) studied the biodegradability and biocompatibility of a green nanocomposite food packaging material made by blending chitin nanofibers and bamboo cellulose nanofibers. It is known that chitin has good biodegradability and biocompatibility and blended with cellulose which has great mechanical proprieties, can help develop bio-nanocomposite food packaging materials. The biodegradation tests revealed that the nanocomposite material is fully biodegradable within a week. Beside great biodegradability proprieties, the newly developed nanocomposite materials also possess good mechanical and thermal proprieties.
Yu et al. (2018) studied the biodegradability of SiO_2 enhanced Poly(vinyl alcohol) and chitosan (PVA/CS) biodegradable films. The addition of SiO_2 to the PVA/CS films was made by hydrolysis of sodium metasilicate in presence of PVA and chitosan solution. The results showed a weight loss of about 60% after 30 days in soil of the SiO_2 enhanced PVA/CS films. The permeability of oxygen and moisture of PVA/CS biodegradable films was reduced by 25.6% and 10.2%, respectively. Also, oxygen and water barrier proprieties were tested and the results were promising.
Biodegradation studies of cassava starch-based foams incorporated with grape stalks were made by Engel et al. (2019). These samples were obtained by thermal expansion. The results showed that the foams samples were completely biodegraded after 7 weeks. The cassava starch-based foams incorporated with grape stalks presented good properties in the applicability test, showing a promising application in the storage of foods with low moisture content.

4. CONCLUSIONS

Polymeric materials are widely used in modern society because they are light, relatively inexpensive and easy to process. The polymeric materials obtained, starting from natural biopolymers, such as polysaccharides (such as starch and cellulose) and generally agricultural products, can be biodegradable and can play a considerable role in solving the environmental problems raised by the use of plastics.
An essential condition for the biodegradation of polymers is aerobic composting, performed in a specific environment by controlling temperature, air flow, humidity and coagulation, using a carbon

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dioxide measuring installation. The results obtained from the aerobic biodegradation of the biopolymer packaging materials under controlled composting conditions are encouraging.

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