Biodegradable Food Packaging: Benefits and Adverse Effects

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Abstract. The article considers the problem of transition to environmentally safe types of food packaging materials. Features of modern biodegradable food materials and evolutionary generations of packaging materials are explored. Based on literature review, the author identifies a new generation of biodegradable food packaging – smart bio-packaging, representatives of which can be considered materials that have both "green" properties and advanced consumer qualities. Examples of such innovative biodegradable packaging are given: films and containers with antiseptic properties, enriched with vitamins and edible. It is generalized that bio-plastic has acceptable organoleptic, mechanical and chemical properties and can be an alternative to synthetic polymers. At the same time, the analysis of biopolymer production from the resource position revealed adverse environmental, economic and anthropogenic effects. In this context, the author presents "Paradox of ecological ricochet": a contradiction between positive properties of biodegradable food materials and problems of increasing environmental burden for obtaining biomass. It is concluded that eco-safety of bioplastics depends on such factors as composition of materials, production process and how these material is destroyed after use.

1. Introduction

In the context of global environmental challenges, the relevance of research aimed at obtaining eco-friendly packaging materials is growing. A modern "green" trend is the development of various types of biodegradable packaging for food industry. Special interest in the World in recent years has been shown to biodegradable food packaging materials that have both eco-properties and progressive consumer qualities. The conclusions of scientific research confirm the possibility of using some of plant and animal components as a proper alternative to synthetic materials derived from petroleum products. Films and containers made of biodegradable polymers are used for packaging meat, dairy products, baking and other products. Another common use is disposable bottles and cups for various drinks, plates and pallets. The intended consumer market for such materials may be the production of bags for collecting and composting food waste, as well as bags for supermarkets. Despite the advantages, the production of bio-polymers has economic barriers and negative environmental effects.

The purpose of this study is to analyze the features of modern biodegradable food materials and problematic aspects of their production. The objectives of the study are to uncover the evolutionary stages of improving biodegradable plastic; to identify new generation of biodegradable food packaging based on a review of scientific research; to analyze adverse effects of the production and use of packaging made of natural materials.
2. Materials and methods

Global production of plastic polymers has grown from 2 million tons in the 1950s to 400 million tons in 2015. Almost half of all plastics were produced after 2000 year [1]. One of the most popular segments of plastic use is food packaging. After use, plastic packaging is discarded and turned into waste that does not decompose many years. Environmentalists rightly say that our generation leaves a "time bomb" to descendants, meaning a variety of non-recyclable packaging. It is known that cotton and paper decompose in the soil for 2-5 months, milk bags for 5 years, plastic bags from 10 to 20 years, plastic containers almost do not decompose, and the resistance of glass containers is up to 1 million years [2]. Study [3] identified the "Plastic trap" paradox, which is a contradiction between the positive properties of plastic (low price, strength) and the environmental problems as a result of clogging the ecosystem with plastic waste.

Promoting the principles of sustainable development and circular economy involves the use of eco-oriented approaches to production, so that the amount of non-recyclable waste is reduced [4]. To reduce the amount of harmful plastic packaging, researchers and manufacturers pay active attention to the development of biodegradable materials that can be recycled and disposed of with minimal environmental consequences. Based on sources [5–7], packaging materials can be classified into evolutionary stages: first, second, third generations and the author also identifies fourth level – smart bio-packaging (table 1).

Table 1. Evolutionary system of biodegradable packaging generations.

| Packaging generation       | Characteristic                                                                 | Examples                                                                 |
|----------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------|
| First generation            | These materials are decomposed or have been fragmented into smaller molecules during the composting, their complete decomposition was not possible. Micro-particles of these materials pollute the soil, air and water. | Low-density polyethylene with starch fillers and pro-oxidizing additives. |
| synthetic polymers)        | These materials made from synthetic polymers with the addition of biodegradable elements. High-pressure polyethylene is used, natural plasticizers, as well as acids or natural anti-antisepsics to increase the life of packaged products. | Mixtures of gelatinized starch (40-75%) with addition of hydrophilic copolymers (ethylene-acrylic acid, polyvinyl alcohol, vinyl acetate). |
| Second generation          | This packaging consists of fully biodegradable materials and can be divided into three main categories depending on their origin and production method: 1) polymers extracted directly from biomass; 2) polymers obtained by classical chemical synthesis from biomass monomers; 3) polymers obtained by directly using natural or genetically modified organisms. | Cellulose, starch, corn, polylactide, chitin, collagen, gelatin, soy, hemicellulose in deciduous trees and annual plants such as barley. |
| (composite polymers)       | This category includes materials for food products that have both "green" properties and advanced consumer qualities: 1) bioplastics that have antibacterial properties to extend the shelf life of products; 2) edible packaging; 3) smart packaging made of algae that shows the freshness of the product [8]. | Biopolymers with the addition of silver, turmeric and other spices. Packaging of algae, gelatin, agar-agar. |

| Third generation            | The packaging consists of fully biodegradable materials and can be divided into three main categories depending on their origin and production method: 1) polymers extracted directly from biomass; 2) polymers obtained by classical chemical synthesis from biomass monomers; 3) polymers obtained by directly using natural or genetically modified organisms. | Cellulose, starch, corn, polylactide, chitin, collagen, gelatin, soy, hemicellulose in deciduous trees and annual plants such as barley. |
| (biopolymers)              | This category includes materials for food products that have both "green" properties and advanced consumer qualities: 1) bioplastics that have antibacterial properties to extend the shelf life of products; 2) edible packaging; 3) smart packaging made of algae that shows the freshness of the product [8]. | Biopolymers with the addition of silver, turmeric and other spices. Packaging of algae, gelatin, agar-agar. |

| Fourth generation          | This category includes materials for food products that have both "green" properties and advanced consumer qualities: 1) bioplastics that have antibacterial properties to extend the shelf life of products; 2) edible packaging; 3) smart packaging made of algae that shows the freshness of the product [8]. | Biopolymers with the addition of silver, turmeric and other spices. Packaging of algae, gelatin, agar-agar. |
Unlike most plastics, biodegradable polymers can be broken down in the environment by microorganisms such as bacteria or fungi. A polymer is generally considered fully biodegradable if its entire mass is decomposed in soil or water over a period of six months [9]. In many cases, the decomposition products are carbon dioxide, water, methane, biomass and inorganic compounds. In study [10] was concluded that biopolymer materials have a more advantageous property as a thermal packaging material compared to other materials. Plastics are relegated to a lower rank due to their low thermal properties of the packaging material under conditions of low structural modification.

From raw materials with renewable cycle, starch-containing ones are most often used. Thermoplastic starch is one of the key research areas for the production of relatively cheap biodegradable materials [11, 12]. The main sources for industrial starch production are potatoes, rice, wheat, and corn. Starch is not a true thermoplastic, but with plasticizer (water, glycerin, sorbitol and others) at high temperature (90-180° C) and shear, it melts and liquefies, allowing it to be used on injection, extrusion, and inflatable equipment used for synthetic plastics [9].

New generation packaging (4 G) is a concept that combines environmental friendliness and progressive consumer properties of packaging material. Smart packaging consists of a special material based on algae. Packaging reacts to the external environment and condition of the product that is wrapped in it (active packaging). When food spoils, the packaging material changes its color, so buyer can easily determine that the product has been lying in unsuitable conditions for a long time or has been re-frozen. The packaging may also change color to indicate that the product is counterfeit [8].

Also innovative packages include antifungal, antiseptic, bactericidal, edible, anti-adhesive coatings, self-decomposing and useful (enriched with vitamins) films. They not only protect products from unwanted external influences and damage, but also improve their appearance, contribute to a longer retention of quality, and sometimes give new properties. The results of experimental use of innovative materials can be considered on the example of some studies:

1. Biodegradable packaging with silver. Food retains its high-quality texture longer and maintains its freshness. However, this increases the cost of packaging [6]. In addition, recycling packaging with a metal substance will require a more complex method of waste processing [13].

2. Biodegradable packaging film using antibacterial agents (chitosan, plant essential oils, plant extracts, bacteriocins) for packaging fruits and vegetables. This film will increase the shelf life of products [14].

3. Packaging with the addition of cheese whey. Cheese whey can be used as an antimicrobial agent in the production of packaging material to extend the shelf life of food products. Combination of curd serum with polysaccharides, lipids and other additional ingredients can improve physical condition of product. Cheese whey with agro-industrial waste based on starch can be used as an alternative method of obtaining an antimicrobial drug. The film showed acceptable physical characteristics and antimicrobial activity, which makes it possible to extend the shelf life of food products [15].

4. Biodegradable film based on bacterial exopolysaccharide (xanthan) for meat and fish packaging. Packaging had a positive effect on sensory, physical, chemical and microbiological indicators. When storing packaged chilled pork, its mass loss decreased from 2.16 to 0.21%, and its water activity decreased, which positively affected the microbiological stability of pork during storage. The content of free fatty acids decreased by 50 %, and peroxides by 7% [16].

5. Biodegradable container from gelatin and natural polysaccharides for dairy products. Organoleptic, physico-chemical and microbiological indicators of product quality and safety during storage in a biodegradable container were studied. The experiment showed that cottage cheese, which was in the developed biodegradable packaging, kept its consumer properties longer. It is shown that the use of this package can increase the shelf life of the product by 40-50 % [17].

6. Edible food film made from apple raw and plasticizers from agar, carrageenan or xanthan gum. This films have a yellowish color (characteristic of apple sauce). The film with the addition of xanthan gum has the most acceptable taste properties. For apple-based edible films with the addition of agar and xanthan gum as a plasticizer, there is a tendency to rise the tensile strength with an increase of plasticizer [18].
3. Discussion of research results

"Green" trends and smart technologies aimed at improving the environment and the quality of life cover many areas of human activity. "Green" and smart cities [19], architecture and lighting [20], materials and food are being designed. The same progress is being made in the field of food packaging. Packaging materials must be resistant to mechanical stress and weather factors, and not swell when in contact with the product; must not contain carcinogens, mutagens or allergens, and it must not change the organoleptic and physiological properties of products [21]. It is important that packaging materials are disposed of or recycled after using.

This study showed that active research is underway to develop various modifications of eco-friendly food packaging that allows improving the organoleptic, microbiological, physical and chemical properties of products (fourth generation of smart bio-packaging). Modern technologies are able to process packaging, which has the functions of extending the shelf life and the ability to eat. Such packages are called active, since they affect the product directly. The production of baked dishes (plates, spoons, cups) is a green trend. This direction is important for tourist destinations, where a large amount of disposable plastic dishes creates high anthropogenic risks [22].

However, widespread production of bio-materials is not possible for at least two reasons. First, bio polymers are more expensive than synthetic polymers. Table 2 shows the cost of the main biodegradable polymers in comparison with the cost of polypropylene [23]. In addition, the production of new materials is an investment project with high expenditure and unpredictable profitability. But this is an example of "green startup" that could be funded by commercial banks within green lending programs, since the financing of eco-friendly industries is part of socially responsible banking [24].

Table 2. Cost of polypropylene and biodegradable polymers.

| Polymer                          | Price, USD / kg. |
|---------------------------------|------------------|
| Polypropylene                   | 1.65             |
| Polylactide                     | 2.42             |
| Polyhydroxybutyrate-valerate    | 3.5              |
| Polyhydroxybutyrate             | 4                |
| Poly-L-lactide                  | 4.5              |
| Thermoplastic starch            | 5.5              |

Secondly, the production of bio-packaging requires a sufficient amount of plant biomass. Accordingly, its production requires soil areas, water, energy, fertilizers, labor, transport and other resources. In the process of obtaining biomass, the soil will be depleted, carbon dioxide and methane will be released, harmful chemicals will enter the underground water and waste will be incinerated. This situation can be described as a "Paradox of ecological ricochet or rebound": the volume of non-degradable plastic decreases, but the harm from the use of other resources increases.

There is also a problem with the increasing use of GMOs for growing biomass. Study [25] notes that there is a trend to increase the use of GMOs for all biotechnological maize hybrids: in 2008, 85% of the acreage in the USA was planted with bioengineered maize. Scientists have concerns that the effects of GMOs are not well understood. Human health hazards associated with GMOs may include allergic reactions inherent in the toxic gene and its products, as well as changes in metabolism. It is also shown that production of starch and lactic acid is dangerous for workers, as harmful substances are released during chemical reactions. Therefore, an important issue is the process of obtaining natural components for biodegradable packaging and possible harm.

Thus, actual question is that most of the bioplastics currently available on world market are mixture of biological and petroleum-based materials and they are not environmentally sustainable. The
sustainability of bioplastics depends on a number issues, including the composition of these materials, production process and how the material is destroyed after use.

4. Conclusion

In the study author systematizes generations of food packaging materials and identifies the new category – fourth generation of packaging (4 G), representatives of which can be considered materials that have both "green" properties and advanced consumer qualities. This are bioplastics that have antibacterial properties to extend the shelf life of products; edible packaging; smart packaging that shows the freshness of the products. A review of scientific papers has shown that these types of materials have acceptable physical, chemical and organoleptic characteristics. The main barriers for mass production of biodegradable materials are their high cost (2-3 times more expensive than polypropylene) and high demand for biomass. In the process of obtaining biomass, soil depletion, the release of carbon dioxide and methane, the leakage of harmful chemicals into groundwater and an increase in plant waste can occur. Based on this, the author formulates "Paradox of ecological ricochet": in the production and use of bio-packaging, the volume of non-degradable plastic decreases, but the harm from obtaining biomass and other resources may increase. It can be assumed that further research will focus on the development of biodegradable polymer materials from agricultural and food waste, which will reduce environmental harm and increase the sustainability of packaging industry.

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