PRODUCTION AND CHARACTERIZATION OF BIOFILMS: A THEORETICAL ANALYSIS

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ABSTRACT

The generation of plastic waste is becoming an increasing environmental concern due to its long decomposition time and the production of microplastics. With the growing population, the search for alternatives to conventional plastic packaging is becoming a global priority. In this context, biofilms emerge as a promising solution, as they have a significantly reduced decomposition time compared to traditional plastics. This study aims to review the production and characterization of biofilms, covering aspects such as raw materials used and physicochemical properties. The effectiveness of biofilms as substitutes for conventional polymers is highlighted, offering several advantages such as food protection, extended shelf life for packaged products, and oxidation prevention. The research also investigates the technical and economic feasibility of large-scale biofilm production, aiming for its application in various industrial sectors. Additionally, potential innovations in biofilm formulation are explored, including the use of natural and plant-based compounds to improve their ecological and functional properties. In summary, biofilms represent a promising alternative to address environmental challenges associated with the overuse of plastics, providing a sustainable and effective solution for modern packaging needs.

Keywords: biopolymer; raw material; biofilm; characterization; decomposition.

1 INTRODUCTION

For many years, materials derived from non-renewable sources have been utilized as fuels in the chemical industry. However, over the decades and driven by market demands, there has emerged a necessity to find a viable alternative that addresses industry demands while aligning with environmental preservation imperatives.[1]

The significant daily volume of discarded packaging from market-derived products, combined with inadequate selective collection of urban solid waste and high associated costs, further exacerbates concerns about environmental pollution. According to the Ministry of the Environment, through the National Solid Waste Policy, it has been noted that approximately 24% of potentially recyclable solid waste from Brazilian municipalities consists of plastics. The accumulation of polymers in landfills poses a significant environmental challenge due to their inherent resistance to degradation.[2]

For several decades, petroleum has been the main source of raw material for polymers. However, the significant amount of toxic waste generated by its by-products has led to a search for new materials of natural origin. With advances in technology, products derived from alternative and environmentally friendly sources have gained prominence. The aim is to reduce the environmental impact caused by the disposal of plastic packaging, raise awareness among the population about the correct path for reusing these materials, and thus drive recycling practices.[3]

Compared to petroleum-derived films, natural films have advantages such as low toxicity, greater availability, and lower cost. Additionally, biopolymers contribute to reducing greenhouse gas emissions, such as carbon dioxide, and promote environmental stability.[4] Their biological degradation utilizes the natural carbon cycle, avoiding an increase in their concentration in the environment. In summary, natural polymers represent a sustainable option for various industrial applications, with the potential to mitigate negative environmental impacts associated with the use of petroleum-derived polymers.[5]

2 MATERIAL & METHODS

A literature review was conducted through article searches on the ScienceDirect and Web of Science platforms.

3 RESULTS & DISCUSSION

Biofilms have been the subject of numerous studies in recent decades, and their applications extend beyond merely forming a barrier between the internal and external environment. They perform specific functions in food preservation due to the presence of additives aimed at enhancing and/or improving their physicochemical properties (mechanical, thermal, and barrier properties). This is because the raw materials used in biopolymer formation still exhibit limitations compared to conventional packaging. As a solution, various biopolymers such as proteins and polysaccharides have been under investigation for use as raw materials. Starch, pectin, chitosan, alginate, cellulose, and their derivatives have been highlighted among researchers for their excellent mechanical, optical, and sensory properties, as well as their high coefficient of water vapor permeability. Furthermore, they can be combined.[6]

To produce a film-forming solution, the use of basic constituents is necessary, such as high molecular weight polymers, termed forming agents (lipids, proteins, and polysaccharides), solvent (water and ethanol), plasticizing agents (glycerol, sorbitol, and triacetin), and also a pH adjusting agent. Each component of the mixture contributes specific properties to the final product. Typically, film formation involves inter- and intramolecular associations or cross-linking of polymer chains, forming a semi-rigid three-dimensional network that retains the solvent. Among the formation mechanisms, simple precipitation, complexation, and thermal gelatinization are the most important. [7]

There are two main methods used for the production of biofilms: casting and extrusion. The casting technique is commonly employed in laboratories due to its simplicity, not requiring specialized equipment and low production costs. This method involves dissolving the biopolymers in a suitable solvent, followed by molding and drying of the solution.[8]The first stage involves the solubilization phase, during which biomaterials, bioactives, plasticizers, and other necessary materials for biofilm formation are added. A specific solvent is then introduced, and to prevent bubble formation, the solution may undergo processes such as centrifugation, vacuum processing, or sonication. The second stage consists of casting a portion of the solution onto a flat and leveled surface. Finally, the formed film is dried, and the solvent is evaporated.[9]

However, the most commonly used technique within the dry processing method is extrusion. The equipment employed for this production is divided into three parts: feeding zone, kneading zone, and heating zone. In the first stage, the film-forming solution is prepared and introduced into the feeding zone, where the components are mixed under high pressure and air compression.[14] Subsequently, the solution moves to the kneading zone, where tension, temperature, and density increase. Finally, in the heating stage, the film acquires its final suitable characteristics. Through a nozzle with a defined speed, the final product is extruded and dried.[10]

The extrusion method is promising and offers advantages such as low energy consumption, faster processing, solvent-free operation, and the potential for large-scale production compared to the casting process. Films produced by extrusion exhibit improved mechanical and optical properties.[11] However, the extrusion method requires investment in specialized equipment. Another limitation is the need for specific and resistant polymers capable of withstanding the low temperatures and humidity required in the process.[12]

The components constituting edible films are primarily categorized into four groups based on their structure: polysaccharides, proteins, lipids, and composites. Recent studies have explored the production of films by combining these groups to identify their advantages and synergies. It is noted that the mechanical and barrier properties necessary for formulating a good film depend not only on the compounds utilized but also on their compatibility.[13]

Many food products may lose quality or deteriorate due to moisture absorption from the environment, contact with oxygen and carbon dioxide, or exposure to aromatic and lipid compounds. Therefore, the use of packaging is crucial to ensure the durability and quality of food, preventing the growth of fungi and bacteria, as well as the occurrence of unpleasant odors and visible color changes. In addition to acting as a selective barrier controlling the permeation of water vapor between the internal and external environment, packaging also protects food against physical damage, and mechanical shocks, and prevents the entry of unwanted gases and odors.[14]

The characterization of biodegradable films is conducted through analyses of their solubility, thickness, and thermal properties. Film thickness is defined as the distance between the two main surfaces of the film under examination, providing insights into its mechanical strength, and barrier properties, and allowing for an estimation of the shelf life of food packaged with such material. Variations in thickness can impact the mechanical performance and barrier properties of the material.[15]

The properties of polymeric microstructures are crucial for achieving optimal performance in packaging production. Microstructural evaluation involves examining the surface area, homogeneity, roughness, crystallinity, and interactions between multiple layers. It also allows for the assessment of defects and micro-fissure ruptures that can lead to a decrease and loss of barrier and mechanical properties.[16]

Food may harbor pathogenic microorganisms, posing a risk to food quality and human health. Hence, films with antimicrobial properties play a pivotal role in the market by preventing the proliferation and growth of microbes in food, ensuring their quality and safety for consumption. [17]

In Table 1 below, the characteristics associated with each type of edible biofilm applied in food products are listed.

Table 1 Characteristics associated with each type of biofilm.

Biopolymeric Matrix	Food Application	Main Results
Chitosan	Strawberries	The antioxidant capacity was increased, and the shelf life was extended.[18]
Carnauba wax	Fresh-cut apples	Physicochemical properties were improved[19]
Xanthan, alginate, and gellan gum	Fresh-cut jackfruit bulbs	Microbial growth was inhibited, and the shelf life was extended[20]
Alginate	Fresh-cut mangoes	The browning agent was delayed, and shelf-life was extended[21]
Sunflower oil	Fresh-cut pineapple	Quality was preserved and shelf-life was extended[22]
Papaya puree and alginate carrageenan	Papaya	Shelf life was extended and ripening was delayed[23]
Gelatin, corn starch, and waxy maize starch	Red grapes	Quality was maintained[24]
Cithosan	Figs	Antioxidant capacity was preserved, color change was delayed and *Alternaria alternada* growth was inhibited[25]
Alginate, chitosan, apple fiber, and orange fiber	Blueberries	Sensory quality was improved, and shelf-life was extended[26]

4 CONCLUSION

After the bibliographic research conducted, we concluded that biofilms are a great alternative to replace films based on synthetic polymers, as they promote environmental sustainability. Regarding the differences in terms of the economic viability of biopolymers, their production should be viewed in the future from the perspective of natural resource preservation. From an environmental and societal standpoint, it is apparent that increased biopolymer production can encourage local markets to utilize often overlooked natural sources, thus promoting the preservation of a healthy environment.

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