DOI 10.59476/ilpmt2024.60-69

# RECENT PROGRESS IN THE DEVELOPMENT OF COATINGS FOR PAPER FOOD PACKAGING APPLICATIONS

**Aida Michailidou, Stamatina Theohari**
University of West Attica, Greece

**Abstract**

Relevance and aim of the research: Many types of coatings have been developed to meet the demanding needs and properties of paper-based packaging, which is the most widely used sustainable category of food packaging. The purpose of this paper is to list and classify special sustainable coatings, such as bio-based coatings and coatings based on nanomaterials (NPs) that provide barrier, optical, mechanical, anti-microbial and other properties as well as additional functions to the final product for food paper packaging.

Methodology and results: The study is an overview of the previously published works on trends and challenges in the development of healthy and eco-friendly for sustainable food paper packaging applications, which are green alternatives to conventional coatings. As known, paper/paperboard packaging, because of its structure made from cellulose fibers, is naturally sensitive to microbial attack due to the poor barrier properties (i.e., hydrophilicity, porosity, low grease resistance, high absorptivity to gases and water vapors). Thus, paper packages must be properly coated to withstand and keep the food safe, preventing temperature, humidity and other factors of the surrounding from affecting the composition of packaged food. However, the current market is based on the application of commonly used coatings, which are typically made from fossil oil or synthetic polymers, waxes and /or fluor-derivatives that improve surface hydrophobicity and barrier properties. Nowadays, the use of these materials is limited because of problems arising from fossil-oil resources, poor recyclability, and environmental issues. Therefore, these coatings must be replaced by new materials, with high biodegradability, recyclability and compostability features. Recent studies are focused on biopolymers including polysaccharides such as chitosan, starch, etc., proteins such as whey, wheat gluten, and zein, polyesters as polylactic acid (PLA), polycaprolactone (PCL), and polyhydroxyalkanoates (PHAs) that are investigated to formulate coatings with barrier properties for food packaging paper. Petroleum-based polymers are commonly used in paper coating. Due to the good affinity with the substrate, they create suitable barriers to gases and aroma and increase the mechanical strength of the paper packaging. Moreover, biopolymer products have been developed as counterparts to smoothly replace petroleum-based polymers., they can be made from natural raw materials and sources, such as vegetal and marine biomass, this way they can be biodegradable, non-toxic. Additionally, they act as a basis for the incorporation of additives with specific functions for coated paper (ie, active-antimicrobial properties). The methods of chemical modification and combination as well as the processing and production of these new coatings for paper packaging are still under investigation. The addition of certain nanoparticles (NPs) such as metals and oxides in biopolymers and green coatings could be advantageous to add value and enhance the processing, performance and functionality of food paper packaging.

Conclusions & practical implications: The application of coatings on paper-based food packaging is extensively investigated to replace petrochemical derivatives by choosing environmentally friendly alternatives that come from natural and renewable resources. These options determine the ultimate recyclability, biodegradability and even compostability of the final product. The incorporation of certain nanomaterials in the coatings promises to provide a wide range of enhanced properties and improve barrier characteristics of the paper-based food packaging.

***Keywords:*** *Barrier properties, Bio-based coatings, Nanomaterials, Paper food packaging, Sustainability*

## Introduction

Paper-based packaging is the most widely used packaging for food and non-food products. However, for food packaging, there are obstacles to overcome. Paper-based packaging consists of very porous cellulose fibers, which easily absorb humidity. Moreover, the most important barrier properties the food packaging has to meet are moisture vapor transmission, liquid water resistance and oil and grease resistance. Therefore, the paper substrate is often coated with hydrophobic coating materials such as polyethylene (PE), polyvinyl alcohol, rub latex and fluorocarbon to improve their water vapor barrier or waterproof properties. Different types of coatings, such as water-based biopolymers, due to their greater environmental compatibility, are making inroads into more traditional petroleum-based wax and plastic laminate paperboard products for fresh food bakery, frozen food, and take-out container applications. In addition, nano-biocomposites have been studied at an accelerating pace for developing active and smart packaging.

Given the recent progress in the field, we can anticipate a robust pace of ongoing developments. Food packaging plays a crucial role in addressing the sustainability challenges associated with food consumption. Globally, approximately 55% of paper usage is dedicated to packaging, reflecting a recent trend toward reducing single-use plastics (Praveen, 2022).

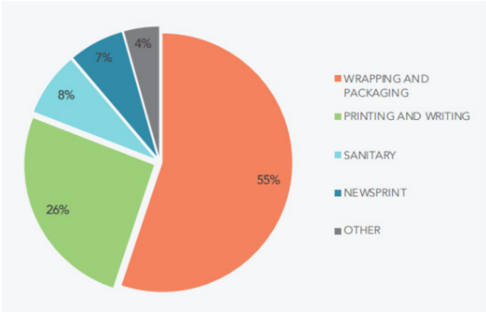


*Figure 1: Global paper consumption: How paper affects the environment 2023. Source: Tappi.org*

Nanotechnology has paved the way for the development of new architectures and unique patterns that eventually have yielded nano-structured and nanocomposite coatings with outstanding performances. From a sustainability perspective, the range of paper and paperboard products has expanded greatly through the rational use of these coating technologies. To render technological functionalities such as 'gas and moisture permeation resistance, hydrophobicity, antimicrobial protection, scratch resistance and cohesive strength', the paper-based surfaces of packaging are coated or treated with several conventional and non-conventional coating materials (Nassar, 2012).

Biopolymers including polysaccharides, proteins, and polyhydroxy-alkanoates (PHAs) can be used to formulate new pathways for the assembly of fully bio-based and functional paper coatings for food packaging. However, difficulties associated with the processing of most biopolymers in their pure form may arise from hydrophilicity, crystallization behavior, brittleness or melt instabilities, sealability, etc., that hinder full exploitation at an industrial scale. As an option to enhance the behavior of biopolymers, certain classes of nanomaterials (NPs) such as metals (Ag, Au, Cu), oxides (ZnO), nano-clays (NCs) and nano-emulsions (NEs) have numerous applications to add value to the manufacturing of active food packaging (He Y, 2022). Nanocomposites, a fusion of traditional food packaging materials with nanoparticles, are gaining interest in the food packaging sector because, in addition to their remarkable antimicrobial spectrum of activity, they display great mechanical performance and strong resistance characteristics to external influences (e.g., heat, pressure, pH, salinity, etc.) (Nassar, 2012).

## 1. Biodegradable coatings classificaton

Biodegradable polymers, which break down naturally in the environment, offer several advantages over traditional plastics. These include properties like conventional plastics, preservation of fossil fuels, and reduced environmental pollution. In contrast, synthetic polymers, derived from petroleum, are often non-biodegradable. However, researchers are increasingly interested in nature-derived polymers (such as chitosan, cellulose, and starch) due to their biodegradability, abundance, and sustainability. These natural polymers, with their high thermo-processibility, find applications in areas like packaging and biomedical implants, contributing to a greener, more sustainable future. Examples of such nature-derived polymers or biopolymers that can be processed into coating include proteins, polysaccharides (e.g., starch, chitin, cellulose and derivatives), lignin, natural rubber etc. Aliphatic polyesters, such as poly(lactic acid) (PLA) and polyhydroxyalkanoates (PHAs) (e.g., polyhydroxybutyrate (PHB), polyhydroxybutyrate valerate (PHBV), etc.), bio-derived poly(butylene succinate) (PBS) (Praveen, 2022).

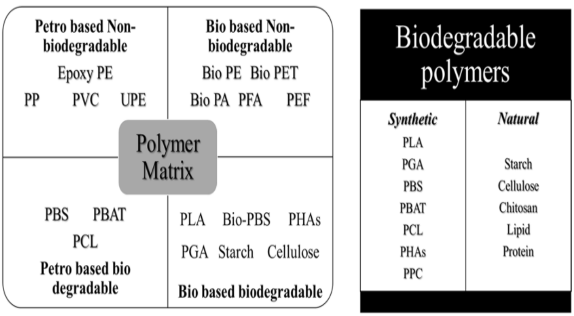


*Fig.2 Classification of different kinds of coatings such as biodegradable and non-biodegradable and classifications of biodegradable polymers based on origin such as synthetic and natural.*

## 2. Barrier Properties

Barrier properties are essential for maintaining food quality and safety. Packaging systems with optimal barrier properties protect their contents against water vapour, gases, light, and aroma compounds. Many polymers such as polyolefins (polyethylene, polypropylene), poly(vinyl chloride), aliphatic polyamides, poly(ethylene terephthalate), polycarbonate, and others are used as protective barrier films against the mass transport of small molecules of gases, vapours, and liquids. For paper packaging materials, the water vapor transmission rate (WVTR) is one of the most crucial barrier properties (Tyagi, 2021). When water vapor passes through the package, it affects the freshness of food and also increases the growth of microbes that spoil the food. Moisture reduces the shelf life of the food materials promoting undesirable reactions like oxidation and vitamin degradation. As paper is made of fibers, it alone cannot provide sufficient barrier properties for packaging applications. So, different coating materials are tried to improve the water vapor barrier properties.

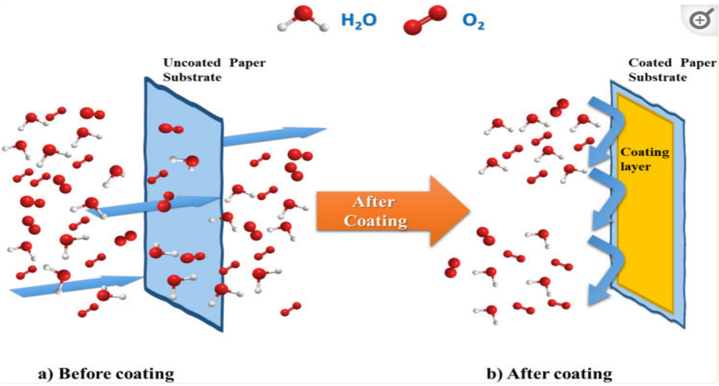


*Fig.3 Barrier properties of paper before and after the coating application*

For packaging applications, the barrier properties of paper play an essential role in preserving the freshness of the product and extending shelf life. The main barrier properties important for packaging are water vapor transmission rate (WVTR) and oxygen transmission rate (OTR) (Praveen, 2022).

## 3. Polysaccharides Based Coatings

Among the materials studied to develop biodegradable packaging films and coatings are polysaccharides such as cellulose, chitosan, starch, pectin and alginate. These polysaccharides can form films and coatings with good barrier properties against the transport of gases such as oxygen and carbon dioxide.

Polysaccharides can be classified according to their source, dividing them into four categories, namely plant, algal, animal, and microbial polysaccharides (Nechita, 2020).

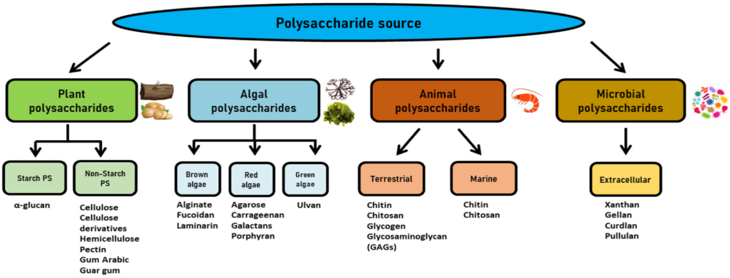


*Fig.4 Classification of polysaccharides according to the sources.*

Recent studies have provided an extensive experimental review of the main functional properties of the most promising polysaccharides for potential application in the field of food packaging. Their permeability to water vapour and oxygen, as well as their mechanical and optical properties, were measured under standardized conditions for poly-saccharide films with different percentages of glycerol used as a plasticizer. SA (Sodium Alginate) presented the highest oxygen barrier, with permeance values comparable to those of conventional high oxygen barrier plastics, such as EVOH (ethylene Vinyl Alcohol) and PVDC ( Polyvinylidene chloride). The most promising application of polysaccharides could be their use as coating materials on paper-based packaging, offering a good protective barrier against oxygen for oxidation-sensitive food products. They might also help in the strategies to replace conventional coating materials, which are based on synthetic polymers, leading to recyclability issues for such multilayer materials (Wu Y, 2023).

## 4. Protein-Based Coatings

Protein-based films and coatings have gained significant attention in recent years as sustainable alternatives to conventional plastic packaging materials. These materials are derived from protein sources like casein soy, collagen, agricultural and other byproducts. These biomaterials offer a wide range of applications across different industries. For food packaging applications, the most interesting segments are the biodegradability and functionality, that these biomaterials can provide. Additionally, protein-based coatings can enhance the appearance, texture, and preservation of food items. They help prevent moisture loss, inhibit oxygen permeation, and reduce the transfer of unwanted odors or flavors (Purewal, 2024).

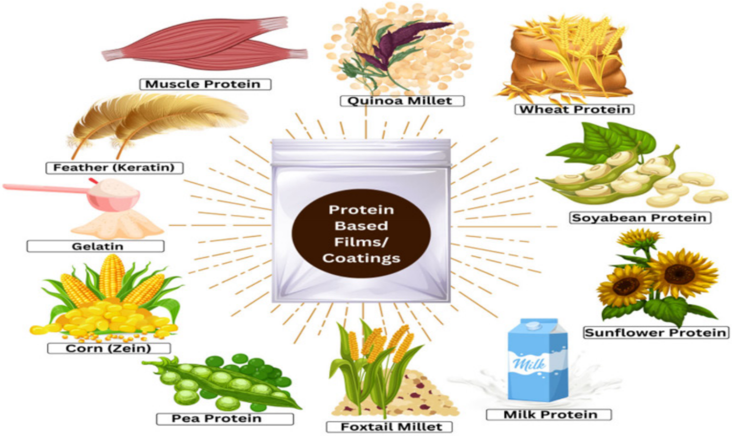


*Fig.5 Sources used in the preparation of protein-based films / coatings.*

Ongoing research and development efforts continue to enhance the properties, functionality, and application potential of edible coatings and films, further solidifying their position as an environmentally friendly alternative to conventional packaging materials. Each protein source possesses unique characteristics that impact the film properties, like the strength, barrier performance, and film-forming ability. These films act as edible barriers that protect food products from moisture loss, oxygen exposure, and microbial contamination (Wu Y, 2023). They are particularly useful for extending the shelf-life of perishable foods, such as fruits, vegetables, meats, and dairy products. These may include plasticizers for improved flexibility, cross-linking agents for enhanced mechanical strength, and bioactive compounds for antimicrobial or antioxidant properties. Such modifications expand the potential applications of protein-based films, including controlled-release systems and active packaging.

**5. Polyesters**

Polyester barrier coatings play a significant role in food paper packaging. These coatings, including Polyethylene terephthalate (PET), provide excellent oxygen barriers, durability, and heat resistance. Additionally, researchers explore bio-based alternatives, such as Poly Lactic Acid (PLA) and polyhydroxyalkanoates (PHAs), which offer biodegradability and sustainability. Dispersion barrier coatings are also gaining prominence, reducing plastics in food packaging. Polyhydroxyalkanoates (PHAs), these bio-based materials are synthesized by various prokaryotic microorganisms and offer several valuable properties, such as biocompatibility. PHAs are bioresorbable, meaning they can be broken down naturally over time. When exposed to natural conditions (such as soil, water, or compost), PHAs break down into harmless components (Kunam, 2022). This process contributes to sustainability and reduces plastic waste. In summary, PHAs offer a promising avenue for sustainable materials in various fields, from medicine to packaging. Their ability to balance biocompatibility, bioresorbability, and biodegradability makes them a valuable resource for a greener future. Poly(lactic acid) (PLA) is a bioplastic with several noteworthy properties. It is derived from lactic acid molecules, which are fermented from plant matter under controlled conditions.  PLA breaks down naturally after use, without harming the environment. PLA is made from renewable resources, contributing to sustainability. It serves as an alternative to petroleum-based plastics in various fields, including packaging and consumer goods. In conclusion, PLA offers a versatile and eco-friendly solution, bridging the gap between functionality and sustainability (Praveen, 2022).

## 6. Nanocomposites

Nanocomposites have become a promising avenue for enhancing food packaging materials. The industry aims to create sustainable packaging solutions that contribute to a circular economy by reducing traditional plastic consumption while maintaining desired properties. Nanocomposites are nanoparticles (NPs) that are incorporated into polymer matrices. They offer improved functionalities and can potentially replace complex multilayered polymer structures. Incorporating low concentrations of nanofillers significantly improves the barrier, mechanical, and thermal properties of polymers. Nanocomposites can introduce antimicrobial and antioxidant features relevant to food packaging. Some biopolymer nanocomposites are thermoplastic starch, which is widely studied and suitable for packaging (Chollakup, 2021).

## Conclusions

Bio-polymer composite coatings for paper represent a sustainable alternative, providing the opportunity to obtain barrier properties (low oxygen and water vapor permeability) and specific functionalities for fully protective food packaging. The application of coatings on paper-based food packaging is extensively investigated to replace petrochemical derivatives by choosing environmentally friendly alternatives that come from natural and renewable resources (Praveen, 2022). These options determine the ultimate recyclability, biodegradability and even compostability of the final product. The incorporation of certain nanomaterials in the coatings promises to provide a wide range of enhanced properties and improve barrier characteristics of the paper-based food packaging.

**References**


1. Nechita P, Roman M, (2020) Review on Polysaccharides Used in Coatings for Food. Packaging Papers. *Coatings* 2020, 10(6), 566; https://doi.org/10.3390/coatings10060566
2. Praveen, K. Dakuri, R. Konala, A, (2022) Bio-based materials for barrier coatings on paper packaging. *Vol.:(0123456789)1 3Biomass Conversion and Biorefinery.* https://www.researchgate.net/publication/363246328_Biobased_materials_for_barrier_coatings_on_paper_packaging
3. Tyagi, P. Salem, K. Hubbe, M. (2021). Advances in barrier coatings and film technologies for achieving sustainable packaging of food products- A review. *Trends in Food Science & Technology* 115 (2021) 461–485. https://doi.org/10.1016/j.tifs.2021.06.036
4. Kopacic S. Walzl A. Zankel A, (2018). Alginate and chitosan as a functional Barrier for Paper-Based Packaging Materials. Coatings 2018, 8(7), 235; https://doi.org/10.3390/coatings8070235
5. Urena M. Phung T. Gerometta M, (2023). *Potential of polysaccharides for food packaging applications.* Part 1/2 : An experimental review of the functional properties of polysaccharide coatings. *Food Hydrocolloids 144*. https://doi.org/10.1016/j.foodhyd.2023.108955.
6. Wu Y. Wu H. Hu L, (2023). Recent Advances of Proteins, Polysaccharides and LipidsBased Edible Films/Coatings for Food Packaging Applications: a Review. *Food Biophysics* (2024) 19:29–45. https://doi.org/10.1007/s11483-023-09794-7
7. Purewal, S.S.; Kaur, A.; Bangar, S.P.; Singh, P.; Singh, H. Protein-Based Films and Coatings: An Innovative Approach. *Coatings 2024*, 14, 32. https://doi.org/10.3390/ coatings14010032
8. Kunam P., Ramakanth D., Akhila K., (2022). Biobased materials for barrier coatings on paper packaging. https://doi.org/10.1007/s13399-022-03241-2
9. He Y. Li H. Fei X. Peng L. (2021). Carboxymethyl cellulose/cellulose nanocrystals immobilized silver nanoparticles as an effective coating to improve barrier and antibacterial properties of paper for food packaging

applications. *Carbohydrate Polymers*. 252:117156, https://pubmed.ncbi.nlm.nih.gov/33183607/
10. Nassar M.A, Youssef A.M, (2012). Mechanical and antibacterial properties of recycled carton paper coated by PS/Ag nanocomposites for packaging. *Carbohydrate Polymers*. 89:(1):269-74. https://pubmed.ncbi.nlm.nih.gov/24750633/
11. Chollakup R. Kongtud W. Sukatta U. (2021) Eco-Friendly Rice Straw Paper Coated with Longan (*Dimocarpus longan*) Peel Extract as Bio-Based and Antibacterial Packaging. *Polymeric Materials for Food Packaging II.* 13(18), 3096; https://doi.org/10.3390/polym13183096