



Biopolymer-Based Food Packaging

Innovations and Technology
Applications

Edited by

Santosh Kumar • Avik Mukherjee • Joydeep Dutta

WILEY

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Edited by

*Santosh Kumar
Central Institute of Technology Kokrajhar
Kokrajhar, India*

*Avik Mukherjee
Central Institute of Technology Kokrajhar
Kokrajhar, India*

*Joydeep Dutta
KTH Royal Institute of Technology
Stockholm, Sweden*

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List of Contributors

R. Anandalakshmi

Advance Energy & Materials Systems Laboratory (AEMSL), Department of Chemical Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam, India

C. Anandharamakrishnan

Computational Modeling and Nanoscale Processing Unit, Indian Institute of Food Processing Technology (IIFPT), Ministry of Food Processing Industries, Government of India, Thanjavur, Tamil Nadu, India

Laxmikant S. Badwaik

Department of Food Engineering and Technology, School of Engineering, Tezpur University, Napaam, Assam, India

Indra Bhusan Basumatary

Department of Food Engineering and Technology, Central Institute of Technology Kokrajhar, Kokrajhar, Assam, India

Arpita Das

School of Life Science and Biotechnology, Adamas University, Barasat, West Bengal, India

K. Dharmalingam

Advance Energy & Materials Systems Laboratory (AEMSL), Department of Chemical Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam, India

Joydeep Dutta

Functional Materials, Department of Applied Physics, SCI School, KTH Royal Institute of Technology, Stockholm, Sweden

Gitanjali Gautam

Department of Food Engineering and Technology, School of Engineering, Tezpur University, Napaam, Assam, India

Dipankar Halder

Department of Food Technology and Biochemical Engineering, Jadavpur University, Kolkata, India

Sweety Kalita

Department of Food Engineering and Technology, Central Institute of Technology Kokrajhar, Kokrajhar, Assam, India

Vimal Katiyar

Department of Chemical Engineering,
Indian Institute of Technology Guwahati,
Guwahati, Assam, India

Anjali Khuntia

Agricultural & Food Engineering
Department, Indian Institute of
Technology Kharagpur, Kharagpur, India

Srinivasan Krishnamoorthy

Computational Modeling and Nanoscale
Processing Unit, Indian Institute of Food
Processing Technology (IIFPT), Ministry
of Food Processing Industries,
Government of India, Thanjavur, Tamil
Nadu, India

Santosh Kumar

Department of Food Engineering and
Technology, Central Institute of
Technology Kokrajhar, Kokrajhar,
Assam, India

Charu Lata Mahanta

Department of Food Engineering and
Technology, School of Engineering,
Tezpur University, Napaam,
Assam, India

Rajib Majumder

School of Life Science and Biotechnology,
Adamas University, Barasat, West Bengal,
India

Gulshan Kumar Malik

Agricultural & Food Engineering
Department, Indian Institute of
Technology Kharagpur, Kharagpur, India

N. Arul Manikandan

Department of Chemical Engineering,
Indian Institute of Technology Guwahati,
Guwahati, Assam, India

Atanu Mitra

Department of Chemistry, Sree Chaitanya
College, Habra, West Bengal, India

Jayeeta Mitra

Agricultural & Food Engineering
Department, Indian Institute of
Technology Kharagpur, Kharagpur, India

Sudip Mitra

Centre for Rural Technology, Indian
Institute of Technology Guwahati,
Guwahati, Assam, India

J.A. Moses

Computational Modeling and Nanoscale
Processing Unit, Indian Institute of Food
Processing Technology (IIFPT), Ministry
of Food Processing Industries,
Government of India, Thanjavur, Tamil
Nadu, India

Avik Mukherjee

Department of Food Engineering and
Technology, Central Institute of
Technology Kokrajhar, Kokrajhar,
Assam, India

Kannan Pakshirajan

Department of Biosciences and
Bioengineering, Indian Institute of
Technology Guwahati, Guwahati,
Assam, India

N. Sai Prasanna

Agricultural & Food Engineering
Department, Indian Institute of
Technology Kharagpur,
Kharagpur, India

Yashaswini Premjit

Agricultural & Food Engineering
Department, Indian Institute of
Technology Kharagpur, Kharagpur, India

G. Pugazhenth

Department of Chemical Engineering,
Indian Institute of Technology Guwahati,
Guwahati, Assam, India

Manashi Das Purkayastha

Food Technology Programme, Department
of Horticulture, Assam Agricultural
University, Jorhat, Assam, India

K. Radha Krishnan

Department of Food Engineering and
Technology, Central Institute of
Technology Kokrajhar, Kokrajhar,
Assam, India

Ruchi Rani

Department of Food Engineering and
Technology, School of Engineering,
Tezpur University, Napaam,
Assam, India

Abhishek Roy

Advance Energy & Materials Systems
Laboratory (AEMSL), Department of
Chemical Engineering, Indian Institute of
Technology Guwahati,
Assam, India

Priyadarshini S. R.

Computational Modeling and Nanoscale
Processing Unit, Indian Institute of Food
Processing Technology (IIFPT), Ministry

of Food Processing Industries,
Government of India, Thanjavur, Tamil
Nadu, India

C. Shashikumar

Centre for Rural Technology, Indian
Institute of Technology Guwahati,
Guwahati, Assam, India

Namrata Singh

Department of Food Engineering and
Technology, Central Institute of
Technology Kokrajhar, Kokrajhar,
Assam, India

Siddhartha Singha

Centre for Rural Technology, Indian
Institute of Technology Guwahati,
Guwahati, Assam, India

K. Sudharsan

Centre for Food Technology, Alagappa
College of Technology, Anna University,
Chennai, India; Department of
Microbiology, SRM Arts and Science
College, Kattankulathur, Chengalpattu
District, Tamil Nadu, India

M. Sukumar

Centre for Food Technology, Alagappa
College of Technology, Anna University,
Chennai, India

Preface

The idea of compiling a book on “*Biopolymer-Based Food Packaging: Innovations and Technology Applications*” took seed in early 2019. It stemmed from the awareness and growing interest among consumers and readers working at the interface of food, health, and the environment. From the perspective of growing food needs of an ever-increasing population, mostly in developing countries like India, the urge to develop such a book project in this emerging area was perhaps more compelling for the food manufacturing business. As the world is diligently focusing on developing sustainable alternatives to petroleum-based products, including synthetic plastics-based food packaging, biopolymers are gaining increasing attention as sustainable environmentally friendly alternatives. This book is a complete, systematic, sequential account of the contemporary development in the area of application of biopolymers as emerging alternatives in food packaging applications. It aims to be a unique resource for academic researchers, professionals in food packaging and other related industries, research scholars, graduate students, entrepreneurs, and people related to the area of food preservation and shelf-life, environmental safety, and human health. Also, the book introduces the functionalities and shortcomings of biopolymer-based food packaging materials, their characterization, and benefits in preservation and/or packaging of food products.

This book comprises fourteen chapters, covering, in their purview, different polysaccharide, protein, and microbial polymer-based food packaging films and coatings, including biopolymer-based blends and nanocomposites. The first few chapters introduce biopolymers, their blends and nanocomposites, and their chemistry, as well as providing a general introduction to food packaging applications. Chapters 4–9 describe extensively various biopolymers and their potential applications, including their importance as active and intelligent food packaging systems. Chapters 10 and 11 focus on incorporation of nanomaterials as fillers to improve the physicochemical, mechanical, thermal, barrier, optical, and antimicrobial properties of food packaging nanocomposites. Chapters 12 and 13 detail the use of plant-based bioactive compounds, including essential oils and essential oil-derived compounds in active biopolymer-based edible food packaging. The last chapter of the book, Chapter 14, provides a comprehensive overview of biopolymer-based edible food packagings and their effectiveness in shelf-life extension of perishable food items.

1

An Overview of Natural Biopolymers in Food Packaging

Santosh Kumar^{1,*}, Indra Bhusan Basumatary¹, Avik Mukherjee^{1,*}, and Joydeep Dutta^{2,*}

¹ Department of Food Engineering and Technology, Central Institute of Technology Kokrajhar, Kokrajhar 783370, Assam, India

² Functional Materials, Department of Applied Physics, SCI School, KTH Royal Institute of Technology, Hannes Alfvéns väg 12, 114 19, Stockholm, Sweden

* Corresponding authors: Santosh Kumar, s.kumar@cit.ac.in; Avik Mukherjee, ak.mukherjee@cit.ac.in; Joydeep Dutta, joydeep@kth.se

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1.1 Introduction

The prefix “bio” in the term “biopolymer” signifies that these polymers are of biological origin, i.e. inherently produced in living organisms. Biopolymers, bio-based polymers, biodegradable polymers, and bioplastics are used synonymously in specific contexts, but each term has a different meaning. Bio-based polymers are materials produced from natural resources such as plants, animals, and microorganisms that can be biodegradable (e.g. starch, polylactic acid [PLA]) or non-degradable (e.g. biopolyethylene) [1]. Biodegradable polymers are materials that completely degrade when exposed to soil, air, water, and microorganisms over a specific time period. Biodegradable polymers may be natural (e.g. starch, cellulose, proteins, lipids) or synthetically produced (e.g. polycaprolactone and polybutylene succinate). A bioplastic is a plastic polymer manufactured from a natural or renewable source, and it is biodegradable [2]. Biopolymers are primarily composed of repeating units of monomers made of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) and are found in living organisms such as plants, animals, and microorganisms. Based on this definition, biopolymers include bio-based polymers and natural polymers, including biodegradable polymers such as polysaccharides, proteins, lipids, and

polynucleotides (DNA and RNA). However, biopolymers such as DNA and RNA have complex molecular structure, in which monosaccharide, protein/amino acids, and functional groups such as phosphate groups are joined together by complex intramolecular interactions like hydrogen bonding, disulfide bridges, and hydrophobic interactions to create three-dimensional (3D) structure and termed as bio-based heteropolymers or biomacromolecules [3].

The physicochemical properties of biopolymers such as stiffness, elasticity, conductivity of electricity and heat, resistance to corrosion, appearance such as transparency, and color depend on the type(s) of monomer, degree of polymerization, and type(s) of intramolecular bonds. Compared to synthetic polymers obtained from fossil fuels, biopolymers offer the obvious advantage of eco-friendly degradation, which leads to effective waste management and a healthy environment. The biopolymers are excellent candidates for various applications such as food, pharmaceuticals, and cosmetics and in several industries including packaging, agriculture, textiles, and water treatment due to their biocompatibility, non-toxicity, and biodegradability [4–6]. However, impact strength, tensile strength, permeability, and thermal stability of biopolymers are relatively inferior compared to synthetic (i.e. petroleum-based) polymers. Reinforcement of fillers or additives in biopolymers significantly improves the mechanical properties, such as tensile and impact strengths of the resulting composites, and thermal and optical properties [7–9]. Cellulose, chitosan, starch, polyvinyl alcohol (PVA), polylactic acid (PLA), polyglycolic acid (PGA), polycaprolactone (PCL), polyhydroxybutyrate (PHB), polybutylene succinate (PBS), etc. have gained substantial attention as biopolymers in food packaging applications [5, 6, 8].

Synthetic polymers like polyethylene (PE), polypropylene (PP), nylon, polyester (PS), polytetrafluoro-ethylene (PTFE), and epoxy are commonly known as plastic and are derived from petroleum hydrocarbons [10]. These materials are still an integral part of our human life, and they have found their way into our daily routine. The demand for petroleum-based polymers in our commercial world is increasing because of their versatility, high mechanical strength, flexibility, resistivity, transparency, chemical inertness, low mass, and low cost [11]. Moreover, these plastic do not readily react with the product with which they are in contact, and they have excellent resistance to water, gases, temperature, and chemical degradation. Synthetic plastics are made from petroleum hydrocarbon, which is a non-renewable resource, and they emit large quantities of greenhouse gases during production [11]. In addition, burning of plastics can emit toxic chemicals such as dioxins [12]. Plastics that are used for short time periods and single-use plastics should not be made of synthetic plastics due to their low density and slow decomposition. As reported by various environment protection agencies, plastics alone account for more than 25% (by volume) of the total municipal solid waste generated. Synthetic plastics-based food packages/containers and utensils take many years, sometimes even more than a hundred years, to degrade in the environment (Figure 1.1a), whereas natural biopolymer-based food packages/containers and utensils decompose within a few weeks to a few months (Figure 1.1b). Thus, synthetic plastic-based food packages and containers become a significant problem for the environment and living beings. They impact the quality of air, water, and soil and indirectly plant, animal, and human lives. Accumulation



Figure 1.1 Lifecycle of (a) synthetic plastics-based food packages/containers and (b) biopolymer-based food packages/containers and utensils.

of large amounts of plastic waste in the marine ecosystem causes choking and entanglement of marine flora and fauna [13].

As an alternative to petroleum-based plastics, biopolymers have significant potential to be used in food packaging applications [5, 6]. These would help to reduce the impact of synthetic plastics waste because of rapid degradation of biopolymer-based plastics in the environment. They are decomposed by the enzymatic activity of naturally occurring microorganisms in the environment such as bacteria, fungi, and algae and by chemical processes such as chemical hydrolysis. During biodegradation, biopolymer-based food packages and containers are converted into simple organic molecules, carbon monoxide (CO), methylene (CH), water, biomass, and other natural substances. Biopolymers such as chitosan and PLA are naturally recycled by biological processes (Figure 1.2). Thus, biopolymers are characterized by easy disposal, recycling, biodegradation, and composting and by their eco-friendly nature. In addition, some of them have advantageous features such as inherent antimicrobial and antioxidant activities, because of the presence of different functional groups in their polymeric chains. Despite these advantages, biopolymers lack adequate mechanical and barrier properties, which makes them unsuitable for use as food packaging [14]. Many researchers have focused on this and propose the use of crosslinkers such as nanofillers and blending of two or more biopolymers to address these challenges. This chapter provides a comprehensive overview of various biopolymers and their properties and applications in food packaging and preservation.

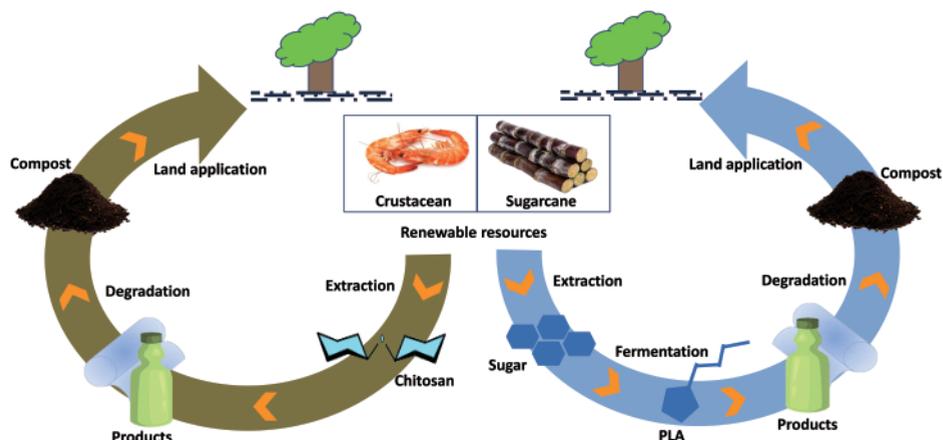


Figure 1.2 Lifecycle of chitosan (left) and PLA (right).

1.2 History and Background

“Biopolymers” can be defined as polymers that are naturally produced or are obtained from living organisms. The repeating monomer units of biopolymers are saccharides, nucleic acids, or amino acids, and sometimes various additional chemical side chains and functional groups. Historically, biopolymers have been commonly used as food, for making clothes and houses, and as fuel for cooking. They are biodegradable in nature and are obtained from natural renewable resources, which has inspired a renaissance of research interest. Biopolymer-based composite materials are sustainable and have the potential to replace the fossil fuel-based synthetic plastics that have been used on a large scale since the industrial revolution. Fossil fuels are limited resources, and due to non-biodegradability they cause significant environmental problems. Therefore, biopolymers can be used as sustainable and environmentally friendly alternatives to synthetic plastic for food packaging applications.

Silk is an ancient protein polymer, with an amino acid composition that depends on the producing species. Silks are produced by spiders, silkworms, and several lepidoptera larvae. *Bombyx mori*, a silkworm, is the most popular species for silk production. This silk is characterized by fibroin fibers held together by a glue-like protein called sericin, which is absent in spider silk. Silk fibers have high toughness, good strength, and high elasticity. These properties, including resistance to failure under compression, make silk an attractive material for food packaging applications. In a study, silk fibroin was used to develop a coating formulation (Figure 1.3a) for postharvest shelf-life extension of fruits such as strawberry (Figure 1.3b) and banana (Figure 1.3c) [15]. Researchers reported reduction in oxygen diffusion through silk fibroin thin films/coatings due to increased beta-sheet content. The fruits treated with water-based silk fibroin edible coatings had enhanced postharvest shelf-life at ambient conditions by reducing the rate of cell respiration and transpiration.

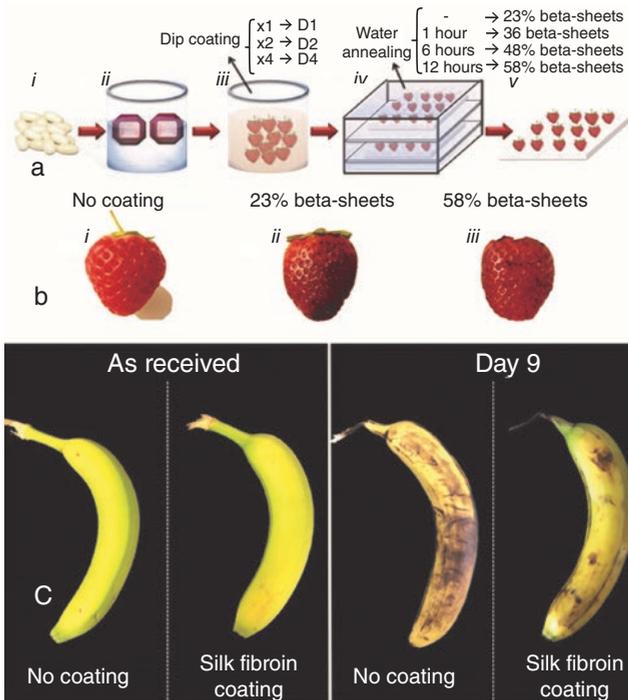


Figure 1.3 (a) Dip-coating application of silk fibroin coating formulation on freshly picked strawberries. (b) Images of coated strawberries: (i) no coating (freshly picked), (ii) coated with silk fibroin edible coating (23% beta-sheet, i.e. no water annealing applied), and (iii) coated with silk fibroin (58% beta-sheet, i.e. exposed to water annealing post-processing). (c) Time lapse photography of silk fibroin coated banana stored at 22°C and 38% relative humidity (RH), indicating that silk fibroin coating decreased the ripening rate [15]. (Source: (a) [15], Figure 01A, p 04, CC by 4.0 licence/with permission from Springer Nature. (b) [15], Figure 04, p 08 CC by 4.0 licence/with permission from Springer Nature.)

In the nineteenth century, another natural polymer, cellulose, started impacting everyday life. Cellulose was also known as Celluloid, Parkesine, Xylonite, and Ivoride, and it was invented by Christian Schönbein (a Swiss professor), Alexander Parkes (an English inventor), and John Wesley Hyatt (an American entrepreneur). In 1847, Parkes started working on cellulose, and he developed the formulas and processes to manufacture cellulose nitrate after spending the next 15 years in the laboratory.

Milk casein has been used as a dietary source of protein since the domestication of livestock. The technologies for making plastics from casein were first patented in 1885 and 1886, in Germany and the USA, respectively [16]. However, the patented material easily biodegraded, and no useful products could be made due to lack of hardening agent in the patented protocol. Clearly, easy biodegradation was a disadvantage or non-desirable a century ago, but today biodegradability is one of the most desirable properties for sustainable packaging.

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