Chapter

Fabricating Natural Biocomposites for Food Packaging

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Abstract

Nowadays, there are dominant scientific breakthroughs to advance the packaging industry to identify innovative and emerging fruitful results for making the food packaging systems, in particular, more efficient, resilient, and sustainable. Therefore, friendliness packaging research has been gaining momentum, thanks to global environmental awareness, and also consumer ecological consciousness, and leading companies are committing to a more holistic worldview of packaging in response to more sustainable processes to reduce pollution and any depletion of resources. High-yielding and cost-effective production and design of packaging, involving synthetic materials use reduction and development of new bio-based packaging materials, are very much part of this holistic approach. Thus, in comparison with petroleum-based materials, potential bio-based materials may have benefits for all agents comprised: the producers, customers as well as the whole environment. This chapter explores a review of relative topics across all disciplines that could accelerate understanding toward this goal. It walks through conventional materials, and then important natural and synthetic polymers from the context of food packaging. Moreover, it provides an overview of the performance of bioplastics and their limitations. State-of-the-art main trends on green biocomposites thereof, their potential to transform the food industry, are also herein considered.

Keywords: bioplastics, food packaging, sustainable, polymers, biocomposites

1. Introduction

Food packaging is basically defined as the process of enclosing food to keep it from spoiling by any probable contamination sources [1]. It is at the heart of the current food industry because almost no foods are sold unpackaged. Food packaging is an important step in the long journey starting from farmer to customer, including packaging that must be user-friendly for handling, transporting, and marketing produce ending with their appeal to the consumer [2]. Packaging and its materials add a major expense to the produce industry; therefore, it is critical that packers, shippers, buyers, and consumers understand the full range of available packaging options [3]. Packaging has made it possible to have year-round access to many foods that would not have been possible otherwise. Food packaging has evolved from being simply a container for food to something that can play an important role in food quality by having various characteristics that have been developed to protect the food. Good packaging reduces waste and ensures that the food retains its desired quality for the meant duration of its shelf life.

Today, there are lots of packaging materials and designs on our sides. It should be noted that some packages have actually allowed for the creation of new supermarket categories. Examples include fresh-cut produce and microwave popcorn bags, which owe their existence to the suitable packaging that has been figured out just right [4]. Despite its importance and the vital role it plays, the packaging is often considered as to some extent unnecessary, a serious waste of resources, and an environmental menace. Such points of view arise as a result of the fact that, by the time most consumers come into contact with a package, its job has, in many cases, been done. Consumer demand, on the other hand, will change for years to come as the quality and quantity of food packaging must significantly increase [5]. The industry of food packaging is mainly depending on the utilization of polyolefins (POs). Polyolefin is a comprehensive term for the two mostly used plastics in food packaging, polyethylene (PE), and polypropylene (PP) [6]. Both have an effective combination of properties such as strength, lightness, flexibility, stability, and ease of processing. However, whether they are suitable for recycling and reuse is debatable. At the end of the twentieth century, plastics were found to be persistent pollutants in many environmental niches since they are massively nonbiodegradable. Accordingly, environmental pollution led to an increased interest in developing more sustainable materials in order to deal with the negative effects of plastic pollution [7]. It is important to recognize the potential reduction in pollution that would result from reusing and recycling materials. Hence, the world begins to initiate movements that will clearly eliminate the unfriendly environmental impacts resulted from the existing packaging systems. A new system is required in which consumption is reduced and materials are recycled. A solution can be found in biologically augmented materials. Nowadays, the concerned societies harbor the utilization of natural-based materials more and often. The main attempt resembling that is the turning over from plastics to natural fiber composites (NFCs) as a more so of applicable green alternatives [8].

2. Food packaging science and emerging trends

Food packaging incorporates a wide range of technological activities, including design, package fabrication, shelf-life testing, distribution, and marketing. Food packaging science is a discipline that applies the perfect blend of four pioneer science areas: materials science, food science, information science, and socioeconomics in order to understand the requirements of any packaging system [9]. Material science and food science have been the two major guiding principles in the development of food packaging. Material science is essential to comprehend the appearance, mechanical strength, barrier, and physical and chemical properties of any substance used [10]. Food science is concerned with the kinetics of food deterioration and governing its shelf-life. Food packaging technology is a science-based solution to specific food packaging needs; examples include tamper-proof packaging, microwavable packaging, and modified atmospheric packaging, all of which aim to improve consumer safety, quality, and convenience [11]. The primary goal of the field of information science is to examine consumer attitudes and behaviors toward food packaging, and then analyze the results to determine what the most important features of packaging are for consumers, which are comfort for use and durability [12]. In regard to socioeconomic needs, the very distinguished ones are lifestyle changes, in a way that reflects the quality of life through the added value offered to consumers through packaged products, profitable companies, packaged product safety, and environmental protection [13].

2.1 Traditional vs. modern packaging

Traditional or conventional packaging deals with the utilization of wooden or paper parts for packaging perishable food products such as vegetables and fruits. This kind of classical packaging as an option often fails due to several whys, including, it is only viable, therefore, for those products that are showing natural protection against influencing elements resembling daylight, moisture, pathogens, and contaminants [14]. Moreover, many use a fragile material that can be broken with the blows, hence inefficiency, and some materials are heavy, therefore incompatible to storage and transport easily. Presently, these methods are being avoided and hardly practiced anywhere. This led to the development of a new packaging option for food products [15].

Food product development innovations and packaging technologies are the lifeblood of the food industry. Currently, the scope is to meet consumers' demand for nutritious and safe food while minimizing the negative environmental effects of food packaging [16]. This has posed a challenge to replace the existing food packaging practices and drove the emergence of modern packaging approaches. Modern technologies, as opposed to the traditional mode of packaging, are a current necessity. These technologies are related to tailored and elegant packaging, but they also ensure preservation, increased shelf life, the wholesomeness of the product, and ease of transportation and storage. Such technologies can be used for various personalized applications, for instance, extension of shelf life and eliminating risks of contamination. Modern packaging technologies have already transformed the accessibility of a product. Novel packaging technology enabled the adjustment of preservation formula to food products of varying origins, physicochemical characteristics, and sizes without losing their nutritional value [17]. Latest packaging materials and technologies involve green innovations including biopolymers and smart packaging, just to name a few. In the case of food packaging, smart packaging is highly regarded because it provides numerous benefits, including further functional properties similar to antioxidant and antibacterial. Such effort may prolong the product's shelf life and reduce food spoilage and loss. These state-of-the-art packaging technologies in synergy with innovations in food product designs will provide new plentiful pioneer opportunities for the food industry [18]. These state-of-the-art packaging technologies, when combined with innovations in food product design, will create a plethora of new groundbreaking opportunities for the food industry.

3. Food packaging materials

The aim when the food is packaged mostly is to be safely transported and correctly stored. The proper combination of packaging materials and technologies ensures that product quality and freshness are maintained during distribution and storage. Package design and structure are important considerations. That is, not only a container, but it must also protect what it sells and sell what it protects [9]. One of the most important aspects of packaging from a business standpoint is that it identifies the appearance of the product in the distribution chain and distinguishes it when reaching the consumer. Today's food packaging frequently combines several materials to take advantage of each material's functional or esthetic properties. Advances in the field of food packaging research may have an impact on the environment as it continues. Aside from food preservation, current techniques are focused on two extra goals: the suitability of the materials used and the generation of eco-friendly products with no presence of side effects on health.

Food packaging materials that have traditionally been used include wood, paper, and polymers, to most new biocomposites. Plastics do not fare well, but neither do wood or paper. However, there is a shift in demand, which makes biocomposites the finest among all [19].

3.1 Wood

Wood has naturally favorable mechanical, physical, and chemical properties, which makes it an excellent packaging material that possesses a good weight-to-strength ratio, and on the other hand, has a high hydration capacity. Aside from its natural moisture content, wood can absorb or release water in equilibrium with the food with which it comes into direct contact. This is one of the characteristics that, for example, seafood, vegetable, and fruit industries stakeholders seek [20]. Furthermore, the majority of wood species have the naturally occurring acidic pH range of 4.3–5.2, which influences bacterial survival on their surfaces [21]. Wooden materials are less expensive to produce than other containers and are still widely used. Depending on the country's regulations and marketing chains, they can be considered for both single-use and reusable packaging. However, in most applications, plastic containers have largely replaced wooden containers because they are more cost-effective, easier to clean for reuse, and do not risk contaminating foods with slivers. Nevertheless, wood as a material is more renewable and after use represents a lower impact on the environment than plastic [22].

3.2 Paper

Paper-based packaging accounts for more than 30% of the global packaging market and is widely used for the packaging of food products due to its broad range of capabilities at a low cost [23]. The most important aspect of paper packaging is that their inert nature extends the shelf life of packed products. Furthermore, paper and paperboard are easy to recycle and environmentally friendly. This kind of packaging is extensively used for packing a variety of milk and soft drink products, baked goods, and a lot more. The standard paper, on the other hand, cannot be used frequently due to the reduced moisture barrier, which leads to microbial contamination. Furthermore, it lacks mechanical strength, which is required for transportation and storage [24]. There have also been several reports that show safety concerns and toxicity risks. In the year 2004, Ozaki et al. [25] conducted a study involving chemical of concern analysis present in paper packaging. The research stated that abietic acid (AA) and dehydroabietic acid (DHA) of contaminants usually to be reported in paper packaging were found to be toxic and potentially genotoxic at higher concentrations. The food contamination risk by the use of paper-based material in its packaging remains on the table, despite the few reported studies of some sort of paper in a treated form that is widely used for various levels of product packaging including foods [24].

3.3 Polymers

Food packaging materials have evolved over time, from primitive tree barks to modern plastic packages. Polymeric materials are quite diverse and adaptable. They can be soft or stiff, transparent, or opaque, thermosets, or thermoplastics and can be made into films or containers of various shapes and sizes. They are, on average, much less expensive and, without a doubt, much lighter. Countless polymers have been chemically synthesized or extracted from natural sources for a variety of applications. The enormous range of development in polymers necessitated their classification on various bases, the most important of which were origin and stiffness [26].

3.3.1 Synthetic polymers

Nowadays, thanks to their predefined properties, polymers are becoming more popular in food packaging. Their desirable performance of mechanical strength thermal stability and, as good barriers to gases and aromatic compounds, synthetic-based polymers are in high demand as packaging materials. The main reasons for the popularity of such polymers are their low cost and widespread availability. Namely, polyolefins are one of the most common plastics used in food packaging. Polyethylene and polypropylene stand out among the finest polyolefin categories owing to their lightweight, processability, flexibility, strength, reusability, and resistance to moisture and chemicals [27].

3.3.1.1 Polyolefins

Polyolefins (POs) are by far the largest class of synthetic polymers made and used today. PO is a collective term for multiple types of plastics: polyethylene (PE) and polypropylene (PP), the two most frequently used plastics in food packaging industries [6, 28]. Several factors have been principally responsible for the great success that POs have enjoyed: low cost of production, lightweight, and broad range of mechanical and chemical resistance properties. The combination of all of these factors has led to the enormous number of ways in which polyolefins are now being so vast in our lives [29].

3.3.1.1.1 Polyethylene

Polyethylene (PE) is the most basic plastic in terms of structure, and it is made by additional polymerization of ethylene gas in a high-temperature pressure reactor. Depending on the temperature, pressure, and catalyst of polymerization, a variety of low, medium, and high-density resins is produced. The processing conditions determine the properties of the final outcome [30].

The advancement of PE and its derivatives has revolutionized the market, allowing the plastic to better compete with glass bottles. Polyethylene-based materials are currently preferred for milk and juice bottles, grocery, retail, trash bags, as well as bread and frozen food bags. Polyethylene is a heat-sealable material that can be formed into tough films with good moisture and water vapor barrier. Furthermore, when heat resistance is required for packaging, so polypropylene-based materials opt. Nonetheless, when compared with other plastics, they do not provide in particular a high barrier to fats, oils, or gases [23].

Low-density polyethylene (LDPE) and high-density polyethylene (HDPE) are the two of the most commonly used polyethylenes in the food industry. LDPE is nontoxic, stretchable, and shrinkable. It is a good moisture barrier, but it has low oxygen permeability and is ineffective as an odor barrier. It is widely used for bags as well as coating papers or boards because it is less expensive than most films. Because it is stronger, thicker, less flexible, and brittle, HDPE is a better barrier to gases and moisture than LDPE. HDPE packaging is waterproof and tear and puncture-resistant [30].

3.3.1.1.2 Polypropylene

Polypropylene (PP) is a low-cost polymer that is catalytically synthesized from propylene. It has good advantages such as good impact resistance, transparency, excellent mechanical property, high melting point, and low density, making it ideal for a wide range of applications. Also, PP has a respectable degradability among polyolefines. Experiments, however, revealed that when used in room-temperature applications, PP has excellent and desirable physical, mechanical, and thermal properties. The PP material has some drawbacks as well, including low-temperature standing, brittleness, and poor aging resistance [31, 32].

Oriented PP is a clear, glossy film with high tensile and puncture resistance. It has a moderate permeability to gases and odors and a higher barrier to water vapor, so humidity changes are unlikely to affect it. It stretches, but not as much as polyethylene While the properties of PP and PE are similar, there are some differences. Lower density, a higher softening point, and greater rigidity and hardness are among these characteristics [33]. It is used in applications that are similar to those of LDPE [34]. It is most commonly found in the packaging of biscuits, snacks, and dried foods [35].

Although these are used primarily for food applications, there are numerous reasons for their success and rapidly increasing market share in packaging technology. Yet, the majority disadvantage of this kind of polymers produced is their poor biodegradability. Gradually, they contributed significantly to a major source of waste accumulation after being used, thus getting involved in environmental hazards. Hence, the incompatibilities with those synthetic materials for packing small volumes of packages necessitate the search for another viable option [36].

3.3.2 Health and environmental impacts

While food packaging is an important part of the food industry and helps to store foods properly, it can also be a source of concern for food safety. When heated, certain packaging materials, such as certain types of plastic, polythenes, and so on, can release toxins, posing a health risk to consumers. A variety of substances are used in food packaging, including dyes for printing interesting and colorful labels and adhesives to keep packaging closed. To protect consumers effectively, the relevant authority certifies each of these food packaging materials independently, subjecting them to stringent testing standards.

Over the last few decades, the food industry is growing exponentially. On the flip side, the impact of industrial development needs to be analyzed. The materials used in food packaging have a negative impact on the environment. The synthetic polymers, including plastics, and their specific use in the food packaging industry posed a burden on annual solid waste generation. In the current scenario, solid waste management is a noteworthy challenge to a human in concern of the environment, and plastic-based polymers waste is a leading one and remains associated with several ecological issues. The more critical increase in packaging material usage and failure of the natural recycling system, along with the high cost of conventional packaging materials, all prompted to look for alternatives [37]. Natural polymers are the first choice for packaging need to explore and utilize on a large scale. They combine the available packaging materials to be associated with minimal damage, and the latest inventions, including, of course, biodegradability.

3.3.3 Natural polymers

A lot of emphasis is given in recent times to create new, more productive, eco-friendly content and develop packaging material compatible with food products. The use of natural polymers is a key major packaging material for the future. Biopolymers for packaging applications were developed because they were not only biodegradable but also divisible and displayed additional advantageous properties similar to customized applications. They are exceptionally well suited for the use of advanced packaging technologies such as active, intelligent, and modified atmosphere packaging [38]. While the concept of sustainable packaging is also prevailing, recent investigations are, therefore, focused on procuring materials from bioresources, and their utility in the synthesis of natural polymeric choices to taking over and replacing the chemical-based ones. Biopolymers are made from bio-based resources, though the bio-based resource content varies in practice [39]. Among the polymers derived from natural resources, bioplastic is a leading candidate.

3.3.3.1 Bioplastics

Nowadays, bioplastics, whose building components are originated from renewable raw materials, have become more popular. These products deal with a high proportion of potentials for enhanced natural recycling. Biomass for bioplastics production can be extracted directly from plants or produced by microorganisms in fermentative processes. Some currently produced and applied biopolymers based on renewable resources include Poly Lactic acid, cellulose, and starch, which are biopolymers that are directly obtained from argo-wastes [40]. Being materials produced from agricultural feedstocks, such sustainable concept, enlighten the approach of turning waste into a wealth of resources. However, "bio-based" does not necessarily imply "biodegradable" or "compostable" [41, 42]. Bio-based products contain renewable raw materials that can be replenished through natural processes. Polymers that can be degraded by microorganisms in the environment over time are examples of biodegradable products [43]. Biodegradable plastics include compostable bioplastics. As a matter of fact, while all compostable bioplastics are biodegradable, not all biodegradable bioplastics are compostable.

Although these materials are environmentally friendly and easy to recycle, they have a number of disadvantages. Physical protection and mechanical strength for transportation and storage are the essential requirements for packaging. The main issue with these innovative materials if used alone for packaging purposes, biopolymers, or bioplastics shows some limitations in terms of functionality: their poor water barrier properties, brittleness, high vapor permeability, and low heat resistance [44–46]. Thus, biopolymers are strengthened with fillers to enhance their mechanical properties, barrier properties, and heat outstanding [44, 45]. Additionally, material product compatibility is an important factor to consider before commercial application. Such products in food packaging provide less evidence for the large-scale commercial claim.

3.3.3.1.1 Bioplastic reinforcement

As mentioned above, bioplastics alone have some limitations, including low water, heat resistance, and brittleness. Interestingly, some research has been done on the reinforcement of bioplastics through chemical and physical cross-linking treatments to enhance the strength of bioplastics. Quite a lot of potential additives can be used as fillers for bioplastics; these additives are in the micro to nano-sized form. Such fillers can boost the mechanical properties, barrier properties, and heat resistance of bioplastic composites compared with those of virgin bioplastics [44]. Although filler reinforcement can greatly improve the bioplastic performance, the environmental and human health safety concerns posed by these materials during their application should not be forgotten [47, 48].

4. Prospects of biocomposites for food packaging

A polymer composite is a multiphase material in which reinforcing fillers are integrated with a polymer matrix, resulting in synergistic mechanical properties that neither component alone can achieve [49]. Biocomposites are composite materials composed of natural fiber and biopolymers such as polysaccharides. Plant-derived fiber and bio-derived plastics resemble biopolymer or bioplastic; these kinds of composites are sometimes referred to as green composites and apparently exhibit more friendliness. Plus, they include biofibers and matrix polymer systems as the combination of two or more biopolymers may result in the creation of a new biopolymer tailored to specific needs and with brand new or more enhanced features [50].

Biocomposite packaging options can be made from a variety of natural sources, including polysaccharides. In current times, the polysaccharide family has managed to develop as novel origin materials as a replacement for their nonbiodegradable petrochemical-based counterparts. The ability to produce and contribute to the formation of a variety of polysaccharide films by imparting hardness, viscosity, and gel-forming capacity. The nontoxic properties allow for biodegradation and do not produce harmful by-products to the environment. It also has excellent gas permeability properties, which extend the product's shelf life [49].

4.1 Polysaccharides

Biopolymers used as raw materials in the manufacture of biodegradable films should be renewable, abundant, and cost-effective. In some cases, they can be derived from waste. Polysaccharides such as starch, cellulose, and chitosan are among the materials being researched under consideration for biodegradable packaging films and biocomposites. These polysaccharides can procedure films with good barrier properties against gas exchange including oxygen and carbon dioxide. On the other hand, tensile strength and elongation percentage are the important mechanical properties because their desirable values are needed to maintain the integrity of the packed food. The tensile strength values that have been showed by polysaccharide-based films differ, but actually some of them exhibit similar values to those noticed in synthetic polymers. Tensile strengths of films based on high amylose starch or chitosan, for example, are comparable to high-density polyethylene films. The major area of concern is the elongation percentage values, which are significantly lower than those observed in synthetic polymers. Accordingly, researchers are looking into combining polysaccharides with other materials to improve the barrier and mechanical properties of biopolymers that could replace synthetic polymers [51].

4.1.1 Starch

Starch is a polysaccharide that naturally accumulates in plants. Potatoes, corn, and wheat are the primary sources of starch for commercial production. Starch contains two major polymeric constituents: amylose in straight chains and amylopectin with highly branched glucose chains [52]. Starch on its own is brittle and incapable of forming films with the desirable properties. For product packaging, starch-based materials have poor mechanical properties. Unless it is plasticized with other materials, chemically modified, or modified with a combination of such forms of treatment, it lacks high elongation, tensile, and flexural strength. Rewardingly, glycerol is the key player used as a plasticizer [53].

4.1.2 Cellulose

Cellulose and its derivatives are among the most abundant and widely used polymers in the packaging industry. Cellulose is a very important polymer in the food industry. It is the well-known biodegradable polysaccharide from which cellophane film can be made. There are numerous natural sources of cellulose, such as biowastes and agricultural wastes, which explains why it is readily available and at competitively low prices. From 1839 to 2021, all past and present studies have introduced the discovery of cellulose and its numerous functional properties; its use in the preservation of fruits and vegetables and in the preparation of various types of composite films notably [54].

4.1.3 Chitosan

After cellulose, chitosan is the world's second most abundant polysaccharide. Because this biopolymer is primarily derived from waste products in the shellfish industry, commercial supplies are currently plentiful, and as a result, it is reasonably priced. Chitosan is a biocompatible, biodegradable, and nontoxic material that is ideal for packaging films. Chitosan is more versatile than chitin due to its structural properties and the ability to create films with different properties and barriers [55]. This biopolymer has been demonstrated to have excellent film and coating properties, as well as an inherent antimicrobial property. As a result, many chitosan-based films have been fabricated and applied in the food packaging industry. However, its high-water sensitivity causes a loss of barrier properties, limiting its industrial application for packaging. Blending this polysaccharide with other more water-resistant polymers has proven to be a viable solution to the solubility problem. Furthermore, it has been demonstrated that reinforcing this biopolymer with fillers can result in novel composites with improved physical properties, such as water resistance, without sacrificing biodegradability.

5. Conclusions

It is common knowledge that every human activity has an impact on the environment. The massive increase in demand for food and food products contributed to the refinement of current synthetic materials as well as the development of more useful and safe ones. The use of biopolymers and their development are one step toward green packaging. Several biopolymers were developed to achieve this goal adapting new avenue in eco-friendly food packaging. Such a change would undoubtedly reduce the use of packaging, a single-use material, minimizing the generation of waste, hence leading to more ecologically responsible packaging materials and achieving more clean processes. Bioplastics have considerable potential as replacements of fossil-based plastics in many applications; they have been applied in several food packaging industries. Furthermore, bio-based materials aid in the transformation of primary by-products into value-added by-products, particularly when residual biomass is used as a raw material in biocomposites. This is a significant growing opportunity for developing countries where agriculture is one of the main economic activities, with agriculture playing a critical role in the development of strategies toward more equitable markets from the standpoint of sustainable development. Furthermore, biomass-derived compounds have a lower overall environmental impact. Finally, the high versatility of biocomposite materials allows for the development of customized packaging materials for various products, as well as intelligent alternatives with enhanced properties, ensuring the product's quality, wholesomeness, integrity, and safety for a longer period of time. In this regard, there is a global trend toward developing materials with optimized properties in terms of product preservation, resource use, and waste generation throughout the entire cradle-to-grave path. In conclusion, the development of green biocomposites for the packaging industry has the potential to address modern society's need for sustainability.

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