FOOD PRESERVATION TECHNOLOGY SERIES

Edible Films *and* Coatings

Fundamentals and Applications

Edited by

María Pilar Montero García
M. Carmen Gómez-Guillén
M. Elvira López-Caballero
Gustavo V. Barbosa-Cánovas

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Preface

In recent decades, there have been many documents referring to research in the development of edible and nonedible films and coatings made from biodegradable materials. Before continuing, it may be useful to clarify what we mean by films and coatings, as there may be separate words for these two concepts in some languages while one word is used to refer to both in others. In both cases, they are materials that cover food, and they may also be described as edible packaging. Film is a type of packaging that is made separately and then applied to food as a covering. Coatings are solutions applied on the surface of food that remain attached to the food; often they are extremely thin and transparent, making them imperceptible to the human eye.

The advances in this area have been breathtaking, and, in fact, their implementation in the industry is already a reality, especially with regard to coatings, as their application in the food industry is relatively simple, despite the fact that there are always obstacles to be overcome. However, the development of biodegradable films is also a fact, although it is still in its infancy. One of the most typical cases is the manufacture of biodegradable bags made from potato peel or from starch obtained from various sources, generally cross-linked with polylactic acid.

Even so, there is still a need for broad development in various fields and from various perspectives. A particularly novel application is their use as edible coatings or films in the design of gourmet foods, where fantasy and imagination provide a lot of scope for innovation in terms of shapes, textures, and colors—in other words, sensory appearance in every sense. With new advances in the incorporation of bioactive compounds, the possibilities are numerous, as there are not only a wide range of compounds but also the ways in which they are incorporated and even loaded in carriers that control their release and activity present challenges in which further advances are constantly being made. Once again, there are two possibilities, depending on the form that the "activity" takes, whether it is directed toward the preservation of food or to the effect after ingestion. Films and coatings also have the potential for applications in agronomy, as yet little explored and exploited, which could provide considerable advances in the preservation and quality of food.

All these matters, and also the management of any waste produced, are rigorously treated in this book from a critical viewpoint, for we feel it is important not only to describe the scientific advances that have been made but also to comment on the weaknesses and gaps that may remain. We hope that this book proves to be a real advancement in comparison to previous publications, making it genuinely worth reading.

We acknowledge the collaboration of all those who have participated in the publication of this book and express our most sincere gratitude for their dedication, effort, and contribution.

The book is produced under the auspices of CYTED (Latin American Science and Technology Development Program), as part of the project "Obtainment of additive materials from plant by-products from the region and their application in the development of biodegradable packaging for agro-food and nutraceutical use" (Action 309AC0382), within the area of Promotion of Industrial Development. Accordingly, special emphasis has been placed on its applicability.

We are very fortunate to be performing work that continues to fill us with enthusiasm every day and that enables us to enjoy the studies in which we are involved—and we have found much enjoyment over the years of working together. We hope that you too will find much to enjoy in the pages of this book.

This is a great opportunity for the CYTED-Agrobioenvase group, providing a way for us all to come to a common understanding of the advances in this field. We will undoubtedly be enriched by these chapters with their different points of view and by the knowledge of all those who are involved. For this reason, we did not want the book to be produced only by the CYTED-Agrobioenvase group, feeling it necessary to include other groups of researchers who could provide new vitality and different viewpoints and thus enrich this work. Accordingly, we conducted an examination and selection of participants of great prestige, who are experts in their specific subject.

The 29 chapters are arranged into sections, making it easier for the reader to find information. We hope that the material presented will be of interest and that you will enjoy reading it.

Editors

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11

Films and Coatings from Agro-Industrial Residues

Mariana S.L. Ferreira, Renata Linhares, and Milena Martelli

CONTENTS

11.1 Introduction

Disposal of wastes from nondegradable packaging represents a worldwide huge problem; this fact has challenged the scientific community to develop biodegradable packaging to reduce the environmental impact (Krochta and Johnson, 1997; Tharanathan, 2003). Hence, the development of polymeric materials, based on renewable sources, has become increasingly important over the last two decades, due to the inevitable rising prices of petroleum-based materials and the relevant environmental concerns.

Proteins and polysaccharides have historically been the most tested renewable and biodegradable materials for film or coating processing with the potential to replace many of the currently used hydrocarbon-derived plastics. Indeed, a wide range of naturally occurring polymers derived from renewable resources are nowadays available for biomaterials applications, such as polysaccharides from plants (starch, cellulose, pectin, alginate, carrageenan, gums), polysaccharides from animals (hyaluronic acid, chitin, chitosan), polysaccharides from fungi (pullulan, elsinan, scleroglucan), polysaccharides from bacteria (xanthan, polygalactosamine, curdlan, gellan, dextran, chitin), proteins (soy, zein, wheat gluten, casein, serum, albumin, collagen/gelatin), lipids/surfactants (acetoglycerides, waxes, surfactants), and other polymers (lignin, natural rubber) (Yu, 2009). However, even if these polymers present a renewable feature, they have been extracted from sources that could be further used for human consumption. Therefore, the utilization of alternative sources from agro-industrial residues would be a promising way of recycling such wastes into useful products in an eco-friendly manner.

Bio-derived polymers can be alternatively obtained from agro-industrial residues, which represent a nutritional, inexpensive, and eco-friendly raw material. In food agro-industry, about one-third of the total production has been annually discarded. Fruits and vegetables are extensively processed generating a very large amount of residues, mainly composed of peels, seed, stalks, and pomace, which are frequently discarded. In the same way, agricultural and forestry wastes (sugarcane bagasse, cereal straw, hulls and bran, oil cake, fruit pomace, etc.) constitute very profitable biomass residues for biopolymer production. Chitin and chitosan are also important bio-derived polymers generated by the seafood processing industry. Seafood by-products (head, skin, fin, scales, bones, cartilages, crustacean shell) represent novel sources that can be processed enzymatically for the production of these polymers. In this way, this chapter presents an overview of bio-derived polymers processed from agro-industrial residues in order to produce coating and film-forming matrices.

In brief, biopolymers, such as polysaccharides and proteins obtained from by-products of agricultural origin, have been more and more proposed for the formulation of biodegradable materials, since they are harmless, biocompatible, and susceptible to biodegradation, except when severe chemical modifications are applied, derived from renewable sources, and nontoxic to the soil and the environment. Additionally, in this chapter, some critical issues and strategies for future applications of alternative sources are discussed, highlighting some efforts to overcome the poor barrier properties, as well as some nutritional or biodegradability aspects, in order to boost their use as packaging material. Depending on specific applications of the films, targeted film functionality can be achieved by incorporating proper matrices and by improving biopolymeric extraction. More recently, nano-based materials from agro-industry by-products have been developed and applied into biopolymeric films, showing significant improvement in both mechanical and barrier properties.

11.2 Films and Coatings from Plant Industry Residues

11.2.1 Fruit and Vegetable Industry Residues

Plant residues are extensively processed for the beverage manufacture generating a large amount of residue, which is frequently discarded, causing disposal problems. This intense process entails the production of large amount of waste, estimated between 30% and 40% of agro-industrial waste. Classically, the outer layers and extremities of fruits and vegetables are removed during processing, mainly by peeling and pressing; they comprise essentially stalks, peels, seeds, and crashed pulps, which still contain large amounts of bioactive molecules and biopolymers that can be used for the preparation of biodegradable films and coatings.

11.2.1.1 Pectin Films

Pectin is one of the major cell wall structural polysaccharides of higher plants and thus widely available from underutilized agricultural waste. Since it is readily modified, through demethylation, considerable attention has been given to pectin in the preparation of biodegradable films and coatings. Pectin is composed of water-soluble pectinic acids (colloidal polygalacturonic acids) of different methyl ester contents and degrees of neutralization, able to form gels under appropriate conditions, such as with the presence of sugars and acids (Gitco, 1999; Ranganna, 1986).

Due to the gel-forming properties, pectin presents the potential to form a cohesive structural matrix prior to the preparation of biodegradable films (Arevalo et al., 2009; Batista, 2004; Nascimento et al., 2012). However, its operating efficiency depends on the nature of the ingredients added to the formulation; when glycerol and starch were added to the pectin filmogenic solution, the films showed good mechanical and flexibility properties (Fishman et al., 2000; Nascimento et al., 2012). In some cases, the use of glycerol or other suitable plasticizer is required to make starch-based films sufficiently flexible and nonbrittle. Indeed, the increase in glycerol concentration was directly related with the increase of strength and flexibility of pectin-based films (Coffin and Fishman, 1993, 1994). Pectin has been demonstrating high potential for the development of biodegradable films such as single or reinforcement material together with other matrices in composite films (Espitia et al., 2014; Galus and Lenart, 2013; Penhasi and Meidan, 2014).

TABLE 11.1

Variability in Anhydrouronic Acid, Methoxyl Content, and Gel Grade

Fruit Wastes Used for Pectin Extraction	Anhydrouronic Acid (%)	Methoxyl Content (%)	Gel Grade (%)
Mango peel	56.7	7.3	199
Jackfruit ring	66.0	7.7	159
Banana peel	53.0	7.0	99
Nutmeg ring	59.5	7.5	167
Pumello peel	64.2	8.6	202
Passion fruit ring	46.2	5.0	73
Cocoa pod husk	52.8	7.0	129
Lime peel	72.5	9.9	213
Mangosteen ring	73.2	10.5	171

Madhav and Pushpalatha (2002) showed that very pure pectin, presenting high levels of anhydrouronic acid, can be obtained from different fruit by-products, such as mangosteen rinds and lime peel (Table 11.1). Currently, the main sources of industrial by-products for the extraction of pectin are apple pomace and citrus peels (Videcoq et al., 2011). Previous works have shown that films made from elastic methoxyl citrus pectin and high amylose starch have very good mechanical properties (Coffin and Fishman, 1993, 1994). The films had tensile strength of the order of 3×10^8 dyn/cm^2, approaching the values found in commercial plastics (Coffin and Fishman, 1993). Further blend films based on sugar beet and almond pectin were developed, presenting similar mechanical properties comparable to citrus pectin films, but very low oxygen permeability (OP) (Coffin and Fishman, 1994).

Overall, fruit pomaces are mainly obtained from the fruit juice industry and represented a very rich source of pectin. The passion fruit shell (mesocarp) is a by-product of the industrial juice production and represents about 55%–90% of the fresh fruit (Arvanitoyannis and Varzakas, 2008; Kulkarni and Vijayanand, 2010). About 15% (db) of pectin can be extracted from the dried mesocarp of passion fruit (Kulkarni and Vijayanand, 2010). Previous study showed that films prepared with passion fruit mesocarp flour, using glycerol as plasticizer, presented higher viscosity, endurance, and strength when compared to starch films. On the other hand, it showed that they had low flexibility and high hydrophilic character (Nascimento et al., 2012).

Hence, water extracts of fruit pomace have also been appointed as a new film-forming material, able to form natural colors and fruit flavors of edible films. Cranberry pomace extracts were used to form films added with low or high methoxyl pectin, sorbitol, or glycerol (Park and Zhao, 2006). Films incorporated with low methoxyl pectin and sorbitol showed higher tensile strength, lower elongation at break, and lower permeability to water vapor when compared to other films obtained. Hence, targeted film functionality can be achieved by incorporating proper pectin type and concentration and plasticizer into pomace extracts (Park and Zhao, 2006).

Fruit pomace represents also good candidates for thermoforming applications, since some of these components aside from pectin, such as proteins, organic acids, and sugars, have thermoplastic properties. For this reason, fruit pomaces can also be processed to create biocomposites through the incorporation of other biopolymers. Park et al. (2010) demonstrated the feasibility of creating biocomposite boards from berry fruit pomaces (blueberry, cranberry, and wine grape pomaces) combined with soy flour, which can be applied in the packaging industry.

11.2.1.2 Starch Films

Globally, starch has been considered as one of the most promising resources on the development of biomaterials. The starch can be also extracted from fruit by-products, and according to its origin, this biopolymer will have different physicochemical properties and functionalities. Therefore, starch-based films can present different mechanical and barrier properties (Liu et al., 2005). Starch-based films provide effective barriers against oils and fats, but moisture barriers are ineffective and thus considered as limiting attribute (Durango et al., 2006; Larotonda et al., 2004; Oliveira and Cereda, 2003). Similar to pectin films, polyols are commonly used as plasticizers in starchy films to improve their flexibility (Gontard et al., 1993; Laohakunjit and Noomhorm, 2004). However, the hygroscopic characteristics of glycerol-plasticized starch films contributed to increase even more film hydrophilicity (García et al., 2009).

Remarkably, the unexplored parts of fruits have also been used to obtain starch-based films. Barbosa et al. (2011) produced films based on starch extracted from jackfruit pits added with glycerol. The plasticized starch films prepared from jackfruit pits showed high hydrophilicity and water vapor permeability (WVP) and low stability. Typically, the hydrophilic behavior depended directly on the amount of glycerol and water activity of the starch films. In the same context, Ooi et al. (2012) prepared biodegradable films with tropical fruit waste flours blended with polyvinyl alcohol (PVA). Rambutan skin waste flour and PVA, in the presence of glycerol as plasticizer or cross-linker agents, were used to prepare biodegradable films. In the preparation of plasticized biodegradable PVA/tropical fruit waste flour blends, these authors showed an improvement of the tensile strength and Young's modulus, lower elongation at break, and lower absorption and WVP throughout the cross-linking reaction.

11.2.1.3 Films from Fruit and Vegetable Purees

Since 1996, the fruit and vegetable purees obtained from industrial by-products or destined to waste, especially from seasonal fruits, have been suggested as an alternative source for the production of flexible films (McHugh et al., 1996). These films are mainly composed of cellulose and pectic compounds. Banana, for example, is a very fragile and highly perishable fruit, which can be rapidly rejected by the consumers (Martelli et al., 2013); from its harvest to the market, losses can reach up to 50% of the total volume produced (Sebrae, 2008). Therefore, overripe fruits represent an interesting raw material for plastic processing (Martelli et al., 2013).

The banana (Martelli et al., 2013; Sothornvit and Pitak, 2007), tomato (Du et al., 2008, 2009), mango (Azeredo et al., 2009; Sothornvit and Rodsamran, 2008, 2010), and carrot (Wang et al., 2011) purees are being processed and evaluated with respect to film production, characterization, and bactericide and fungicide properties, resulting in materials with good oxygen barrier, moisture, carbon dioxide, lipids, flavors, and acceptable mechanical properties. In Table 11.2, some results of mechanical properties, WVP, and OP of the films produced from mashed pulp of fruits and vegetables are summarized.

Films based on fruit purees offer sensitive mechanical properties and little flexibility, requiring the addition of plasticizers or other polysaccharides to improve resistance and processability. The incorporation of pectin, cellulose nanofibers, and chitosan nanoparticles has been evaluated such as reinforcing materials within fruit puree matrix for film production. The formation of nanocomposites, either fiber or particle forms, also proved very useful in improving the mechanical and barrier properties (Azeredo et al., 2009; Lorevice et al., 2012; McHugh and Olsen, 2004; McHugh and Senesi, 2000). Taken both aspects together, Martelli et al. (2013) demonstrated that overripe bananas with chitosan nanoparticles and small concentrations of pectin and glycerol proved satisfactory results when employed as a raw material for processing edible films. The obtained films showed good mechanical properties, although lacking of antimicrobial activity, due to the small amount of nanoparticles added to the chitosan films.

Multicomposite plant residues obtained from the juice processing of whole fruits and vegetables (Ferreira et al., 2015), which means including all edible and nonedible parts, such as peels, seeds, and stalks, represent a rich source of biopolymers, especially dietary fibers (Andrade et al., 2014). Therefore, it has been recently applied to develop biodegradable films and coatings (Andrade et al., 2016; Fai et al., 2016; Ferreira et al., 2016). Although the rheological behavior of the filmogenic solutions revealed the predominantly liquid-like character of the samples, the use of fruit and vegetable residue flour resulted in stand-alone and very flexible films without the addition of plasticizers (Ferreira et al., 2016). Hence, fruit and vegetable residues flour has been applied in the film packaging and coating of fruits and minimally fresh-cut carrots (Fai et al., 2016; Ferreira et al., 2016).

The formulated films exhibited promising characteristics as homogeneous aspect and high water solubility, which can be used for specific purposes in the food industry. Incorporation of potato skins

TABLE 11.2

Mechanical Properties (Maximum Strength at Break [σ_{max}] and Maximum Elongation [ε_{max}] and Elastic Modulus or Young's Modulus [E]) and Barrier (Water Vapor Permeability and Oxygen [O_2P]) of Biodegradable Films Based on Mashed Fruits and Vegetables

Film	σ_{max} (MPa)	ε_{max} (%)	E (MPa)	WVP (g·mm/ kPa·h·m^2)	O_2P (cm^3·μm/ m^{2}d·kPa)	Test Conditions (WVP, O_2P)
Peach (McHugh et al., 1996)	—	—	—	4.2	69.6	RH = 80% T = 25°C
Damascus (McHugh et al., 1996)	—	—	—	4.3	—	RH = 80% T = 25°C
Apple (McHugh et al., 1996)	—	—	—	5.8	—	RH = 76% T = 25°C
Pear (McHugh et al., 1996)	—	—	—	7.8	—	RH = 74% T = 25°C
Apple, alginate (~1.4%) (Rojas-Grau et al., 2007)	2.9	51.1	7.1	4.95	0.43[c]	RH = 83% T = 25°C
Banana flour (4%), glycerol (30%) (Sothornvit and Pitak, 2007)	6.0	8.2	1.8	—	23	RH = 50% T = 25°C
Tomato, pectin (~2.1%) (Du et al., 2008)	11.4[a], 13.7[b]	11.2[a], 9.6[b]	248[a], 317[b]	2.4[a], 2.2[b]	—	RH = 81% T = 25°C
Mango (Sothornvit and Rodsamran, 2008)	1.2	18.5	8.3	8.9	41.2	RH = 50% T = 27°C
Mango (Azeredo et al., 2009)	4.1	44.1	19.9	2.7	—	RH = 83% T = 25°C
Overripe banana (4.5%) (Martelli et al., 2013)	1.1 ± 0.1	15 ± 2	11 ± 1	3.03	—	RH = 54% T = 25°C
Overripe banana (4.5%), pectin (0.5%) (Martelli et al., 2013)	3.2 ± 0.5	23 ± 3	21 ± 3	2.95	—	RH = 54% T = 25°C
Overripe banana (4.5%), pectin (0.5%), chitosan nanoparticles (0.2%) (Martelli et al., 2013)	4.5 ± 0.7	18 ± 2	43 ± 3	2.33	—	RH = 54% T = 25°C
Carrot (Wang et al., 2011)	7.5–21.9	4.4–46.2	—	0.26–0.99	10.8–17.5[c]	RH = 81% T = 23°C

[a] Batch process.

[b] Continuous process.

[c] Relative humidity (RH); RH, 50% and T, 25°C.

improved the tensile strength of films (Andrade et al., 2016; Ferreira et al., 2016). However, the high content of soluble compounds, such as sugars and globular proteins, has been appointed as a crucial factor in providing more flexibility but also less strength and stretchability of films than fruit starch–based films (Andrade et al., 2016; Sothornvit and Rodsamran, 2008).

11.2.2 Sugarcane Bagasse

Sugarcane bagasse (or "bagasse," as it is commonly called) is one of the largest cellulosic agro-industrial by-products. It represents a fibrous residue of cane stalks leftover after the crushing and extraction of sugarcane juice for ethanol and sugar production. The sugar and growing ethanol production makes the sugarcane industry one of the main economic segments in Brazil, the country leader in the sugarcane ethanol production. Generally, sugarcane mills generate approximately 225 kg of bagasse (db) per ton of cane; especially 70–80 million tons of dried bagasse is annually available in China, while in Brazil considering jointly sugar and ethanol production, it reaches 140 million tons (McKendry, 2002; Porto et al., 2013).

The bagasse contains up to 75% of cellulose and hemicellulose. It represents a complex polymer that chemically is mainly composed of, in dry-weight basis, about 40%–50% of cellulose forming a crystalline structure; 25%–35% of hemicelluloses, which are mainly composed of xylose, arabinose, galactose, and mannose monomers; and about 19% lignin and minor amounts of minerals, waxes, and other compounds (Adsul et al., 2004; Pandey et al., 2000; Jacobsen and Wyman, 2002).

Especially, in the biotechnology industry, bagasse has been considered a low-cost source for the extraction of lignocelluloses, which are being used as raw material for the development of various products, offering significant economic, environmental, and scientific benefits (Adsul et al., 2004; McKendry, 2002; Sabiha-Hanim and Siti-Norsafurah, 2012). The use of lignocellulosic feedstock for the development of biodegradable films or coatings can be considered an important and promising feature due to the potential to form an excellent barrier against WVP, which is generally increased in films based on biopolymers having very hydrophilic characteristics (Doherty et al., 2007; Driemeier et al., 2011).

Hemicelluloses extracted from crop residues present a good potential for the development of biodegradable films. Recently, Sabiha-Hanim and Siti-Norsafurah (2012) developed biodegradable films with alkaline hemicellulose extracted from crushed sugarcane. The different extracts of hemicelluloses resulted in films with thickness between 0.13 and 0.15 mm and are presented with wide-ranging properties, for instance, 36.9%–67.1% water solubility, 250.4–483.3 g·m²/day WVP, and 0.31–1.72 MPa tensile strength.

Previous work has shown that biodegradable films developed from hemicelluloses of oil palm fronds extracted by using different concentrations of alkali solution presented good barrier properties such as tensile strength between 11 and 15 MPa, 64%–93% water solubility, and 180–210 $g{\cdot}m^2$/day WVP (Noor Haliza et al., 2006). All hemicelluloses alkaline extracted produced self-supporting films with different properties, according to the difference in hemicelluloses composition, particularly the lignin content (Noor Haliza et al., 2006; Sabiha-Hanim and Siti-Norsafurah, 2012).

The bagasse contains biopolymers and antioxidant compounds mainly represented by the lignin–hemicellulosic complex, which have shown film-forming potential with hydrophobic and good mechanical characteristics. In addition to this film-forming potential, bagasse has also been tested as reducing free radicals (Adsul et al., 2004; Dizhbite et al., 2004; Fengel and Wegener, 1989). Indeed, the lignin extracted from crushed sugarcane is a natural phenolic polymer, which has a potential antioxidant. Li and Ge (2012) showed that lignin alkali extracted from bagasse has a significant free radical scavenging activity, due to their large amounts of phenolic hydroxyl (OH) and methoxyl groups (OCH_3) obtained during alkaline processing treatment. These functional groups played more important roles in the antioxidant activity of lignin than the molecular weight and polydispersity. Even if no relationship between film-forming and antioxidant capacities of bagasse is available in the literature, the alkali treatment applied for hemicelluloses extraction can add an antioxidant attribute to the bagasse-based films.

11.2.3 Residues from Cereal Straw, Bran, and Other Fiber Sources

The global agricultural sector produces very large amounts of biomass from several other crops in addition to sugarcane, such as soybeans, maize, rice, and wheat. These agricultural crop residues, mainly represented by the dry plant stalks, such as cereal straw and also bran, are produced in billions of tons around the world representing an abundant, inexpensive, and readily available source of lignocellulosic biomass.

By-products from the cultivation of corn, wheat, rice, sorghum, barley, sugarcane, pineapple, banana, and coconut are the major sources of agro-based biofibers (Reddy and Yang, 2005). These lignocellulosic fibers include advantageous characteristics when added as reinforcement to traditional biopolymeric fillers such as gluten and starch. They have low density, nonabrasive nature, and high levels of fillers, availability, and renewability (Pervaiz and Sain, 2004; Rouison et al., 2004; Woodhams et al., 1984). Moreover, these fibers provide high stiffness and tensile strength to the films (Satyanarayana et al., 2009).

Therefore, agricultural activities generate a substantial volume of waste that provides renewable fiber sources that can be readily incorporated in the production of biodegradable films. Several types of natural fibers from plant by-products have been explored as fillers in starch- and gluten-based biocomposite films, for example, pea hulls (Chen et al., 2009), coconut, sisal and jute fibers (Corradini et al., 2009), wheat straw (Montaño-Leyva et al., 2013), and lignin extracted from wheat straw (El-Wakil, 2009).

Several blends of composite films based on fibrous lignocellulosic components derived from agro-industrial wastes resulting from sugarcane, citrus fruits, corn, wheat, and wood processing, in conjunction with gelatin, starch, and polyvinyl alcohol (PVA), have been proposed (Chiellini et al., 2001, 2004). Notwithstanding the hydrophilic character of the biopolymers used as fillers, these agro-industrial residues showed to be suitable for blending in higher amounts in the production of cast films in the presence of cross-linking agents.

The wheat straw is an important agricultural waste applied in the biodegradable films production. Over 500 million of tons of wheat straw are annually produced in the world (Zhang et al., 2012). In Canada, the 6th in the world rank of wheat production, tons of unused wheat straws are produced each year and only a very small percentage has been applied as biomaterial or energy production (Tampier and Probe, 2002). Similar to other fibrous materials, the wheat straw has a suitable chemical composition for a film-forming material, consisting mainly of cellulose, hemicelluloses, and lignin, as summarized by Carvalheiro et al. (2009) (Table 11.3).

More recently, studies have also added natural lignocellulosic fiber from wheat straw (Montano-Leyva et al., 2013) by using a thermomechanical process and also other natural sources of lignocellulosic fiber as hemp and wood (Kunanopparat et al., 2008a,b) to form wheat gluten–based composite materials. Addition of natural fiber, in compression-molded films, has significantly improved the mechanical properties of these matrices, by increasing tensile strength and elastic Young's modulus, despite the decrease in the elongation at the break.

Hemicelluloses from wheat straw were also applied as reinforcement material in gum bases, such as κ-carrageenan/locust bean gum polymeric blend films (Ruiz et al., 2013). The incorporation of hemicelluloses from wheat straw, under certain proportion and in the presence of glycerol, caused decrease in WVP and increased in tensile strength, presenting a good potential as reinforcement for biodegradable films.

Rice bran is the most important rice by-product available worldwide. It is produced in large quantities and is considered as a low-cost underutilized by-product of rice-milling industry, which presents a good protein quality. Defatted rice bran contains about 12%–20% of total protein (Hamada, 2000), among which are different types of albumin, globulin, prolamin, and glutelin (Adebiyi et al., 2008b). In the last decades, its film-forming potential has been investigated in the literature (Adebiyi et al., 2008a; Gnanasambandam et al., 1997; Shih, 1996; Shin et al., 2011). Globally, the rice bran protein films presented functional properties comparable to those of the soy protein–based ones (Adebiyi et al., 2008a).

The corn stalk and corn cob are also widely produced and also represent interesting agro-industrial residues. Kayserilioglu et al. (2003) showed that the extracted xylan corn stalk added to a wheat gluten matrix has the potential to form suitable biodegradable films. Moreover, corn cobs have been proposed as filler in chitosan-based films in the presence of a cross-linking agent (Yeng et al., 2013).

TABLE 11.3

Average Macromolecular Chemical Composition of Wheat Straw (% Dry Weight)

Component	Learmonth (1971)	Carvalheiro et al. (2009)	Kabel et al. (2007)	Nabarlatz et al. (2007)
Cellulose	56.7	38.9	31	28.4
Lignin	16.6	—	—	—
Pentosans	28.4	—	—	—
Hemicelluloses	—	23.5	24.2	22.5
Xylan	—	18.1	20	17.4
Arabinoxylan	—	3.0	2.5	2.5
Acetyl groups	—	2.5	1.7	2.6
Klason lignin	—	18.0	25	15.9
Proteins	—	4.5	—	—

The interesting composition of soy hulls gives to this soy by-product the film-forming potential. Soy hulls present an average of 56.4% alpha cellulose, 12.5% hemicelluloses, 18% lignin (Alemdar and Sain, 2008b), and 7%–16% pectin (Monsoor and Proctor, 2001). Even if not widespread in the literature, Park et al. (2010) showed a feasibility of a soy–pomace system to provide appropriate mechanical properties for a variety of biomaterial applications where biodegradability was the key factor.

Cotton stalk consists of the left biomass available in the field after the harvest of seed cotton. About 25 million tons of cotton stalks are generated annually in India (Shaikh et al., 2009), and cotton stalk is the major agricultural waste in Turkey (Akpinar et al., 2007). Cotton stalk contains about 69% holocellulose (36% cellulose and 21% hemicelluloses) and 27% lignin (Akpinar et al., 2007; Shaikh et al., 2009). Goksu et al. (2007) produced cast films based on xylan extracted from cotton stalk. However, self-supporting continuous films could not be produced using pure cotton stalk xylan; film formation was achieved by using 8%–14% (w/w) xylan and about 1% (w/w) lignin. The WVP decreased when xylan concentration increased, rising the films thickness. The glycerol addition resulted in more stretchable films presenting higher water permeability and lower water solubility values.

It is interesting to note that the use of all these biobased and renewable materials can be envisaged not only to offer an alternative to petroleum-based materials but also to offer lower environmental global impact. In this way, singular green composite materials have been studied and proposed as a source of bio-derived polymers, such as fibrous residues of *Posidonia oceanica*, an endemic Mediterranean alga, which are deposited in large quantities on the beache coasts (Ferrero et al., 2013). These residues reach the coast in a continuous movement forming very big dried balls. Recently, these authors proposed films by using a fibrous material derived from *P. oceanica* wastes with high cellulose content (90%, db) on a wheat gluten matrix by hot-press molding (Ferrero et al., 2013). The formed films showed cohesive matrices, and the water sensitivity depended on the cellulose content present in the dry waste used.

11.2.4 Edible Oil and Beverage Industry Residues

The use of inexpensive agricultural and food processing by-products also includes oil cakes as feedstock and has been highly favored in view of facilitating better utilization of edible oil cakes as sources of protein, for instance (Nigam et al., 2009). As mentioned earlier, rice bran protein can be used as a film-forming material. However, due to its poor solubility and tendency for aggregation (Adebiyi et al., 2008b), the protein isolated from deoiled rice bran residue has been considered as a more suitable material for film production (Shin et al., 2011). Indeed, rice bran protein is not able to form film with good physical properties, requiring different plasticizers, such as sucrose, fructose, glycerol, polypropylene glycol, and sorbitol, resulting in poor mechanical properties (Shin et al., 2011). In contrast, protein extracts from rice bran oil residues added by gelatin and red algae matrix were efficient for the production of multicomposite biodegradable films (Shin et al., 2011).

The wine grape pomace is a by-product of the alcoholic beverage industry, generally composed of 30% seeds and 70% skins and small stems (Guendez et al., 2005; Mattick and Rice, 1976). Compared to the stems, wine grape pomace seeds and skins have more oil, protein, pectin, and sugar (Llobera and Cañellas, 2007), besides being a rich source of dietary fibers and polyphenols (Katalinić et al., 2010). Overall, the grape skins include 39 types of anthocyanins, hydroxycinnamic acids, catechins, and flavonoids (Kammerer et al., 2004). Wine grape pomace extracts may be utilized as a film-forming material, since these extracts contain pectin, celluloses, and sugars (Deng et al., 2011; Deng and Zhao, 2011). The natural pigments, flavors, and polyphenols from wine grape pomace extracts would provide additional benefits to its applications, such as antimicrobial activity and antioxidant properties (Deng and Zhao, 2011; Tseng and Zhao, 2012).

In pomace-based edible films, the addition of small amounts of film-forming materials (protein or polysaccharide) is generally required to obtain films with adequate mechanical and barrier properties (Cerruti et al., 2011; Corrales et al., 2009; Deng and Zhao, 2011; Mayachiew and Devahastin, 2010). Cerruti et al. (2011) used the polyphenol-containing extract from winery waste as an additive to starch-based films (Mater-Bi®). As a result, an improved productivity in the film processing was achieved, together with an increase in elongation at break and delayed thermal aging of the films. The extract also assigned antimicrobial activity, reducing the rate of disintegration of Mater-Bi films.

Noticeably, food industry residues represent a rich source of biopolymers and functional compounds. Taken all these studies together, plant residues have demonstrated a good potential for application in the preparation of biodegradable films and may be a means to promote the use of these residues largely discarded.

11.3 Films and Coatings from Animal Industry Residues

During the manufacturing of animal products for human consumption (meat and dairy products) or for other human needs (leather), a large production of residues is generated. In the slaughter process, the main available waste products are the blood, liver, hair, bones, feathers, fat, and wastewater. In dairy plants, by-products obtained depend on the type of product produced (e.g., milk, cheese, butter, milk powder, condensate). In cheese production, the wastewater could have a considerable amount of whey. In addition, a large quantity of processing by-products are accumulated from marine bioprocessing plants, including fins, frames, heads, skin, viscera, and shells of crustaceans and shellfish. These residues or by-products present some additional applications, including the biopolymers extraction for developing biodegradable films and coatings.

11.3.1 Animal Bones, Skins, and Feathers

The main animal by-products obtained from the animal processing industry consist of parts of carcasses, catering waste (including used cooking oil), butcher and slaughterhouse waste, blood, feathers, wool, hides and skins, and fallen stock. In the animal industry, the quantity of animal by-products often exceeds 50% of the live weight, and the dressing percentages of carcasses range from 57% (standard cattle grades) to 70% (chicken), depending on the animal (FAOSTAT, 2014). The main polymers produced from animal bones, skins, and feathers are collagen, gelatin, and keratin, respectively.

Collagen is a fibrous structural protein, with a particular amino acid composition, rich in glycine (33%), proline (12%), alanine (11%), hydroxyproline (10%), and hydroxylysine (1%), and occurs as a significant component of the skin, bone, tendon, and connective tissues (Damodaran et al., 2008). For industrial production, first, the insoluble native collagen is converted into a suitable form for extraction by water heating at temperatures higher than 45°C. The production of collagen involves subsequently chemical and enzymatic treatments. One of the most important applications of collagen as packaging material is in the sausage production and also in other meat products, which, due to their preserved fibrous structure, display excellent mechanical and oxygen barrier characteristics (Langmaler et al., 2008).

Remarkable, collagen biomaterials have also wide applications in biomedicine, as reviewed by Lee et al. (2001): drug delivery systems as collagen shields in ophthalmology; sponges for burns/wounds; minipellets and tablets for protein delivery; gel formulation in combination with liposomes for sustained drug delivery, as controlling material for transdermal delivery; and nanoparticles for gene delivery and basic matrices for cell culture systems. It has been also studied and applied for tissue engineering including skin replacement, bone substitutes, and artificial blood vessels and valves.

Alternatively, gelatin is produced by partial hydrolysis of collagen under moist heating. The amino acid glycine is present in the most concentrated form with 20.6 g per 100 g gelatin, followed by proline with 11.7 g and lysine (3.4 g per 100 g gelatin) (GME, 2014). The degree of collagen conversion into gelatin is related to the severity of both the pretreatment and the warm-water extraction process, as a function of pH, temperature, and extraction time (Gällstedt et al., 2011). Hence, two types of gelatin can be obtained, the type A gelatin (isoelectric point at pH ~8–9) and type B gelatin (isoelectric point at pH ~ 4–5) obtained under acid and alkaline pretreatment conditions, respectively. As a result, the gel-forming properties are different between the two types of gelatin.

Industrial applications claim for one or the other gelatin type, depending on the degree of collagen cross-linking in the raw material. A recent review was published with wide information about collagen and gelatin extraction from new sources (Gomez-Guillen et al., 2011). Moreover, new processing conditions and potential novel or improved applications were also related. Indeed, many of which are largely based on induced cross-linking, blending with other biopolymers, or enzymatic hydrolysis (Gomez-Guillen et al., 2011).

Gelatin films have been widely studied as an application in food preservation, either as coatings or as films (Bergo et al., 2013; Gomez-Estaca et al., 2009; Gomez-Guillen et al., 2009; Tongnuanchan et al., 2013; Vanin et al., 2005). Although gelatin is considered highly hydrophilic, globally gelatin films present very good processability and acceptable barrier and mechanical properties. Edible coating was also studied as an oil barrier on deep fat frying of chicken nuggets (Martelli et al., 2006). Interestingly, the gelatin origin and film-processing parameters have significant influence on the functional properties of the resulting gelatin-based films (Gomez-Estaca et al., 2009). Polysaccharide–gelatin interactions have been applied for microencapsulation (Bruschi et al., 2003; Chilvers and Morris, 1987; Nakagawa, 2013), drug release (Kumar, 2000; Tabata and Ikada, 1998; Young et al., 2005), and tissue adhesion (Ohya et al., 2005).

In the same line, keratin comprehends a family of another fibrous protein, rich in cysteine, glycine, proline, and serine. Keratin can be mainly found in hair, wool, feathers, and other epithelial coverings (Perez-Gago, 2012). The amino acid contents vary between different keratins, depending on their nature and conformations: α-keratin is the principal protein of cytoskeleton intermediate filaments in mammalian epithelia, while α-keratin is mainly found in feathers, claws, beaks of birds, and reptilian skins (Kessel and Ben-Tal, 2011). For instance, chicken feathers are agricultural residues rich in keratin contents, probably the most abundant keratinous material (85%–99%) (Shi and Dumont, 2014). An estimated 5 million tons is produced annually as a waste stream from the production of chicken meat, of which over 65 million tons was produced worldwide in 2007 (Poole et al., 2009).

Keratin-based films can be processed after extraction procedures, and it was found that films were mechanically strong (Katoh et al., 2004; Yamauchi et al., 1996). Appropriate selection of plasticizer type and concentration can be helpful in controlling film properties, like WVP (Martelli et al., 2006). According to Shi and Dumont (2014), keratin-based films could have a promising use in the tissue engineering and medical fields, due to their suitable medium for the attachment and proliferation of mouse fibroblast and good mammalian cell adhesion and proliferation.

11.3.2 Milk By-Products

In 2011, the total milk and dairies production in the European Union reaches 156 million tons and 142 million tons, respectively, 98% of which was cows' milk (EUROSTAT, 2014). Bovine milk proteins consist of about 80% casein and 20% whey proteins (Damodaran et al., 2008). Whey proteins are beta-lactoglobulin, alpha-lactalbumin, bovine serum albumin, and immunoglobulin. The composition and functional properties of whey are highly variable as the main by-product of cheese production (Morr and Ha, 1993). About 9 kg of whey are formed when 1 kg of cheese is produced. Because this product is highly perishable, new processes are needed to make use of the possible residues.

Whey proteins have been extracted in order to produce coatings and films. Whey protein films have low tensile strength and high WVP due to the high proportion of hydrophilic amino acid in their structures (McHugh et al., 1994). Their mechanical properties can be improved by blending the protein with other biopolymers, like natural latex and egg white albumin (Sharma and Luzinov, 2013). Due to their good oxygen barrier, whey protein coatings substantially reduced oxygen uptake and rancidity of roasted peanuts (Maté et al., 1996) and improved microbial quality of poultry products (Fernandez-Pan et al., 2013).

11.3.3 Marine Food Processing

During marine food processing, a considerable amount of by-products is produced and that includes trimmings, fins, frames, heads, skin, viscera, and residues from crab, shrimp, and crawfish. Studies revealed that current discards from the worldwide fisheries would exceed 20 million tons, which is equivalent to 25% of the total production of marine capture fisheries (Kim and Mendis, 2006). However, some compounds could be isolated from these by-products, such as fish skin collagen and gelatin, fish oils, omega-3 fatty acids, fish bone as potential calcium or mineral sources, and chitin, chitosan, and their oligomers (Kim and Mendis, 2006). Apart from collagen and gelatin, chitin and chitosan are important bioactive compounds extracted from marine food processing.

Chitin is the second most abundant polysaccharide in nature after cellulose and is found in the exoskeleton of crustaceans, in fungal cell walls, and in other biological materials. Chitin is represented as a linear polysaccharide composed of β-(1→4) linked units of N-acetyl-2-amino-2-deoxy-D-glucose (Soares, 2009). Chitin can be processed in the form of films and fibers, as binders in the paper maker (as revised by Rinaudo, 2006). However, the most important chitin derivatives, in terms of application in biodegradable films and coatings, are the chitosan.

Chitosan (β-(1,4)-2-amino-2-deoxy-D-glucose) is produced by extensive deacetylation of chitin, as revised by Kumar et al. (2004), when the degree of deacetylation reaches values of about 50% and then becomes soluble in aqueous acidic media (Soares, 2009). Chitosan is a biodegradable, biocompatible, nontoxic amino polysaccharide that can easily form gels. Moreover, chitosan presents the potential interest as an inherent antimicrobial film-forming material (No et al., 2002). Due to these characteristics, several works have been studied using chitosan-based films/coatings of food products, as revised by No et al. (2007) mainly for improvement of quality and shelf life of fruits and vegetables (Assis and Britto, 2011; Chien et al., 2007; Devlieghere et al., 2004; Dong et al., 2004; Goy and Assis, 2014; Pilon et al., 2013).

Most of these studies have shown the antimicrobial activity of chitosan and the improvement of shelf life of the fresh food products. The typical mean of chitosan-processing films has been the casting method based on organic acidic water solutions. It is noteworthy that chitosan is already widely used internationally for different applications, but its potential for film packaging and coating applications is not completely explored, especially with regard to active packaging concerns (Fernandez-Saiz and Lagaron, 2011).

11.4 Nanoparticles Obtained from Alternative Sources and Their Application on Biopolymeric Films and Coatings

Among the main polymers that can be extracted from agro-industrial residues, especially chitosan and fibers have been produced in nanoscale in order to improve film/coating properties. In the main polymers, the reduced particle size has higher superficial surface and is more reactive (Durán et al., 2006). The higher reactivity is desired according to the chemical processes involved during film formation.

The study of cellulosic nanofibers as a reinforcing phase in nanocomposites started 19 years ago (Favier et al., 1995). Since then, a huge amount of literature has been devoted to cellulose nanofibers, and it is becoming an increasingly topical subject. Table 11.4 presented the main agro-industrial residues used to produce cellulose nanofibers. Different descriptions of these nanofibers are often referred to in the literature. These include “nanowhiskers” (or just simply “whiskers”), “nanocrystals,” or even “monocrystals.” These crystallites have also often been referred to in the literature as “microfibrils,” “microcrystals,” or “microcrystallites,” despite their nanoscale dimensions. The term “whiskers” is used to designate elongated crystalline rodlike nanoparticles, whereas the designation “nanofibrils” should be used to designate long flexible nanoparticles consisting of alternating crystalline and amorphous strings (Eichhorn, 2011; Silva et al., 2009). The shape and size distribution of fiber crystalline and amorphous strings depends on the lignocellulosic biomass (Elazzouzi-Hafraoui et al., 2008).

Cellulose nanofibers are essentially obtained according to the following steps: partial hydrolysis, using acid (HCl or H_2SO_4) or enzymatic treatments (xylanases and cellulases) to break fiber structure into crystals, and fragmentation using mechanical treatments (high-pressure or ultrasonic treatments). Combined processes can be used, and different nanofiber characteristics are obtained. In general, the addition of cellulose nanofiber improves mechanical and barrier properties of films (Alemdar and Sain, 2008a; Chauve et al., 2005; Samir et al., 2004).

TABLE 11.4

Main Agro-Industrial Residues Used to Produce Cellulose Nanofibers

Agro-Industrial Residue	Procedure	Nanoparticle Dimension	Applications	References
Wheat straw and soy hulls	Alkaline, acid, and mechanical treatments	WS, diameter 30–40 nm SB, diameter 20–120 nm Length, >100 nm	Reinforcement of starch-based thermoplastic polymer (improvement of tensile strength and modulus and glass transition shifted to higher values)	Alemdar and Sain (2008a,b)
Wheat straw	Alkaline and steam explosion, followed by acid treatment (HCl)	Diameter, 10–50 nm	Reinforcements of thermoplastic corn starch composites (improvement of tensile strength and modulus and a reduction in water sorption)	Kaushik et al. (2010), Kaushik and Singh (2011)
Curauá (C) and sugarcane bagasse	Alkaline and bleaching, followed by enzymatic preparation (hemicell/pectinase and endoglucanase) and sonification	C diameter, 55–109 nm Length, 1.3–4.1 μm SB diameter, 20–40 nm Length, 0.25–0.82 μm	Potential for reinforcing polymer composites	Campos et al. (2013)
Rice straw pulp	Grinding and high-pressure homogenization	Diameter, 4–13 nm	Reinforcement of chitosan films (improvement of mechanical and thermal properties)	Hassan et al. (2012)
Sugar beet	Chemical (NaOH, $NaClO_2$) and mechanical treatments (ultrahigh-pressure homogenizer)	Diameter, 30–100 nm Length, >1 μm	• Cellulose microfibrils: stable suspensions • Reinforcement of PVA and phenol formaldehyde resin	Dinand et al. (1996) Leitner et al. (2007)
Potato tuber cells	Alkaline, bleaching, and mechanical treatment (ultrahigh-pressure homogenizer)	Diameter, 2–4 nm Length, >1 μm	Reinforcement of potato starch nanocomposite films (improvement of mechanical properties and reduction in water uptake and water-diffusion coefficient)	Dufresne et al. (2000)
Alfa, eucalyptus, and pine fibers	Catalytic oxidation and mechanical treatment (ultrahigh-pressure homogenizer)	Diameter, 2–4 nm	Reinforcement of unbleached eucalyptus fiber matrix (enhancement of the mechanical properties and reduction in porosity)	Besbes et al. (2011), Alcala et al. (2013)
Sisal fibers	Acid hydrolysis, chlorination, alkaline extraction, and bleaching	Diameter, 2–11 nm Length, 360–1700 nm		Moran et al. (2008)

(*Continued*)

TABLE 11.4 (*Continued*)

Main Agro-Industrial Residues Used to Produce Cellulose Nanofibers

Agro-Industrial Residue	Procedure	Nanoparticle Dimension	Applications	References
Pea hull fiber	Acid hydrolysis, bleaching, and dialysis	Diameter, 7–12 nm Length, 240–400 nm	Reinforcement of pea starch films (improvement of mechanical properties, higher ultraviolet absorption, transparency, and water resistance)	Chen et al. (2009)
Hemp (H) and flax (F) fibers	Acid hydrolysis, bleaching, and dialysis or sonification	H diameter, 20–40 nm F diameter, 10–30 nm Length, 100–500 nm	Reinforcement of pea starch films (improvement of mechanical properties and water resistance)	Cao et al. (2008a,b)
Cassava bagasse	Acid hydrolysis, dialysis, and sonification	Diameter, 2–11 nm Length, 360–1700 nm	Reinforcement of cassava starch films (decrease of hydrophilic character and capacity of water uptake)	Teixeira et al. (2009)

The formation of nanocomposites by nanofiber addition proved very useful in enhancing both mechanical and barrier properties of puree films; the Young's modulus increased 16 times when 36 g of nanofibers/100 g of mango puree (db) was added (Azeredo et al., 2009). For the same concentration used, the tensile ultimate stress increased from 4.0 to 8.8 MPa and WVP decreased by 37%. The possible formation of an entangled network could be responsible for the strong increase in thermomechanical stability of films (Dalmas et al., 2007).

Chitosan nanoparticles have been also studied to improve mechanical properties of films/coatings. Despite their ability to form films, chitosan is known to possess good antifungal and antibacterial properties (Devlieghere et al., 2004; Dutta et al., 2009; No et al., 2007; Vasconez et al., 2009), both desirable for food applications. Recently, chitosan nanoparticles were successfully used as vitamin (B9, B12, C) carrier, with potential applications in foodstuffs (Britto et al., 2012).

The literature reports several attempts to produce chitosan particles with different particle sizes, by ion tropic gelation with sodium tripolyphosphate (Janes and Alonso, 2003) or methacrylic acid (MAA) polymerization (Moura et al., 2008). In the second case, the particle size is dependent on the chitosan concentration used in the nanoparticle preparation and is greatly influenced by the solution pH (pH sensitive). Nanoparticles obtained from both methodologies were incorporated on hydroxypropyl methylcellulose (HPMC) edible films (Moura et al., 2009). Nanoparticles obtained from MAA polymerization with the concentration of 0.2% (w/v) of chitosan presented the most important results for improving HPMC film properties: tensile ultimate stress increased from 30 to 67 MPa and WVP decreased by 40%.

Improvements on mechanical properties and WVP were also observed when the same concentration of MAA chitosan nanoparticles was used as reinforcement of banana puree films (Martelli et al., 2013). In low concentrations, chitosan nanoparticles have been confirmed to be nontoxic according to the analysis performed by Lima et al. (2010).

The approach of nanotechnology as reinforcements in composites offers a way for improving the agro-industrial residue uses, due to nanoparticle ability to chemically modify film/coating surface. A number of methods have been reviewed that enable nanoparticles to be extracted from either plant or animal sources. It has to be remembered that in order to do this, some efforts are needed in order to reduce the large amounts of energy used and effluent generation.

11.5 Concluding Remarks

The generation of immense quantity of agro-industrial residues has long been recognized as wastes, and huge efforts have been made to use these materials in different applications, especially as source of biologically active compounds, such as bio-derived polymers. Both plant and animal residues or byproducts are rich sources of some biopolymers that have been studied as an alternative to produce films and coatings, such as starch, pectin, collagen, gelatin, chitin, chitosan, and fats.

Noticeably, the main drawback of most biopolymer-based films/coatings is the mechanical and moisture barrier properties. It can be concluded that depending on specific applications of the films, targeted film functionality can be achieved by incorporating proper matrices and by improving biopolymeric extraction. To straight this point, several extraction processes have been described in the literature, as well as film and coating production based on blends or multicomposite formulations.

Hence, by producing blend composites, such as combining proteins (e.g., milk proteins, soy protein, collagen, and gelatin) with polysaccharides (e.g., starches, alginates, cellulose, and chitosan) or other polymers, it is possible to improve the barrier and physical properties of films. In other cases, crosslinking techniques could be an interesting process that accounts with chemical, enzymatic, and physical processes to attain materials with better properties. On the other hand, innovative applications need also to be explored in order to further enable uses of biopolymer-based eco-friendly packaging materials.

Recent progress has also been done in the area of nanocomposites with the purpose of improving biopolymeric film and coating properties. The main nanoparticles obtained from agro-industrial residues are cellulose nanofibers based on lignocellulosic biomass (wheat straw, soy hulls, rice straw, sugarcane bagasse, cassava bagasse, sisal, pea, hemp, flax, and others) and also chitosan nanoparticles from marine food processing or bacterial origin. It is important to emphasize that concerns about the toxicity and environmental impact of nanocomposites remain not fully understood, thus requiring more studies.

REFERENCES

Adebiyi, A.P., Adebiyi, A.O., Jin, D.H., Ogawa, T., and Muramoto, K. Rice bran protein-based edible films. *International Journal of Food Science & Technology* 43(3) (2008a): 476–483.

Adebiyi, A.P., Adebiyi, A.O., Ogawa, T., and Muramoto, K. Purification and characterisation of antioxidative peptides from unfractionated rice bran protein hydrolysates. *International Journal of Food Science & Technology* 43(1) (2008b): 35–43.

Adsul, M.G., Ghule, J.E., Singh, R., Shaikh, H., Bastawde, K.B., Gokhale, D.V., and Varma, A.J. Polysaccharides from bagasse: Applications in cellulase and xylanase production. *Carbohydrate Polymers* 57(1) (2004): 67–72.

Akpinar, O. et al. Enzymatic production of xylooligosaccharides from cotton stalks. *Journal of Agricultural and Food Chemistry* 55(14) (2007): 5544–5551.

Alcala, M., Gonzalez, I., Boufi, S., Vilaseca, F., and Mutje, P. All-cellulose composites from unbleached hardwood kraft pulp reinforced with nanofibrillated cellulose. *Cellulose* 20(6) (2013): 2909–2921.

Alemdar, A. and Sain, M. Biocomposites from wheat straw nanofibers: Morphology, thermal and mechanical properties. *Composites Science and Technology* 68(2) (2008a): 557–565.

Alemdar, A. and Sain, M. Isolation and characterization of nanofibers from agricultural residues—Wheat straw and soy hulls. *Bioresource Technology* 99(6) (2008b): 1664–1671.

Andrade, R.M.S., Ferreira, M.S.L., and Gonçalves, E.C.B.A. Evaluation of the functional capacity of fruit and vegetable residue flour. *International Food Research Journal* 21(4) (2014): 1675–1681.

Andrade, R.M.S., Ferreira, M.S.L., Gonçalves, E.C.B.A. Development and characterization of edible films based on fruit and vegetable residues. *Journal of Food Science* 81(2): (2016): 412–418.

Arevalo, K., Aleman, E., Rojas, G., Morales, L., and Galan, L.J. Properties and biodegradability of cast films based on agroindustrial residues, pectin and polivinilic alcohol (PVA). *New Biotechnology* 25 (2009): 287–288.

Arvanitoyannis, L.S. and Varzakas, T.H. Fruit/fruit juice waste management: Treatment methods and potential uses of treated waste. *Waste Management for the Food Industries* 2 (2008): 569–628.

Assis, O.B.G. and Britto, D. Evaluation of the antifungal properties of chitosan coating on cut apples using a non-invasive image analysis technique. *Polymer International* 60 (2011): 932–936.

Azeredo, H.M.C., Mattoso, L.H.C., Wood, D., Williams, T.G., Avena-Bustillos, R.J., and McHugh, T.H. Nanocomposite edible films from mango puree reinforced with cellulose nanofibers. *Journal of Food Science* 74(5) (2009): N31–N35.

Barbosa, H.R., Ascheri, D.P.R., Ascheri, J.L.R., and Carvalho, C.W.P. Permeabilidade, estabilidade e funcionalidade de filmes biodegradáveis de amido de caroço de jaca (*Artocarpus heterophyllus*). *Revista Agrotecnologia* 2(1) (2011): 73–88.

Batista, J.A. Desenvolvimento, Caracterização e Aplicações de Biofilmes à Base de Pectina, Gelatina e Ácidos Graxos em Bananas e Sementes de Brócolos. MSc dissertation (in Portuguese). Campinas, Brazil: Universidade Estadual de Campinas, 2004.

Bergo, P., Moraes, I.C.F., and Sobral, P.J.A. Effects of plasticizer concentration and type on moisture content in gelatin films. *Food Hydrocolloids* 32(2) (2013): 412–415.

Besbes, I., Vilar, M.R., and Boufi, S. Nanofibrillated cellulose from Alfa, Eucalyptus and Pine fibres: Preparation, characteristics and reinforcing potential. *Carbohydrate Polymers* 86(3) (2011): 1198–1206.

Britto, D., Moura, M.R., Aouada, F.A., Mattoso, L.H.C., and Assis, O.B.G. N,N,N-Trimethyl chitosan nanoparticles as a vitamin carrier system. *Food Hydrocolloids* 27(2) (2012): 487–493.

Bruschi, M.L., Cardoso, M.L.C., Lucchesi, M.B., and Gremiao, M.P.D. Gelatin microparticles containing propolis obtained by spray-drying technique: Preparation and characterization. *International Journal of Pharmaceutics* 264(1–2) (2003): 45–55.

Campos, A., Correa, A.C., Cannella, D., Teixeira, E.D.M., Marconcini, J.M., Dufresne, A., Mattoso, L.H.C., Cassland, P., and Sanadi, A.R. Obtaining nanofibers from curaua and sugarcane bagasse fibers using enzymatic hydrolysis followed by sonication. *Cellulose* 20(3) (2013): 1491–1500.

Cao, X., Chen, Y., Chang, P.R., Muir, A.D. and Falk, G. Starch-based nanocomposites reinforced with flax cellulose nanocrystals. *Express Polymer Letters* 2(7) (2008a): 502–510.

Cao, X., Chen, Y., Chang, P.R., Stumborg, M., and Huneault, M.A. Green composites reinforced with hemp nanocrystals in plasticized starch. *Journal of Applied Polymer Science* 109(6) (2008b): 3804–3810.

Carvalheiro, F., Silva-Fernandes, T., Duarte, L.C., and Gírio, F.M. Wheat straw autohydrolysis: Process optimization and products characterization. *Applied Biochemistry and Biotechnology* 153(1–3) (2009): 84–93.

Cerruti, P., Santagata, G., Gomez d'Ayala, G., Ambrogi, V., Carfagna, C., Malinconico, M., and Persico, P. Effect of a natural polyphenolic extract on the properties of a biodegradable starch-based polymer. *Polymer Degradation and Stability* 96(5) (2011): 839–846.

Chauve, G., Heux, L., Arouini, R., and Mazeau, K. Cellulose poly(ethylene-co-vinyl acetate) nanocomposites studied by molecular modeling and mechanical spectroscopy. *Biomacromolecules* 6 (2005): 2025–2031.

Chen, Y., Liu, C., Chang, P.R., Cao, X., and Anderson, D.P. Bionanocomposites based on pea starch and cellulose nanowhiskers hydrolyzed from pea hull fibre: Effect of hydrolysis time. *Carbohydrate Polymers* 76(4) (2009): 607–615.

Chiellini, E., Cinelli, P., Chiellini, F., and Imam, S.H. Environmentally degradable bio-based polymeric blends and composites. *Macromolecular Bioscience* 4(3) (2004): 218–231.

Chiellini, E., Cinelli, P., Imam, S.H., and Mao, L. Composite films based on biorelated agro-industrial waste and poly(vinyl alcohol): Preparation and mechanical properties characterization. *Biomacromolecules* 2(3) (2001): 1029–1037.

Chien, P.-J., Sheu, F., and Yang, F.-H. Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *Journal of Food Engineering* 78 (2007): 225–229.

Chilvers, G.R. and Morris, V.J. Coacervation of gelatin gellan gum mixtures and their use in microencapsulation. *Carbohydrate Polymers* 7(2) (1987): 111–120.

Coffin, D.R. and Fishman, M.L. Viscoelastic properties of pectin/starch blends. *Journal of Agricultural and Food Chemistry* 41(8) (1993): 1192–1197.

Coffin, D.R. and Fishman, M.L. Physical and mechanical properties of highly plasticized pectin/starch films. *Journal of Applied Polymer Science* 54(9) (1994): 1311–1320.

Corradini, E., Imam, S.H., Agnelli, J.A.M., and Mattoso, L.H.C. Effect of coconut, sisal and jute fibers on the properties of starch/gluten/glycerol matrix. *Journal of Polymers and the Environment* 17 (2009): 1–9.

Corrales, M., Han, J.H., and Tauscher, B. Antimicrobial properties of grape seed extracts and their effectiveness after incorporation into pea starch films. *International Journal of Food Science & Technology* 44(2) (2009): 425–433.

Dalmas, F., Cavaillíe, J.Y., Gauthier, C., Chazeau, L., and Dendievel, R. Viscoelastic behavior and electrical properties of flexible nanofiber filled polymer nanocomposites. Influence of processing conditions. *Composites Science and Technology* 67 (2007): 829–839.

Damodaran, S., Parkin, K.L., and Fennema, O.R. *Fennemás Food Chemistry*. New York: CRC Press Taylor & Francis Group, 2008.

Deng, Q., Penner, M.H., and Zhao, Y. Chemical composition of dietary fiber and polyphenols of five different varieties of wine grape pomace skins. *Food Research International* 44(9) (2011): 2712–2720.

Deng, Q. and Zhao, Y. Physicochemical, nutritional, and antimicrobial properties of wine grape (cv. Merlot) pomace extract-based films. *Journal of Food Science* 76(3) (2011): E309–E317.

Devlieghere, F., Vermeulen, A., and Debevere, J. Chitosan: Antimicrobial activity, interactions with food components and applicability as a coating on fruit and vegetables. *Food Microbiology* 21(6) (2004): 703–714.

Dinand, E., Chanzy, H., and Vignon, M.R. Parenchymal cell cellulose from sugar beet pulp: Preparation and properties. *Cellulose* 3(3) (1996): 183–188.

Dizhbite, T., Telysheva, G., Jurkjane, V., and Viesturs, U. Characterization of the radical scavenging activity of lignins-natural antioxidants. *Bioresource Technology* 95(3) (2004): 309–317.

Doherty, W., Halley, P., Edye, L., Rogers, D., Cardona, F., Park, Y., and Woo, T. Studies on polymers and composites from lignin and fiber derived from sugar cane. *Polymers for Advanced Technologies* 18(8) (2007): 673–678.

Dong, H., Cheng, L., Tan, J., Zheng, K., and Jiang, Y. Effects of chitosan coating on quality and shelf life of peeled litchi fruit. *Journal of Food Engineering* 64 (2004): 355–358.

Driemeier, C., Oliveira, M.M., Mendes, F.M., and Gómez, E.O. Characterization of sugarcane bagasse powders. *Powder Technology* 214(1) (2011): 111–116.

Du, W.X., Olsen, C.W., Avena-Bustillos, R.J., McHugh, T.H., Levin, C.E., and Friedman, M. Antibacterial activity against E-*coli* O157: H7, physical properties, and storage stability of novel carvacrol-containing edible tomato films. *Journal of Food Science* 73(7) (2008): M378–M383.

Du, W.X., Olsen, C.W., Avena-Bustillos, R.J., McHugh, T.H., Levin, C.E., and Friedman, M. Effects of allspice, cinnamon, and clove bud essential oils in edible apple films on physical properties and antimicrobial activities. *Journal of Food Science* 74(7) (2009): M372–M378.

Dufresne, A., Dupeyre, D., and Vignon, M.R. Cellulose microfibrils from potato tuber cells: Processing and characterization of starch-cellulose microfibril composites. *Journal of Applied Polymer Science* 76(14) (2000): 2080–2092.

Durán, N., Mattoso, L.H.C., and Moraes, P.C. *Nanotecnologia—Introdução, preparação e caracterização de nanomateriais e exemplos de aplicação*. São Carlos, Brazil: Artiliber Editora Ltda, 2006.

Durango, A.M., Soares, N.F.F., Benevides, S., Teixeira, J., Carvalho, M., Wobeto, C., and Andrade, N.J. Development and evaluation of an edible antimicrobial film based on yam starch and chitosan. *Packaging Technology and Science* 19(1) (2006): 55–59.

Dutta, P.K., Tripathi, S., Mehrotra, G.K., and Dutta, J. Perspectives for chitosan based antimicrobial films in food applications. *Food Chemistry* 114(4) (2009): 1173–1182.

Eichhorn, S.J. Cellulose nanowhiskers: Promising materials for advanced applications. *Soft Matter* 7 (2011): 303–315.

Elazzouzi-Hafraoui, S., Nishiyama, Y., Putaux, J.L., Heux, L., Dubreuil, F., and Rochas, C. The shape and size distribution of crystalline nanoparticles prepared by acid hydrolysis of native cellulose. *Biomacromolecules* 9(1) (2008): 57–65.

Elsabee, M.Z. and Abdou, E.S. Chitosan based edible films and coatings: A review. *Materials Science and Engineering C: Materials for Biological Applications* 33(4) (2013): 1819–1841.

Espitia, P.J.P., Du, W.X., Avena-Bustillos, R.D.J., Soares, N.D.F.F., and McHugh, T. Edible films from pectin: Physical-mechanical and antimicrobial properties-a review. *Food Hydrocolloids* 35 (2014): 287–296.

El-Wakil, N.A. Use of lignin strengthened with modified wheat gluten in biodegradable composites. *Journal of Applied Polymer Science* 113 (2009): 793–801.

EUROSTAT. Available from: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Milk_and_dairy_production_statistics. Accessed on January 13, 2014.

Fai, A.E.C., Souza, M.R.A, Barros, S.T., Bruno, N.V., Ferreira, M.S.L., Gonçalves, E.C.B.A. Development and evaluation of biodegradable films and coatings obtained from fruit and vegetable residues applied to fresh-cut carrot (*Daucus carota* L.). *Postharvest Biology and Technology* 112 (2016): 194–204.

FAOSTAT. Available from: http://www.fao.org/wairdocs/lead/x6114e/x6114e04.htm#b6-2.1.2.%20Quantities%20of%20byproducts. Accessed on January 13, 2014.

Favier, V., Chanzy, H., and Cavaille, J.Y. Polymer nanocomposites reinforced by cellulose whiskers. *Macromolecules* 28(18) (1995): 6365–6367.

Fengel, D. and Wegener, G. *Wood: Chemistry, Ultrastructure, Reactions*. Berlin, Germany: Walter de Gruyter, 1989.

Fernandez-Pan, I., Mendoza, M., and Mate, J.I. Whey protein isolate edible films with essential oils incorporated to improve the microbial quality of poultry. *Journal of the Science of Food and Agriculture* 93(12) (2013): 2986–2994.

Fernandez-Saiz, P. and Lagaron, J.M. Chitosan for film and coating applications. In D.V. Plackett (ed.), *Biopolymers—New Materials for Sustainable Films and Coatings*, pp. 87–106. Chichester, U.K.: Wiley, 2011.

Ferreira, M.S., Fai, A.E., Andrade, C.T., Picciani, P.H., Azero, E.G., Gonçalves, É.C. Edible films and coatings based on biodegradable residues applied to acerolas (*Malpighia punicifolia* L.). *Journal of the Science of Food and Agriculture* 96 (2016): 1634–1642.

Ferreira, M.S.L., Santos, M.C.P., Moro, T.M.A., Basto, G.J., Andrade, R.M.S., and Gonçalves, E.C.B.A. Formulation and characterization of functional foods based on fruit and vegetable residue flour. *Journal of Food Science and Technology* 52(2) (2015): 822–830.

Ferrero, B., Boronat, T., Moriana, R., Fenollar, O., and Balart, R. Green composites based on wheat gluten matrix and posidonia oceanica waste fibers as reinforcements. *Polymer Composites* 34(10) (2013): 1663–1669.

Fishman, M.L., Coffin, D.R., Konstance, R.P., and Onwulata, C.I. Extrusion of pectin/starch blends plasticized with glycerol. *Carbohydrate Polymers* 41(4) (2000): 317–325.

Gällstedt, M., Hedenqvist, M.S., and Ture, H. Production, chemistry and properties of proteins. In D.V. Plackett (ed.), *Biopolymers—New Materials for Sustainable Films and Coatings*, pp. 107–129. Chichester, U.K.: Wiley, 2011.

Galus, S. and Lenart, A. Development and characterization of composite edible films based on sodium alginate and pectin. *Journal of Food Engineering* 115(4) (2013): 459–465.

García, M.A., Pinotti, A., Martino, M.N., and Zaritzky, N.E. Characterization of starch and composite edible films and coatings. In M.E. Embuscado and K.C. Huber (eds.), *Edible Films and Coatings for Food Applications*, pp. 169–210. New York: Springer, 2009.

Gitco, H. *Twenty-Five Prospective Food Processing Projects*. Ahmadabad, India: Gujarat Industrial and Technical Consultancy Organization Limited, Vol. 2, 1999.

GME Market Data. Official website of GME e Gelatin manufacturers of Europe. Brussels, Belgium: GME Market Data, 2014. Available from: http://www.gelatine.org.

Gnanasambandam, R., Hettiarachchy, N.S., and Coleman M. Mechanical and barrier properties of rice bran films. *Journal of Food Science* 62(2) (1997): 395–398.

Goksu, E.I., Karamanlioglu, M., Bakir, U., Yilmaz, L., and Yilmazer, U. Production and characterization of films from cotton stalk xylan. *Journal of Agricultural and Food Chemistry* 55(26) (2007): 10685–10691.

Gomez-Guillen, M.C., Gimenez, B., Lopez-Caballero, M.E., and Montero, M.P. Functional and bioactive properties of collagen and gelatin from alternative sources: A review. *Food Hydrocolloids* 25(8) (2011): 1813–1827.

Gomez-Estaca, J., Gomez-Guillen, M.C., Fernandez-Martin, F., and Montero, P. Effects of gelatin origin, bovine-hide and tuna-skin, on the properties of compound gelatin-chitosan films. *Food Hydrocolloids* 25(6) (2011): 1461–1469.

Gomez-Estaca, J., Montero, P., Fernandez-Martin, F., and Gomez-Guillen, M.C. Physico-chemical and film-forming properties of bovine-hide and tuna-skin gelatin: A comparative study. *Journal of Food Engineering* 90(4) (2009): 480–486.

Gomez-Guillen, M.C., Perez-Mateos, M., Gomez-Estaca, J., Lopez-Caballero, E., Gimenez, B., and Montero, P. Fish gelatin: A renewable material for developing active biodegradable films. *Trends in Food Science & Technology* 20(1) (2009): 3–16.

Gontard, N., Guilbert, S., and Cuq, J.L. Water and glycerol as plasticizers affect mechanical and water vapor barrier properties of an edible wheat gluten film. *Journal of Food Science* 58(1) (1993): 206–211.

Goy, R.C. and Assis, O.B.G. Antimicrobial analysis of films processed from chitosan and n,n,n-trimethylchitosan. *Brazilian Journal of Chemical Engineering* 31(3) (2014): 643–648.

Guendez, R., Kallithraka, S., Makris, D.P., and Kefalas, P. Determination of low molecular weight polyphenolic constituents in grape (*Vitis vinifera* sp.) seed extracts: Correlation with antiradical activity. *Food Chemistry* 89 (2005): 1–9.

Hamada, J.S. Characterization and functional properties of rice bran proteins modified by commercial exoproteases and endoproteases. *Journal of Food Science* 65(2) (2000): 305–310.

Hassan, M.L., Fadel, S.M., El-Wakil, N.A., and Oksman, K. Chitosan/rice straw nanofibers nanocomposites: Preparation, mechanical, and dynamic thermomechanical properties. *Journal of Applied Polymer Science* 125 (2012): E216–E222.

Jacobsen, S.E. and Wyman, C.E. Xylose monomer and oligomer yields for uncatalyzed hydrolysis of sugarcane bagasse hemicellulose at varying solids concentration. *Industrial & Engineering Chemistry Research* 41(6) (2002): 1454–1461.

Janes, K.A. and Alonso, M.J. Depolymerized chitosan nanoparticles for protein delivery: Preparation and characterization. *Journal of Applied Polymer Science* 88(12) (2003): 2769–2776.

Kabel, M.A., Bos, G., Zeevalking, J., Voragen, A.G., and Schols, H.A. Effect of pretreatment severity on xylan solubility and enzymatic breakdown of the remaining cellulose from wheat straw. *Bioresource Technology* 98(10) (2007): 2034–2042.

Katalinić, V., Možina, S.S., Skroza, D., Generalić, I., Abramovič, H., Miloš, M., and Boban, M. Polyphenolic profile, antioxidant properties and antimicrobial activity of grape skin extracts of 14 Vitis vinifera varieties grown in Dalmatia (Croatia). *Food Chemistry* 119 (2010): 715–723.

Kammerer, D., Claus, A., Carle, R., and Schieber, A. Polyphenol screening of pomace from red and white grape varieties (*Vitis vinifera* L.) by HPLC-DAD-MS/MS. *Journal of Agricultural and Food Chemistry* 52 (2004): 4360–4367.

Katoh, K., Shibayama, M., Tanabe, T., and Yamauchi, K. Preparation and physicochemical properties of compression-molded keratin films. *Biomaterials* 25(12) (2004): 2265–2272.

Kaushik, A. and Singh, M. Isolation and characterization of cellulose nanofibrils from wheat straw using steam explosion coupled with high shear homogenization. *Carbohydrate Research* 346(1) (2011): 76–85.

Kaushik, A., Singh, M., and Verma, G. Green nanocomposites based on thermoplastic starch and steam exploded cellulose nanofibrils from wheat straw. *Carbohydrate Polymers* 82(2) (2010): 337–345.

Kayserilioglu, B.Ş., Bakir, U., Yilmaz, L., and Akkaş, N. Use of xylan, an agricultural by-product, in wheat gluten based biodegradable films: Mechanical, solubility and water vapor transfer rate properties. *Bioresource Technology* 87(3) (2003): 239–246.

Kessel, A. and Ben-Tal, N. *Introduction to Proteins: Structure, Function, and Motion*. New York: CRC Press Taylor & Francis Group, 2011.

Kim, S.-K. and Mendis, E. Bioactive compounds from marine processing byproducts—A review. *Food Research International* 39 (2006): 383–393.

Krochta, J.M. and Johnson, C.D.M. Edible and biodegradable polymer films: Challenges and opportunities. *Food Technology* 51 (1997): 61–73.

Kulkarni, S.G. and Vijayanand, P. Effect of extraction conditions on the quality characteristics of pectin from passion fruit peel (*Passiflora edulis f. flavicarpa* L.). *Food Science and Technology* 43 (2010): 1026–1031.

Kumar, M. Nano and microparticles as controlled drug delivery devices. *Journal of Pharmacy and Pharmaceutical Sciences* 3(2) (2000): 234–258.

Kumar, M., Muzzarelli, R.A.A., Muzzarelli, C., Sashiwa, H., and Domb, A.J. Chitosan chemistry and pharmaceutical perspectives. *Chemical Reviews* 104(12) (2004): 6017–6084.

Kunanopparat, T., Menut, P., Morel, M.H., and Guilbert, S. Plasticized wheat gluten reinforcement with natural fibers: From mechanical improvement to deplasticizing effect. *Composites Part A: Applied Science and Manufacturing* 39(5) (2008a): 777–785.

Kunanopparat, T., Menut, P., Morel, M.H., and Guilbert, S. Plasticized wheat gluten reinforcement with natural fibers: Effect of thermal treatment on the fiber/matrix adhesion. *Composites Part A: Applied Science and Manufacturing* 39(12) (2008b): 1787–1792.

Langmaler, F., Mokrejs, P., Kolomamik, K., and Mladek, M. Biodegradable packing materials from hydrolysates of collagen waste proteins. *Waste Management* 28(3) (2008): 549–556.

Laohakunjit, N. and Noomhorm, A. Effect of plasticizers on mechanical properties of rice starch film. *Starch/Stärke* 56(8) (2004): 348–356.

Larotonda, F.D.S., Matsui, K.N., Soldi, V., and Laurindo, J.B. Biodegradable films made from raw and acetylated cassava starch. *Brazilian Archive of Biological and Technology* 47(3) (2004): 477–484.

Learmonth, G.S. *Fillers for Plastics*. London, U.K.: Iliffe, 1971.

Lee, C.H., Singla, A., and Lee, Y. Biomedical applications of collagen. *International Journal of Pharmaceutics* 221(1–2) (2001): 1–22.

Leitner, J., Hinterstoisser, B., Wastyn, M., Keckes, J., and Gindl, W. Sugar beet cellulose nanofibril-reinforced composites. *Cellulose* 14(5) (2007): 419–425.

Li, Z. and Ge, Y. Antioxidant activities of lignin extracted from sugarcane bagasse via different chemical procedures. *International Journal of Biological Macromolecules* 51(5) (2012): 1116–1120.

Lima, R., Feitosa, L., Pereira, A.D.S., de Moura, M.R., Aouada, F.A., Mattoso, L.H.C., and Fraceto, L.F. Evaluation of the genotoxicity of chitosan nanoparticles for use in food packaging films. *Journal of Food Science* 75(6) (2010): N89–N96.

Liu, L., Kerry, J.F., and Kerry, J.P. Selection of optimum extrusion technology parameters in the manufacture of edible/biodegradable packaging films derived from food-based polymers. *Journal of Food, Agriculture & Environment* 3(3/4) (2005): 51–58.

Llobera, A. and Cañellas, J. Dietary fibre content and antioxidant activity of Manto Negro red grape (*Vitis vinifera*): Pomace and stem. *Food Chemistry* 101 (2007): 659–666.

Lorevice, M.V., De Moura, M.R., Aouada, F.A., and Mattoso, L.H.C. Development of novel guava puree films containing chitosan nanoparticles. *Journal of Nanoscience and Nanotechnology* 12 (2012): 2711–2717.

Madhav, A. and Pushpalatha, P.B. Characterization of pectin extracted from different fruit wastes. *Journal of Tropical Agriculture* 40 (2002): 53–55.

Martelli, M.R., Barros, T.T., de Moura, M.R., Mattoso, L.H.C., and Assis, O.B.G. Effect of chitosan nanoparticles and pectin content on mechanical properties and water vapor permeability of banana puree films. *Journal of Food Science* 78(1) (2013): N98–N104.

Martelli, M.R., Santos, J.S., Sobral, P.J.A., and Carvalho, R.A. Efeito de cobertura comestível a base de gelatina na fritura de nuggets. In *CIBIA V—Libro de articulos en extenso del 5º Congresso Ibero-Americano de Engenharia de Alimentos*, Puerto Vallarta, México, 2006, pp. 1–5.

Martelli, M.S., Moore, G., Silva Paes, S., Gandolfo, C., and Laurindo, J.B. Influence of plasticizers on the water sorption isotherms and water vapor permeability of chicken feather keratin films. *LWT: Food Science and Technology* 39(3) (2006): 292–301.

Maté, J.I., Frankel, E.N., and Krochta, J.M. Whey protein isolate edible coatings: Effect on the rancidity process of dry roasted peanuts. *Journal of Agricultural and Food Chemistry* 44 (1996): 1736–1740.

Mattick, L.R. and Rice, A.C. Fatty acid composition of grape seed oil from native American and hybrid grape varieties. *Journal of American Enology and Viticulture* 27 (1976): 88–90.

Mayachiew, P. and Devahastin, S. Effects of drying methods and conditions on release characteristics of edible chitosan films enriched with Indian gooseberry extract. *Food Chemistry* 118 (2010): 594–601.

McHugh, T.H., Aujard, J.F., and Krochta, J.M. Plasticized whey protein edible films: Water vapor permeability properties. *Journal of Food Science* 59(2) (1994): 416–419.

McHugh, T.H., Huxsoll, C.C., and Krochta, J.M. Permeability properties of fruit puree edible films. *Journal of Food Science* 61(1) (1996): 88–91.

McHugh, T.H. and Olsen, C.W. Tensile properties of fruit and vegetable edible films. United States–Japan Cooperative Program in Natural Resources, 2004, pp. 104–108.

McHugh, T.H. and Senesi, E. Apple wraps: A novel method to improve the quality and extend the shelf-life of fresh-cut apples. *Journal of Food Science* 65(3) (2000): 480–485.

Mckendry, P. Energy production from biomass (part 2): Conversion technologies. *Bioresource Technology* 83(1) (2002): 47–54.

Monsoor, M.A. and Proctor, A. Preparation and functional properties of soy hull pectin. *Journal of the American Oil Chemists' Society* 78(7) (2001): 709–713.

Montaño-Leyva, B., da Silva, G.D., Gastaldi, E., Torres-Chávez, P., Gontard, N., and Angellier-Coussy, H. Biocomposites from wheat proteins and fibers: Structure/mechanical properties relationships. *Industrial Crops and Products* 43 (2013): 545–555.

Moran, J.I., Alvarez, V.A., Cyras, V.P., and Vazquez, A. Extraction of cellulose and preparation of nanocellulose from sisal fibers. *Cellulose* 15(1) (2008): 149–159.

Morr, C.V. and Ha, E.Y.W. Whey protein concentrates and isolates: Processing and functional properties. *Critical Reviews in Food Science and Nutrition* 33(6) (1993): 431–476.

Moura, M.R., Aouada, F.A., Avena-Bustillos, R.J., McHugh, T.H., Krochta, J.M., and Mattoso, L.H.C. Improved barrier and mechanical properties of novel hydroxypropyl methylcellulose edible films with chitosan/tripolyphosphate nanoparticles. *Journal of Food Engineering* 92(4) (2009): 448–453.

Moura, M.R., Aouada, F.A., and Mattoso, L.H.C. Preparation of chitosan nanoparticles using methacrylic acid. *Journal of Colloid and Interface Science* 321(2) (2008): 477–483.

Nabarlatz, D., Ebringerová, A., and Montané, D. Autohydrolysis of agricultural by-products for the production of xylo-oligosaccharides. *Carbohydrate Polymers* 69(1) (2007): 20–28.

Nakagawa, K. Characterization of freeze-dried core-shell nanoparticles prepared via gelatin-acacia complex coacervation: A study on particle formation upon freezing. *Drying Technology* 31(13–14) (2013): 1466–1476.

Nascimento, T.A., Calado, V., and Carvalho, C.W.P. Development and characterization of flexible film based on starch and passion fruit mesocarp flour with nanoparticles. *Food Research International* 49(1) (2012): 588–595.

Nigam, P., Pandey, A., Sivaramakrishnan, S., and Gangadharan, D. Edible oil cakes. In P.S. Nigam and A. Pandey (eds.), *Biotechnology for Agro-Industrial Residues Utilisation*, pp. 253–271. Dordrecht, the Netherlands: Springer, 2009.

No, H.K., Meyers, S.P., Prinyawiwatkul, W., and Xu, Z. Applications of chitosan for improvement of quality and shelf life of foods: A review. *Journal of Food Science* 72(5) (2007): R87–R100.

No, H.K., Park, N.Y., Lee, S.H., and Meyers, S.P. Applications of chitosan oligomers with different molecular weights. *International Journal of Food Microbiology* 74(1–2) (2002): 65–72.

Noor Haliza, A.H., Fazilah, A., and Mohd Azemi, M.N. Development of hemicelluloses biodegradable films from oil palm frond (*Elaeis guineensis*). In *International Conference on Green and Sustainable Innovation*, Energy Management and Conservation Center (EMAC), Chiang Mai, Thailand, 2006, pp. 260–265.

Ohya, S., Sonoda, H., Nakayama, Y., and Matsuda, T. The potential of poly(N-isopropylacrylamide) (PNIPAM)-grafted hyaluronan and PNIPAM-grafted gelatin in the control of post-surgical tissue adhesions. *Biomaterials* 26(6) (2005): 655–659.

Oliveira, M.A. and Cereda, M.P. Pós-colheita de pêssegos (*Prunus pérsica* L. Bastsch) revestidos com filmes a base de amido como alternativa à cera comercial. *Ciência e Tecnologia de Alimentos* 23 (2003): 28–33.

Ooi, Z.X., Ismail, H., Bakar, A.A., and Aziz, N.A.A. Properties of the crosslinked plasticized biodegradable poly (vinyl alcohol)/rambutan skin waste flour blends. *Journal of Applied Polymer Science* 125(2) (2012): 1127–1135.

Pandey, A., Soccol, C.R., Nigam, P., and Soccol, V.T. Biotechnological potential of agro-industrial residues. I: Sugarcane bagasse. *Bioresource Technology* 74(1) (2000): 69–80.

Park, S., Jiang, Y., Simonsen, J., and Zhao, Y. Feasibility of creating compression-molded biocomposite boards from berry fruit pomaces. *Journal of Applied Polymer Science* 115 (2010): 127–136.

Park, S. and Zhao, Y. Development and characterization of edible films from cranberry pomace extracts. *Journal of Food Science* 71(2) (2006): E95–E101.

Penhasi, A. and Meidan, V.M. Preparation and characterization of *in situ* ionic cross-linked pectin films: Unique biodegradable polymers. *Carbohydrate Polymers* 102 (2014): 254–260.

Perez-Gago, M. Protein-based films and coatings. In E.A. Baldwin, R.D. Hagenmaier, and J. Bai (eds.), *Edible Coatings and Films to Improve Food Quality*, pp. 13–77. New York: CRC Press Taylor & Francis Group, 2012.

Pervaiz, M. and Sain, M. High performance natural fiber thermoplastics for automotive interior parts. *Training* 2013 (2004): 11–11.

Pilon, L., Britto, D., Assis, O.B.G., Calbo, A.G., and Ferreira, M.D. Effects of antibrowning solution and chitosan-based edible coating on the quality of fresh-cut apple. *International Journal of Postharvest Technology and Innovation* 3 (2013): 151.

Poole, A.J., Church, J.S., and Huson, M.G. Environmentally sustainable fibers from regenerated protein. *Biomacromolecules* 10 (2009): 1–8.

Porto, S.I., Silva, A.C.P., and Oliveira, E.P. Relatório da produção brasileira de cana-de-açúcar. CONAB—Companhia Nacional de Abastecimento. Disponível em: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/13_08_08_09_39_29_boletim_cana_portugues_-_abril_2013_1o_lev.pdf, acesso em January 19, 2014.

Ranganna, S. *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*. New Delhi, India: Tata Me Graw-Hill Publishing Company, 1986, p. 1112.

Rinaudo, M. Chitin and chitosan: Properties and applications. *Progress in Polymer Science* 31(7) (2006): 603–632.

Reddy, N. and Yang, Y. Biofibers from agricultural byproducts for industrial applications. *Trends in Biotechnology* 23(1) (2005): 22–27.

Rojas-Grau, M.A., Raybaudi-Massilia, R.M., Soliva-Fortuny, R.C., Avena-Bustillos, R.J., McHugh, T.H., and Martin-Belloso, O. Apple puree-alginate edible coating as carrier of antimicrobial agents to prolong shelf-life of fresh-cut apples. *Postharvest Biology and Technology* 45(2) (2007): 254–264.

Rouison, D., Couturier, M., and Sain, M. The effect of surface modification on the mechanical properties of hemp fiber/polyester composites. *Training* 2013 (2004): 11–11.

Ruiz, H.A., Cerqueira, M.A., Silva, H.D., Rodríguez-Jasso, R.M., Vicente, A.A., and Teixeira, J.A. Biorefinery valorization of autohydrolysis wheat straw hemicellulose to be applied in a polymer-blend film. *Carbohydrate Polymers* 92(2) (2013): 2154–2162.

Sabiha-Hanim, S. and Siti-Norsafurah, A.M. Physical properties of hemicellulose films from sugarcane bagasse. *Procedia Engineering* 42 (2012): 1518–1523.

Samir, M., Alloin, F., Sanchez, J.Y., El Kissi, N., and Dufresne, A. Preparation of cellulose whiskers reinforced nanocomposites from an organic medium suspension. *Macromolecules* 37 (2004): 1386–1393.

Satyanarayana, K.G., Arizaga, G.G.C., and Wypych, F. Biodegradable composites based on lignocellulosic fibers-an overview. *Progress in Polymer Science* 34(9) (2009): 982–1021.

Sebrae. Banana: Estudos de Mercado. Série Mercado: Report Sebrae/ESPM, 86. Brasília, Brazil, 2008.

Shaikh, A.J., Gurjar, R.M., Patil, P.G., Paralikar, K.M., Varadarajan, P.V., and Balasubramanya, R.H. Particle boards from cotton stalk. Central Institute for Research on Cotton Technology, Mumbai, India, 2009.

Sharma, S. and Luzinov, I. Whey based binary bioplastics. *Journal of Food Engineering* 119 (2013): 404–410.

Shi, W. and Dumont, M.-J. Review: Bio-based films from zein, keratin, pea, and rapeseed protein feedstocks. *Journal of Materials Science* 49 (2014): 1915–1930.

Shih, F.F. Edible films from rice protein concentrate and pullulan. *Cereal Chemistry* 73(3) (1996): 406–409.

Shin, Y.J., Jang, S.A., and Song, K.B. Preparation and mechanical properties of rice bran protein composite films containing gelatin or red algae. *Food Science and Biotechnology* 20(3) (2011): 703–707.

Silva, R., Haraguchi, S.K., Muniz, E.C., and Rubira, A.F. Aplicações de fibras lignocelulósicas na química de polímeros e em compósitos. *Química Nova* 32(3) (2009): 661–671.

Soares, N.F.F. Chitosan—Properties and application. In L. Yu (ed.), *Biodegradable Polymer Blends and Composites from Renewable Resources*, pp. 107–128. Hoboken, NJ: John Wiley & Sons, 2009.

Sothornvit, R. and Pitak, N. Oxygen permeability and mechanical properties of banana films. *Food Research International* 40(3) (2007): 365–370.

Sothornvit, R. and Rodsamran, P. Effect of a mango film on quality of whole and minimally processed mangoes. *Postharvest Biology and Technology* 47(3) (2008): 407–415.

Sothornvit, R. and Rodsamran, P. Mango film coated for fresh-cut mango in modified atmosphere packaging. *International Journal of Food Science and Technology* 45(8) (2010): 1689–1695.

Tabata, Y. and Ikada, Y. Protein release from gelatin matrices. *Advanced Drug Delivery Reviews* 31(3) (1998): 287–301.

Tampier, M. and Probe, P. *Promoting Green Power in Canada*. Pollution Probe Organization, Toronto, Ontario, Canada, 2002.

Teixeira, E.D.M., Pasquini, D., Curvelo, A.A.S., Corradini, E., Belgacem, M.N., and Dufresne, A. Cassava bagasse cellulose nanofibrils reinforced thermoplastic cassava starch. *Carbohydrate Polymers* 78(3) (2009): 422–431.

Tharanathan, R.N. Biodegradable films and composite coatings: Past, present and future. *Trends in Food Science and Technology* 14(3) (2003): 71–78.

Tongnuanchan, P., Benjakul, S., and Prodpran, T. Characteristics and antioxidant activity of leaf essential oil-incorporated fish gelatin films as affected by surfactants. *International Journal of Food Science and Technology* 48(10) (2013): 2143–2149.

Tseng, A. and Zhao, Y. Effect of different drying methods and storage time on the retention of bioactive compounds and antibacterial activity of wine grape pomace (Pinot noir and Merlot). *Journal of Food Science* 77(9) (2012): H192–H201.

Vanin, F.M., Sobral, P.J.A., Menegalli, F.C., Carvalho, R.A., and Habitante, A. Effects of plasticizers and their concentrations on thermal and functional properties of gelatin-based films. *Food Hydrocolloids* 19(5) (2005): 899–907.

Vasconez, M.B., Flores, S.K., Campos, C.A., Alvarado, J., and Gerschenson, L.N. Antimicrobial activity and physical properties of chitosan-tapioca starch based edible films and coatings. *Food Research International* 42(7) (2009): 762–769.

Videcoq, P., Garnier, C., Robert, P., and Bonnin, E. Influence of calcium on pectin methylesterase behaviour in the presence of medium methylated pectins. *Carbohydrate Polymers* 86(4) (2011): 1657–1664.

Wang, X.W., Sun, X.X., Liu, H., Li, M., and Ma, Z.S. Barrier and mechanical properties of carrot puree films. *Food and Bioproducts Processing* 89(C2) (2011): 149–156.

Woodhams, R.T., Thomas, G., and Rodgers, D.K. Wood fibers as reinforcing fillers for polyolefins. *Polymer Engineering & Science* 24(15) (1984): 1166–1171.

Yamauchi, K., Yamauchi, A., Kusunoki, T., Kohda, A., and Konishi, Y. Preparation of stable aqueous solution of keratins, and physiochemical and biodegradational properties of films. *Journal of Biomedical Materials Research* 31(4) (1996): 439–444.

Yeng, C.M., Husseinsyah, S., and Ting, S.S. Chitosan/corn cob biocomposite films by cross-linking with glutaraldehyde. *Bio Resources* 8(2) (2013): 2910–2923.

Young, S., Wong, M., Tabata, Y., and Mikos, A.G. Gelatin as a delivery vehicle for the controlled release of bioactive molecules. *Journal of Controlled Release* 109(1–3) (2005): 256–274.

Yu, L. *Biodegradable Polymer Blends and Composites from Renewable Resources*. Hoboken, NJ: John Wiley & Sons, Inc., 2009.

Zhang, Y., Ghaly, A.E., and Li, B. Physical properties of wheat straw varieties cultivated under different climatic and soil conditions in three continents. *American Journal of Engineering and Applied Sciences* 5(2) (2012): 98–106.