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REVIEW PAPER

Biodegradable packaging materials

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Abstract
Packaging of food is required to ensure the safe handling and distribution of processed food products from the spot of production to the boundary consumer. Polymers and bioactive compounds are used as surrogates for the production of biodegradable food wrappings to ameliorate the nutritional value and improve the shelf life of highly putrescible food products. Moreover, they are environmentally friendly. The biodegradation process can be affected by the polymer's nature and environmental conditions such as light, temperature and humidity. This review work aims to bring out the different kinds of packing materials such as natural biopolymers (polysaccharides and proteins), synthetic biopolymers (aliphatic polyesters) and bionanocomposites. The sources of different biopolymers, production and its applications in the broad spectrum of food packaging are discussed. The review also scrutinizes some of the examples of biodegradable polymers. Besides, few discussions about the use of antimicrobial and antioxidant agents that are used for packaging are also covered.

Keywords Biodegradable · Packaging · Bioactive compounds · Biopolymers · Nanocomposites · Antimicrobial agents

Introduction

Packaging of foods protects them from contamination through the environment and furnishes nutritional information to the consumers [1]. Usually, packing materials are made up of glass, paper, polymeric materials and plastics. Food covering delivers nearly two-thirds of the total waste by volume generated from

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the packaging sector [2]. Plastics are preferable for a reason it provides better material properties beyond glass and metals. A major disadvantage of plastic is that it is non-biodegradable and non-renewable [3]. To lead a healthy lifestyle, good nutrition is inevitable, and this nutrition is provided through food which plays a vital role in everyone's lives. In today's world, most of them were adapted to the food they were kept packed with. Food packing is becoming the fascinating and most productive segment in food industry in this globalized world [4]. Packaging is essential for preserving raw vegetables and fruits and assuring the storage life of packaged foods that are marketed. Food quality that includes both organoleptic and physical factors should be protected throughout the storage [5]. Packing should be done in such a way that it should cover the food from environmental factors.

The packaging of food is done with the substances like plastic, glass, polymers and nanocomposites. However, the food's shelf life and the natural properties are greatly concerned, and the packing materials should not affect the quality of the products [6]. The use of petrochemical-rooted plastics like polyethylene, polyvinylchloride, polystyrene and polyamide as a packing material had been exponentially raised owing to low cost, good tensile strength and protection from moisture, heat, oxygen, unpleasant odor, and microorganisms [7]. On the other hand, it had a crucial effect on the environment. The waste generated by these materials was non-degradable. Recycling may be inconvenient when food contamination, oxidation and the colossal process were required for their diminishment and economically too high [8]. Due to these drawbacks and increasing environmental concerns, researchers were keenly involved in overcoming these limitations with some natural materials. This led to the discovery of biopolymers that are biodegradable and more eco-friendly, recyclable and compostable [9].

From 1970, biopolymers were given much attention because of their less adverse effect on the environment and ecological problems, profitable, safer and harmless [9]. Under different environmental conditions, the polymers extricated from natural or living sources can be easily transformed and degraded by other microorganisms. Biopolymers can be derived using various sources of animal biomass (e.g., polysaccharides like chitosan) [10]. Some of them can be chemically synthesized, bio-based monomers (e.g., polylactic acid) and some through microorganisms (e.g., cellulose, polyhydroxyalkanoates, xanthan). Natural polymers or biopolymers such as starch and cellulose are polysaccharides used to modify the degradation rate and mechanical properties [11]. Biopolymers for food packaging can be made through different combinations of proteins, polysaccharides and lipids. To reduce the waste materials and to enhance the shelf life of the food, a breakthrough was made by researchers, that is, the use of bio-based packaging materials, like biodegradable films from renewable sources [12]. Though biodegradable films were used for food packaging, they hold few limitations like weak mechanical and physical properties [13]. Here comes the implementation of nanocomposites which potentially implement the application of biodegradable films. Therefore, nanocomposites will support lower packaging waste, aid the preservation of fresh food and prolong the shelf life of foods [14].

Characteristics of food packaging materials

Certain characteristics to be monitored for acceptable biodegradable material as a suitable package for foods [12].

- They should allow a controlled oxygen transfer. Excess oxygen can lead to oxidative degradation of the food material, and lesser oxygen will also affect the respiration of food materials. Thus, the material should allow slow oxygen transfer.
- Act as a selective barrier to carbon dioxide and moisture.
- Able to maintain an internal gas composition to regulate ripening and extending shelf life.
- Prevent the movement of lipids.
- Strengthen structural solidarity and lessen the loss of volatile biological components. They should ease the mechanical handling of foods.
- Provide flexibility to include supplements such as antimicrobials and antioxidants.
- Act as a protective barrier against spoiling microbes.

Biodegradable polymers

Biodegradable packaging material can be grouped under three key categories, as mentioned in Fig. 1 .

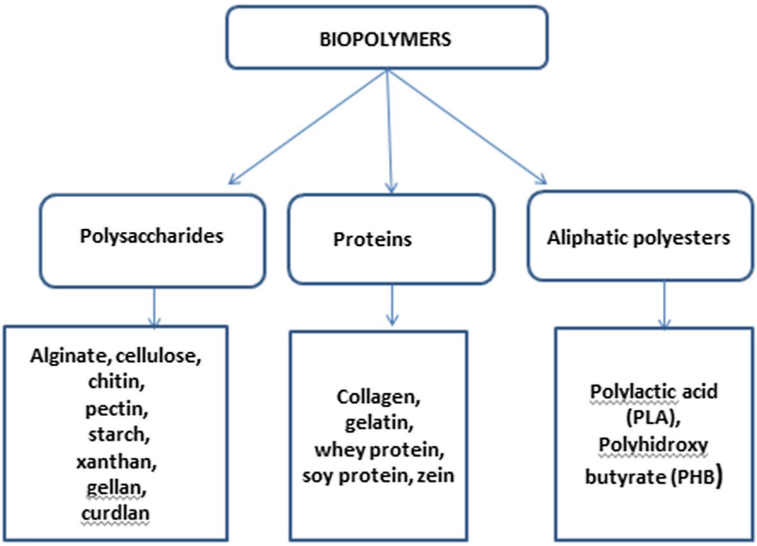

Fig. 1 Classifications of polymers

- The first category involves products based on polysaccharides, namely cellulose and starch, proteins like casein, gluten, etc., which are polymers extracted directly from natural sources such as crops.
- The second class has biologically derived compounds that are chemically modified as packaging materials. Lactic acid produced from the fermentation process can be polymerized into polylactic (PLA) and used as a polyester.
- The third category covers the polymers produced by microbes to store energy-Polyhydroxy-butyrate (PHB), a commonly used polymer derived from microbial sources.

Polysaccharides

Cellulose

Cellulose is an abundant linear polymer that is packed in the form of microfibrils. It is a structural component found in plants and some algae forms and composed of complex carbohydrates [8]. Humans cannot digest cellulose due to a lack of cellulase enzyme secretion, and as a result, they cannot degrade into simpler units. Although they could not be used as food intake, but finds their use in food packaging. The sources of cellulose are wood, sugarcane bagasse, and cotton fibrils, and some microorganisms. Bacterial cellulose is present in pure form without containing impurities. But in the case of naturally occurring cellulose, purification of contaminants is a costly process. The bacterial cellulose manufacturing process is quite expensive, which attracts the plant cellulose for food packaging. Studies had been for selecting an optimal bacterial strain for fermentation with less expensive raw materials responsible for growth [15]. Cellulose properties include low density, high durability, non-toxicity, biocompatibility, biodegradability and good film-forming ability, making the researcher use cellulose as an ideal packaging material [16]. Besides, it is strenuous to use them in commercial sectors due to their hydrophilic nature. [17]. They are divided into two types: i) regenerated cellulose and ii) modified cellulose-based on the materials used in textiles and packaging. Chemical reactions like esterification and etherification were performed on the free –OH (hydroxyl) groups to enhance cellulosic material's thermoplastic behavior [18]. They are categorized as two types: i) regenerated cellulose (ii) modified cellulose-based on the materials used in textiles and packaging. For producing cellophane membrane with hydrophilic layer and suitable mechanical property, cellulose is dissolved in toxic solution and casted in sulfuric acid [17]. Table 1 provides the mechanical properties of some biodegradable films made of cellulose polymers. Bacterial cellulose is even used to produce biodegradable films by processing them into micro/nanofibrils and nanocrystals [19]. [20] recorded the improvised elastic and tensile properties in bacterial cellulose (BC)-guar gum (GG) biodegradable film by incorporating polyvinyl pyrrolidone (PVP)–carboxymethyl cellulose (CMC). Incorporation of microcrystalline bamboo cellulose in seaweed-based biodegradable film reported enhanced mechanical toughness and elongation break point, makes it feasible to implement them as a constructive packaging material.

Table 1 Composition and antioxidant activity of various biodegradable films

Polymer	Bioactive compounds	Composition	Antioxidant activity (DPPH scavenging)
Fish gelatin	Orange peel extract	10 mg/ml	99.70%
Gelatin	Methanolic grape extract		94.06%
Gelatin	Pumpkin residue extract	3%	60.49%
Gelatin	Pumpkin oil cake	85–90%	25%
Polypropylene	Eugenol (in cellulose	0.19 ± 0.05 to 0.82 ±	90–94%
Polypropylene	acetate coating)	0.13 g/m^2	87–92%
Polythene	Clove essential oil (in	0.18 ± 0.03 to 0.77 ±	50%
	cellulose acetate coating)	0.10 g/m^2	
	Barley husk extract	2.37 g/l	

Chitin and chitosan

Chitin is a natural polymer and a structural component of invertebrates, yeast and fungi's cell wall. Low order plants can also produce chitin in smaller amounts. It is nontoxic, bio-compostable and biodegradable [21]. Researchers were focused on improving chitosan properties like mechanical, thermal, gas/water permeability by combining with other polymers [21]. Chitin is closely related to cellulose, but the secondary hydroxyl alpha carbon is substituted with the acetylated amide group. The broth from the fungal industrial process and shells of crustaceans are the natural sources of chitin. It has advantages as the colossal waste from the industries is used more appropriately. Chitin, when treated with alkali, gives rise to a deacetylated product called chitosan. Chitin is water-insoluble and dispersible in solvents like formic acid and acetic acid. It can also be used as a stabilizer and thickener [21]. Currently, chitin is produced from the wastes of food canning industries. However, they have to be associated with other constituents. Firstly, to extract chitin from these constituents, it was treated with sodium hydroxide (NaOH) to remove proteins and then treated with hot hydrochloric acid to eliminate minerals like calcium phosphate or carbonate. Chitin is treated with sodium hydroxide at extreme temperatures to get chitosan. Chitosan films are used to increase mango's shelf life and sensory properties at room temperature [22]. The ripening time of fruits can also be delayed by using chitosan films. Chitin can be modified either by enzymes or chemicals for its employment. The tensile strength of chitosan could be increased when the proper proportion of starch is blended with it. This is due to the development of intermolecular hydrogen between the –NH_2 (amino) group of chitosan and the hydroxyl (–OH) group of starch [23]. The tensile strength of Na (sodium)-MMT (unmodified montmorillonite) chitosan-based nanocomposite film is 35.1 ± 0.9, and the tensile strength of a nano-silver chitosan-based nanocomposite film is 35.9 ± 1.9 [23]. Chitosan whey films were developed with distinct proteins in the absence of transglutaminase [24]. There is a significant reduction in the film's mechanical resistance. In the presence of transglutaminase, the mechanical resistance was increased.

Consumers demand natural preservatives to cancel out the effect of nontoxic nature of films. But in the case of chemical preservatives, it may cause environmental hazards and are harmful to human beings. Ideal packaging material must have both antimicrobial and biodegradable properties. Naturally, chitosan has antimicrobial properties due to the presence of NH_2^+ (amino) group at C2 position [22]. But the information regarding the antimicrobial property of chitosan films is significantly less. The manufacture of chitosan-based products is done worldwide, and they are sold under the brand names NorLife and Kitoflokk for food-related applications.

Pectin

In terrestrial plants, two-thirds of the primary cell walls are made of pectin, which is a hetero-polysaccharide. This provides strength and stability to the plants and safeguards from external environmental factors [25]. It is anionic in nature and a water-soluble biopolymer. The three constituents of pectin are homogalacturonan (HG), rhamnogalacturonan I (RGI), and rhamnogalacturonan II (RGII) [25], and their composition differ for different sources. Homogalacturonan (HG) is a repeated unit of galacturonic acid (GalA), and these units are bonded through by α-1-4glycosidic bond, and the number of residues varies for different pectin sources [26]. Rhamnogalacturonan I cover about 20–35% of the pectin polysaccharides. It is made of repeating units of α-(1→2)-linked rhamnose and α-(1→4)-linked GalA residues. Its composition differs for various pectin sources. In the RGI region, fruits like a kidney bean, apple fruit, mung bean are 100% methyl esterified [27, 28]. Rhamnogalacturonan II accounts for around 10% of the pectin polymer. It consists of (1–4)-linked-α-D-GalA units containing 12 monosaccharide units. Human beings cannot digest this polysaccharide directly due to its complexity and lack of pectin digesting enzymes. Still, it can be digested by microbes that are present in the large intestine. Pectin plays a vital function in biological systems, also extended to other applications such as food emulsifiers, gelling agents, aroma barrier and pharmaceuticals. Initially, it was obtained from apple and citrus fruits. In fruits such as sunflower head, mango peel, sugar beet pulp [29], soybean hull [30], banana peel [31], the percentage of pectin is significantly high. Edible coats over the food act as a barrier for food by protecting them from enzymatic browning and prepared from pectin and a food-grade emulsifier. It also protects the nutritional properties, deters lipid migration and reduces the microbial attack, respiration rate and oxidation process [32]. Low methoxy pectin is cross-liked with calcium cations at low pH (negative log of hydrogen ion concentration), which forms a rigid gel that acts as a water barrier. By employing edible pectin films, the shelf life of avocado was extended to 30 days at 10 °C storage. When avocado fruits are overlaid with pectin, the oxygen adsorption and respiration rate have decreased, which holds up the color change and texture of the fruit [33]. The effectiveness of pectin films is also seen in fresh-cut fruits. It has been observed when pectin is cross-linked with sunflower oil and calcium chloride and coated over the fruits, there is a decrease in wounding stress, and dehydration is prevented for 15 days when stored at 4 °C. Still, the microbial growth over the melon cannot be reduced. Another study reveals that the sucrose with pectin together was coated over fresh melon fruits. By this, the sensory properties of fruits are maintained at 5 °C for up to 15 days. It is reported that sodium alginate solution containing two percent pectin was more effective in keeping the organoleptic properties in sapota fruits for more than 25 days at a cold temperature [34]. Drying is one of the oldest and traditional methods for the preservation of fruits and vegetables. The purpose of drying is to reduce the moisture content, enzymatic activity and to prevent microbial attack. During this process, it may also result in the change of texture, color and loss of vitamins and nutrients. This leads to diminished market prices for fruits. In this case, fruits were pre-treated with pectin films before drying and blanching, and it showed promising results [35]. Therefore, pectin's role in the food industry is favored for many applications like gelling agents, emulsifiers, meat preservation, texturizer and packaging [30].

Starch

Starch is a naturally abundant polymer and is found in various plants such as rice, wheat, rice, bean and potatoes. It is said to be an agricultural polymer, and its size, shape and chemical composition vary depending upon the sources. Nowadays, the research on starch has been increasing owing to its easy accessibility, cheaper cost, renewable property, eco-friendly, biodegradability, composting nature, and causes no harm to food when it is contacted [36]. It does not impart any flavors to food, and the organoleptic properties are maintained. Starch can be easily separated from other components. Amylose and amylopectin are the essential polysaccharides that are present in starch granules. The composition of amylopectin is more (above 80%) in starch granules. The film-forming property of starch is contributed by starch. The starch's hydrogen bonds make them indissoluble in cold water, still partially solubilize when heated, as the crystalline structure gets disrupted [37]. To form a homogenous film of starch, it is essential to gelatinize over water, resulting in breaking the amylopectin matrix by releasing the amylose. Essential techniques are used for film formation from starch are wet processes and dry processes. A variety of starches are actively made into packaging material for food (e.g., cassava, corn, sago, tamarind), and among these, cassava is mainly used. Plasticizers can be added as additives to starch to increase the mechanical properties. In addition to a plasticizer, tri-sodium polyphosphate is introduced during the production of starch films. Hydrogen bonds in the starch are disrupted by the plasticizer. The starch polymer chain's flexibility is simultaneously increased, T_m (melting temperature) and T_g (glass transition temperature) are under decomposition temperature, and plastic material behavior is exhibited. Commonly used plasticizers in the TPS (temperature, high pressure, shearing force) process are sorbitol and glycerol. Different additives such as antimicrobial, antioxidants, fillers are incorporated during film production for compensating the effects of plasticizer-related issues [38]. The mechanical property of the thermoplastic corn starch is improved due to increased interaction between bacterial cellulose nano-whiskers and thermoplastic corn starch. Glycerol and potato starch nanoparticles are added to thermoplastic pea starch, which restricts water diffusion due to the crystallinity structure of potato starch nanoparticles. The oxygen barrier properties of thermoplastic cassava were improved when it is blended with chitosan. Starch foaming technology is the current technology used to develop starch-based food packing materials [39]. Techniques such as microwave heating, extrusion, baking are found used in producing starch foaming materials.

Alginate

Alginate is a requisite polymer that has been widely researched in recent times [40]. It is a non-repeating copolymer of β-D-mannuronic acid (M) and α-L-guluronic acid (G). Like all polymers, it is also abundant, renewable and biodegradable in nature [35]. Alginate is initially present as sodium alginate. Brown seaweed (*Phaeophyceae*) is the source of alginate from where it is extracted. Some alginate could be obtained using the extracellular part of bacteria like *Pseudomonas* and *Azotobacter* [41]. Alginates that are extracted from brown seaweeds have hydroxyl groups in their structure, whereas that obtained from the extracellular matrix of bacteria has an acetyl group. The structure and constituents of alginate vary for seaweeds of different origins that might be due to environmental, physical, growth and climatic conditions which later shows its effect on the mechanical properties of alginate. They act as thickeners, gelling agents, stabilizers in food like sauce, desserts and beverages. It has an indispensable role in food packaging, has it been advantageous. They were coated over the foods such as refined meat, pet food, carb sticks and onion rings that are sold widely worldwide [42–44]. Alginate, when blended with other compounds, it showed a significant increase in their physical properties. When combined with silver nanoparticles and applied as a film, sodium alginate enhances the shelf life of carrots and pear [45]. Upgraded mechanical properties, water resistance and decreased water vapor permeability have been observed when partially hydrolyzed sago starch, glycerol, lemongrass are added with sodium alginate [46]. Sodium alginate with polyethyleneimine, bi-axially oriented polylactic acid, increases film's oxygen barrier properties [47]. It has been reported that calcium alginate with silver-montmorillonite nanoparticles increases the life span of fruits, avoids microbial spoilage of freshly cut fruits and prevents dehydration [6]. Nisin with alginate suppresses bacterial growth [48]. The shelf life of food is increased, and button mushroom quality is preserved when food-grade alginate was used for packaging [49]. Gelatin alginate in the presence of corn oil/olive oil reduces the water deprival from sausages [50]. Propylene glycol alginate and soy protein isolate film increase tensile solidity and decrease water vapor permeability.

The production of alginate from microbial source, *A. vinelandii* was studied [51], and it took place under four steps: (i) precursor formation, (ii) cytoplasm transfer and polymerization (iii) periplasm transfer and modification, (iv) transport through the external surface [52]. Alginate extraction from seaweeds involves multiple processes like drying the raw materials, treatment with a mineral acid and purification process, which transforms alginic acid into water-soluble form by sodium salts [53]. Contamination of proteins and immunogenic in alginate should be carefully checked and purified because it will affect the alginate's purity. Alginates produced through the fermentation process show high physiochemical characteristics like tensile firmness and mechanical properties. Alginate generated through bacteria has necessary essential material properties that depend on acetylation, composition, polymer length and type of modification [54], and chemical properties in contrast to alginate obtained from seaweeds. The packaging attributes of alginate are provided in Table 2.

Alginate has an advantageous effect on food by preserving the quality of the food. The shelf life of raw fish could be lengthened when glucose oxide is coated over alginate films [11, 55]. Alginate-coated cheese maintains the color and gloss [56]. Also, these alginate films also prevent or reduce the loss of moisture and food spoilage that is caused by microbes. In [57], calcium alginate films exert excellence in improving the quality of pork patties. A study on meat has reported that there is a difference in the visible color of coated and uncoated meat [58]. The red color is persistent in the meat coated with calcium alginate compared to uncoated meat. Actually, oxymyoglobin gives a red color to the meat that was maintained only in calcium alginate-coated meat. It was observed that there is a reduction in the shrinkage of meat, and

Table 2 Packaging properties of alginate

Properties	Description
Tensile strength	The linear and well-defined structure of alginate helps in the formation of cross-linkage with calcium ions which increases the cohesive force between the chains resulting in the rise in tensile strength to the packing material [6]
Water solubility	Water solubility is the characteristic feature of biopolymer. The resistivity of film to water is assessed by checking the water solubility of the material. The material that has high water solubility generally has least resistance to water [43]. Alginate in pure state has a water solubility of about 99.5 due to hydrophilic nature. It was observed the solubility decreased highly when cellulose nanoparticles are incorporated with them
Oxygen permeability	Oxygen permeability is another essential parameter for the food products to maintain its shelf life. However, the information regarding the oxygen permeability of biopolymers is less. Oxygen permeability and moisture absorption are the parallel properties of biopolymers in food packaging [51]. The molecular size of the alginate films will influence the moisture absorption. Alginate films exhibit little more permeability when compared to other biopolymers. The reason behind this could be either chemical composition or structure of different polymers
Thermostability	Calcium beads are used in immobilization of enzyme which has no effect on enzyme [6]. During bead formation, firstly enzyme is treated with alginate and then beads are formed (e.g., Increased starch hydrolysis with thermostability are seen in enzymes like glucoamylase and pullulanase during its entrapment in alginate beads)
Antimicrobial activity	The quality, safety and freshness are important when it comes to food [5]. The packing material should assert these and it should maintain the food as it was prepared. Currently packing materials are made with incorporated antimicrobial property to improve the shelf life of the food products. This property of the packing material stops the growth of microbes that present in the foods [5]. The water content and the oxygen consumption are the factors that are responsible for food spoilage. The water content supports the growth of microorganisms that are present in the food

off flavor was also decreased. Additionally, films' functional properties can be built upon after the addition of various proteins, lipids and certain polymers. The storage period of melons was extended when essential oils like cinnamon and lemongrass were included with alginate films.

Xanthan gum

Xanthan gum is synthesized from the microorganism *Xanthomonas campestris*, where glucose acts as source of carbon. It is an exopolysaccharide that was discovered at Northern Regional Research Laboratories in 1963 and is known to be the second microbial polysaccharide that was commercialized. Xanthan gum is a heteropolysaccharide that is made of repeated units of pentasaccharides, mainly consisting of glucose, mannose and glucuronic acid of ratio 2:1:1 [59]. It is non-poisonous and water-soluble in nature. Even at high pH and ionic strength, xanthan's rheological properties are stable [4, 59]. It applies to the food industry and has played a significant role in industries like cosmetic, pharmaceutical, textile, petroleum production and slurry explosives. The xanthan membrane's information is not detailed due to its high cost [60, 61]. Besides, the xanthan-coated acerola showed effectiveness in maintaining the color and reduces weight loss, and increases shelf life [62].

Proteins

Collagen

Collagen is a fibrous hydrophilic protein made up of specific amino acids like glycine, hydroxyproline and proline. Because of the presence of these amino acids, it gets bulged in polar liquids as it is extremely soluble. Collagen is present in skin, connecting tissues and accounts around 30% of overall mass of the human body [63]. Collagen fibrils were formed by self-built collagen molecules in an orderly manner on the exterior cell surface, thus furnishing tensile solidity to the tissues [64]. The disintegration of collagen can be done by blending with weak acid or alkali. The two main collagen constituents are α and β, having molecular weight of 100 and 200 kDa, respectively. It is differentiated into two distinct groups of covalently cross-linked chain pairs α_1–α_1 and α_2–α_2 [65, 66]. Hydrolyzed collagen films of high concentration produce more homogeneous surfaces [64]. One of the greatest commercially flourishing edible proteins is collagen sausage casing. This protein widely replaces natural gut casings for sausages. Collagen has better mechanical properties, and they are not as solid or rigid as cellophane [67]. For collagen, oxygen permeability and relative humidity are directly proportional to each other, like cellophane, but it has an eminent oxygen blockage when nearing null relative humidity [68]. Carbodiimide, microbial transglutaminase or glutaraldehyde are implemented as distinct cross-linking factors to increase the mechanical properties, foreshorten the solubility and boost the stability of the film [69–71].

When collagen film was overwrapped on refrigerated beef, a decreased transudation without crucially influencing the color was noticed [72]. Films constructed on collagen are recommended to store processed meats. It has the following advantages: to diminish shrink loss, shoot up juiciness and consume fluid efflux for baked meats. For biocomposite film production, collagen fibers and collagen powder are used since the fibers play the filler's role by providing a reinforcement effect [73, 74].

Gelatin

Gelatin is a colorless water-soluble protein and translucent and a derivative of collagen (present in skin, connective tissues, bones, tendons of animals [75], a destabilized form of a triple helix. It is a heterogeneous polymer consisting of randomly arranged polypeptide chains such as alpha, beta and gamma. During the early decades, gelatin is manufactured from pig skin used for large-scale industrial production, whereas it is produced from cattle bones for the pharmaceutical industry. But the extraction process is quite expensive and complex. However, for the last 100 years, gelatin is manufactured from fish, where around 1.5% of the overall output of gelatin is obtained from fish [76]. The sources from fish are head, skin, fins, bones, muscle pieces but the rheological properties of fish gelatin are less stable than the mammalian gelatin [77]. The characteristics of initial collagen and the extraction process are the two main factors that influence gelatin properties. The transformation from collagen to gelatin relies upon temperature, pressure and the extraction period. Collagen on heat treatment results in destabilized form by breaking the covalent and hydrogen bonds. Gelatin is majorly categorized as two classes: Type-A and Type-B, depending upon the processing method. Type-A gelatin is derived when acid treatment is done for collagen at pH 8–9. Type-B gelatin has an isoelectric point at pH 4–5. Pig skin-derived gelatin is generally referred to as Type-A gelatin and beef skins and pig cattle hides provide Type-B gelatin [75].

The gelatin quality is designated by the physicochemical characteristics like solubility, color transparency and composition. Other than these attributes, gelatin liquidity and solidity also greatly influence the quality and application of gelatin. They provide texturization, stabilization and emulsification for a bakery. But it is limited to some applications due to less thermal stability. The film-producing ability of gelatin is widely used to preserve the food without a disclosure to oxygen, also prevents food spoilage during transportation and improves the shelf life of foods. The functional attributes of gelatin could be further enhanced by adding distinct materials like plasticizers, cross-linkers, strengthening agents and antioxidants [78, 79]. The promotion of strong bonds and reformations in the hydrophilic nature could be done by the action on a molecular structure to revise the characteristics of gelatin. Besides, the water resistance properties and mechanical attributes of gelatin could be modified by the incorporation of different polymers like chitosan, starch and whey proteins. The composition changes are based on the different sources of gelatin.

Gelatin-based films are already in use to prevent food spoilage and to expand the shelf life of food products. While devising a film, parameters such as chemical nature and organoleptic, mechanical and functional attributes are taken into consideration [78]. Nowadays, researchers are mainly focusing on the techniques to develop a film with good antimicrobial and antioxidant properties [75, 78]. The essential oils and extract from the plants act as antimicrobial agents that are assured safe when incorporated along with the films. Synthetic chemical substances have an adverse effect on food, and they may lead to deterioration. But in the case of natural substances, its impact is low. The natural additives used in the film expanded the shelf life and reduced the food spoilage by oxidation [3].

The use of antimicrobial agents as an additive in packaging materials is extensively in progress to improve the shelf life of the food. Substances such as organic acids, bacteriocins, spice extracts, thiosulfates, enzymes, proteins, isothiocyanates, antibiotics, fungicides, chelating agents, parabens and metals [80] possess good antimicrobial activity and wide range of effects. These antimicrobial agents could be derived from different origins like plants, animals, by-products of fruits and vegetable processing, algae and bacteria. The antioxidant activity of few packaging films made with bioactive compounds is presented in Table 3. Edible films are made chiefly with essential oils. The inclusion of orange leaf essential oil in gelatin films showed antimicrobial activity against five food-borne bacteria even at 2% essential oil by agar diffusion method [81]. It was reported the zone of inhibition for *S. aureus* is around 14.5 ± 0.7 mm and 19.0 ± 1.2 mm for *E.coli* [81]. The growth inhibition was greater than 80% at 10% loading of oil [82] in *E. coil* and *S. aureus* when fish skin extracted gelatin mixed with peppermint and citronella oils at 10% to 30%. In addition, every constituent of essential oil exhibits its own mechanism that stops or prevents the growth of microorganisms, but the explanation is not clearly described [7]. Cell wall damage, leakage of cellular components, cytoplasmic membrane disruption, and decrease in

Table 3 Mechanical properties of biodegradable films made using polymers

Polymer	Additives	Tensile strength (MPa)	Elongation percentage (%)
Hydroxypropyl	Shellac + Lactic	70	7
methyl	acid		
cellulose	(20:1)	57.9	5.64
Hydroxypropyl	4 % glycerol		
methyl		63	5.9
cellulose	Ascorbic acid		
Hydroxypropy		55	4.5
l methyl	Citric acid		
cellulose		28.35	-
Hydroxypropy	Sorbitol	15.82	-
methyl	Glycerol, Sorbitol		
cellulose			
Sugar palm starch			
Sugar palm starch			

proton motive force are the different mechanisms that have been identified until now. The stability of the different types of additives depends upon their incorporation method with gelatin. At high temperatures, they exhibit poor stability, so alternative techniques were developed, including micro- or nano-encapsulations that improve and control the additive's release rate when incorporated with gelatin. *Origanum vulgare L.* essential oil included fish gelatin film has enhanced water vapor permeability and antimicrobial properties [10]. Silver nanoparticles naturally have antimicrobial properties when included with gelatin films improves the hydrophobicity, water vapor content and UV barrier of the film [83, 84]. The silver nanoparticles act on bacteria by attaching to the cell membrane and changing the bacterial cell's structure and morphology. Brown seaweed *Ascophyllum nodosum* is used as an additive in bovine gelatin increases the hydrophilicity and antioxidant properties [9]. In recent years, metallic nanofillers are finding their role for producing enhanced antimicrobial activity implemented gelatin films. In addition to enhanced mechanical and barrier properties, these additives protect food from deterioration and increase the food product's shelf life.

Recently, researchers are keenly involved in developing a promising packaging material that protects the food from external and internal factors. Some studies revealed that the antioxidant property of certain natural substances controls the oxidation process inside the food since this process limits the shelf life of food products besides degrading proteins and lipids. It was observed that the extracts of green tea, ginger leaf showed outstanding antioxidant property by the existence of certain components like polyphenols for green tea and ginkgo leaf extract have flavones glycosides. Gelatins with enriched orange essential oil are produced from orange leaves and are used for coating in shrimps. During cold storage, the shrimps' quality is unaffected, and the shelf life is extended up to 10 days compared to uncoated shrimps [81]. Some additives are light sensitive and have less thermal stability. These factors greatly influence the properties of certain additives. So, encapsulation is used for film processing to protect the additives.

In meat products, to reduce color deterioration, gelatin and chitosan are blended and coated over the meat. This composite coating prevents the deposition of metmyoglobin over the surface that is caused because of rapid lipid oxidation in beef [24]. In addition, the organoleptic properties of beef are maintained for about 5 days during the trials. More than 50% of the world's daily intake of protein is from pork [85]. The gelatin coating over the refrigerated pork protects the quality, shelf life is extended up to 7 days, reduces weight loss, and no significant change in the color. Skate skin extracted gelatin films incorporated with 1% thyme oil showed decreased growth of *L. monocytogenes* and *E.coli* on chicken tenderloin [86]. Apart from meat products, gelatin films are extensively employed for preserving fruits and vegetables. The mixture of starch, gelatin and glycerol are coated over red crimson grapes by casting technique [87]. The mechanical property is increased due to the increased concentration of gelatin in the mixture. Sunflower oil that is packed with film in the absence of artificial antioxidants is stored for up to 35 days at 35 °C. Nowadays, studies are keenly found to find the most promising material applicable for all environmental and internal attributes.

Soy protein

Soy protein is globulin type made up of both acidic and basic polar and nonpolar amino acids. It is composed of two essential constituents: 35% β-conglycinin and 52% glycinin. Basically, soy proteins are classified into 2S, 7S, 11S and 15S [88]. Different chemical procedures and additives are incorporated to enhance the fragile nature and water resistance property of this polymer. Specific plasticizers used for soy protein are glycerol, ethylene glycol and propylene glycol. These plasticizers are widely used than 1, 3-propanediol. The elasticity of soy is highly increased by glycerol and water, however, it extensively decreases the tensile strength [88].

Since soy proteins have the film-forming ability, they are widely used in the Far East for the formation of Yuba films built from soy protein–lipid films [89]. To alter the film properties, [90] prepared soy protein isolates were treated with alkali. Due to alkali treatment, a better film appearance and high percentage elongation were seen in soy protein. However, there was no change in water vapor permeability (WVP), oxygen permeability (O_2P) and tensile strength (TS). From soy protein isolates, mechanical properties, total soluble matter (TSM) and protein solubility (PS) values of cast films are studied by [91]. According to this, 7S films had lower TS values, greater TSM and PS estimates than 11S films. Commercial soy isolates (CSI) had lower TS than soy isolate (SI) films, and CSI films were remarkably darker and well enhanced yellowish than SI films. The inhibitory property of food-class antimicrobials like lysozyme, nisin, ethylene diamine tetraacetic acid (EDTA) was studied by [92], incorporated into soy protein isolate films.

A composite film comprised of a mixture of soy protein isolate and gelatin in a ratio of 4:6 to 2:8 could be prepared [93]. Within this ratio, the blend provides a better mechanical property. The antimicrobial effect of soy films was studied on fresh ground beef, at 4 °C. There was no significant impact on the overall viable count of lactic acid bacteria and *Staphylococcus* species, but they observed a substantial decrease in *Coliform* and *Pseudomonas* species counts [94]. These films have a better ability to carry flavoring agents [92]. The soy protein-based film applications were reported in microencapsulating additives of flavors, medication, and as a glaze on fruits, vegetables and cheese [95]. Soy isolate films are used as protective coverings on meat pies and moist cakes, where water vapor permeability is compulsory [96, 97].

Aliphatic polyesters

Polylactic acid

Renewable resources like sugar feedstock, corn, etc., produce lactic acid monomer on fermentation. Polylactic acid (PLA) is one of the most signified biopolymers, achieved through depolymerizing the monomers of lactic acid [98]. PLA is used for film packaging since it has a high molecular weight, high transparency, high water solubility resistance and good processing ability [99]. PLA is a copolymer that links poly-L-lactic acid and poly-D-lactic acid. PLA organoclays blend was first prepared on dissolution of PLA into hot chloroform in dimethyl distearyl ammonium, thereby a solid tactoid formation was observed. PLA layered silicate nanocomposite membrane (PLSNM) was prepared by [100]. The gas permeability of PLSNM decreased when organoclay content in PLA increased. Compared with the other grades of nanoclay, the oxygen disclosure properties of PLSNMs with Cloisite 30B were highly significant. PLA could be immobilized with much organic clay such as hexadecyl amine-MMT (C16-MMT), dodecyl trimethyl ammonium bromide-MMT (DTA-MMT), Cloisite 25A [23]. A good interaction was noticed between nanocomposite of amorphous PLA and chemically modified kaolinite, followed by a 50% increase in oxygen barrier properties [98]. PLA-derived nanocomposite materials are used widely to study their biodegradation in the environment among bio-based nanocomposites [101–104]. The breakdown of polymers like PLA takes place through the following six steps (i) water uptake, (ii) hydrolysis of ester bond, (iii) breakdown into oligomer, (iv) dissolution of oligomer fragments (v) molecular transfer of soluble oligomer (vi) eventual decomposition into CO_2 and H_2O [105]. Hence, degradation of the polymer attains a higher rate on increasing the hydrolysis tendency of PLA matrix. Although the hydrolysis pattern of PLA and its nanocomposites were quite the same, the decomposition of PLA nanocomposite was highly attained in comparison with polylactic acid due to terminal hydroxylated edge groups in the clay layers.

PLA nanocomposite was prepared using the melt intercalation method using various proportions of clay to check the biodegradability of nanocomposite [106]. The extent of biodecomposition of PLA films was measured using two methods. The first method was to calculate the quantity of released lactic acid. The second method was by measuring the change in mass of PLA composite in the course of hydrolytic degradation. Compared to PLA, PLA nanocomposite exhibited degradation more than ten times of PLA (according to first method) or 22 times (as per change in mass). The category of clay and their concentration affects the rate of biodegradation.

Tests were carried out on the hydrolytic deterioration of PLA and its nanocomposite using phosphate buffer solution [98]. The bio-breakdown of PLA nanocomposite was higher in comparison with Polylactic acid. Therefore, the more hydrophilic the filler, the more pronounced will be the degradation. PLA-supported packaging finds its application as beverage packs in countries like America, Europe and Japan [107]. Few of the foods commercially packed using PLA-based packaging materials are juices, water, milk, yogurt, cheese and butter [107].

Polyhydroxybutyrate

According to food science, polyhydroxybutyrate (PHB) could be applied for nutrient delivery, encapsulation of food supplements, and in the development of packaging materials [108, 109]. PHB films release kinetics with Fickian diffusion when it is incorporated with antimicrobial agents. It results in the effective control of the growth of many microorganisms [108]. Incorporation of vanillin (4-hydroxy-3-methoxy benzaldehyde) in PHB about 10 to 200 µg/g was done to scrutinize the growth of bacteria constituting *E.coli*, *S. flexneri*, *S. typhimurium* and *S. aureus* and fungal growth constitute *A. fumigates*, *A. parasiticus*, *A. flavus*, *A. niger*, *A. ochraceus*, *P. clavigrum* and *P. viridicatum*, respectively [109]. PHB films expressed greater inhibitory effect on fungi in comparison with bacteria. Since smaller particles have the mechanism of penetrating more easily into the cellular membrane systems, it is used widely against target microorganisms than larger particles.

PHB is produced by the accumulation of carbon and energy by several bacteria. The size of PHB is 0.5 µm, and present in the cytoplasm exhibiting granular shape. Up to 90%, the polymer could be formed under suitable conditions concerning dry bacterial mass. To isolate PHB, breaking of the cell wall is needed. This can be done by applying mechanical shear, enzymatic digestion, or by centrifugation, which leads to the extraction of the polymer. In the 1960's, the first PHB was produced on a kilogram scale, but it becomes brittle with aging because of its stereochemical regularity and leads to progressive crystallization. This disadvantage could be overcome by incorporating co-monomers or adjoining additives like plasticizers.

When eugenol is mixed with PHB, about 10 to 200 µg per gram of PHB inhibited the growth of *S. aureus*, *E.coli*, *S.typhimurium*, *Bacillus cereus*, *A.flavus*, *Aspergillus niger*, *Penicillium sp.* and *Rhizopus sp.* [110]. The antimicrobial effect was improved when pediocin extracted from *Pediococcus acidilactici* was added with eugenol as 80 µg per gram in PHB films compared to only eugenol [110].

Polyhydroxybutyrate-co-3-hydroxy Valerate (PHBV) was produced in 1970 using some certain constituents into the culture medium. This improves the properties of PHBV but the market price of copolymer is high and also the toxic conditions end up in lower productivity. Also, due to crystallization kinetics results in longer processing cycle times. PHB application possibilities can be broadened implementing annealing method, which gets toughened. The melting temperature of PHB is 180 °C, where PHBV temperature can be lowered to 137 °C by the addition of 25% hydroxyl valerate. The introduction of hydroxyl valerate enhances thermoplastic processability and mechanical stability.

Bionanocomposites

New advancements have been introduced to magnify polymer production in food packaging, such as the use of nanoparticles as additives. At present several nano-reinforcements have been developed, such as nano clay (layered silicates) [111], cellulose nano-whiskers [36], ultra-fine layered titanate [112] and carbon nanotubes [113]. Among the above-said reinforcements, only layered silicates such as clay had drawn considerable heed in packaging sector. Uses of nano clay in food packaging have numerous advantages like low cost, simple processability, natural abundance and environment-friendly.

The application of polymer-based silicate (PLS) nanocomposites technology was first implemented by Toyota Central Research Laboratories in 1986 [114, 115]. In food packaging, the implementation of polymer nanocomposites was done in beverages/bottles, layered covering of paperboard juice cups, and cast and blown films. With the help of nanocomposite packaging, the shelf life of the packed food is extended to 3–5 years since it has lowered flavor shrinkage, extended thermal resistance and greater oxygen barrier characteristics [116].

Structure and properties of layered silicates

The repeatedly adopted silicate in PLS nanocomposites comprises Montmorillonite (MMT), hectorite and saponite. These silicates are associated with layered silicate or phyllosilicates [117]. The silicate skeleton is two-dimensional, and thickness of 1 nm and has an edgewise extension of 100 µm. Due to the isomorphous substitution of Si^{4+} (silicon) for Al^{3+} (aluminum) or Al^{3+} for Mg^{2+} (magnesium), gives rise to a negative charge which is counterbalanced by the Na^{+} (sodium) placed in the domains between adjacent layers of silicate.

PLS nanocomposites make use of layered silicates because of two main properties. They are (i) the silicate particle's capability to spread into individual layers; due to this, the aspect ratio reaches 1000 for fully dispersed separate layers can be achieved. (ii) by means of ion exchange reactions with organic and inorganic cations, their surface chemistry gets fine-tuned.

An additional class of nanofillers used in polymers is layered double hydroxides (LDHs) [118, 119]. LDH particles are comprised of Magnesium Aluminum hydroxide layers. On comparing with layered silicates, these hydroxide layers establish a positive charge counterbalanced by the anions, which is present in the domain of adjoining layers [120, 121].

Formation of nanocomposites

Formation of nanocomposite could be done by the diffusion polymer chain into the galleries between silicate layers to produce structures. Solid layered diffusion of polymers can be done by two steps: intercalation and exfoliation. Intercalation occurs when a small amount of polymers penetrates the galleries, which gives rise to a fine expansion of silicate layers [122]. This forms a multilayered structure with a few nanometers gap.

Typically intercalation of polymer chain could be done by the upcoming two techniques. In the first technique, which is also called "In situ Polymerisation," the polymer formation between the intercalated sheets can be achieved by expanding nanofillers within the liquid monomer [122]. In the second technique, the polymer matrix's fusion with the layered inorganic cations by using solvents or in the molten state in which the polymer is soluble. A polymer can form an intercalated nanocomposite if the layer surface fits with the chosen polymer [123, 124].

An exfoliated nanocomposite comprises thick platelets of nanometer size, which is spread homogeneously throughout the polymer matrix. The layers do not separate when the polymer and silicate are immiscible and thus form as agglomerates or tactoids.

Recently, a new revolutionary method for the preparation of nanocomposites was developed. It was done by mixing solid state at room temperature (ball mixing) [125, 126]. In this case, the dispersion of the solid layer is stimulated by the energy transfer between milling tools (generally balls) and polymer mixture, which successively results in the ground and fully mixed material. Among the available techniques used for nanocomposites preparation, ball mixing gains its importance since it does not require higher thermal treatment or any other solvents.

Characterization of nanocomposites

Normally, the characterization of nanocomposites is done by X-ray diffraction analysis (XRD) and transmission electron microscopy analysis (TEM) [117, 118]. XRD is used to diagnose the intercalated structure by identifying the interlayer spacing. TEM allows picturizing the interior surface of the nanocomposite and its distribution throughout the polymer [118]. TEM and XRD are the most elemental techniques used to evaluate the nanocomposites structure. Also further techniques are also implemented nowadays to obtain a broad knowledge about the nanostructure and its physical, mechanical and thermal attributes as differential scanning calorimeter (DSC) [117], nuclear magnetic resonance (NMR) [127] and Fourier-transform infrared spectroscopy (FTIR) [128]. Dynamic mechanical analysis is used nowadays to characterize the viscoelastic property of packaging materials [129].

Materials based on edible nanocomposites

Edible coatings and films are thin, uninterrupted layers of edible matter that are implemented as a coating between food components to offer a mass transfer resistance [13, 130]. It is done by using a paintbrush, by spraying, dipping, or receptive characteristics of the food [131–133].

Edible coatings and films can be split up into two groups: water-soluble polysaccharides and lipids. Water-soluble polysaccharides incorporate cellulose derivatives, alginates, pectin, starch, chitosan. Mostly water-soluble polysaccharides are named as gums or hydrocolloids [134, 135]. Hydrocolloids render hardness, crispness, compactness, thickening quality, viscosity, adhesiveness and gel-forming ability [136]. Lipids incorporate waxes, acylglycerols and fatty acids and provide an extra gloss to the sweet products. To slow down the respiration and minimize the moisture content in fruits, they are coated with waxes [137]. At times, composite films are used, which will increase the advantage of lipid and hydrocolloid compounds [138].

Even though edible films are more fascinating sector, only a few research works [139, 140] recommended incorporating nanoparticles to enhance the physical and mechanical characteristics. Edible films are feasible to incorporate the food additives and other substances, which will amplify the product color, flavor, texture and control the microbial growth [83, 84]. To uphold the attributes of edible films, the incorporation of nanoparticles as carriers or additives is more reliable.

Biodegradable polymers and their sources

Mango peel extract

The effect of mango peel extract when blend with gelatin films was investigated [141], as the mango peel extract was found to be rich in antioxidants. It was found that when 1–5% concentrations were used, the films showed scavenging of free radicals to a greater extent than control film. It was also observed that blending more amount of mango peel extract lowered the films' solubility and increased the strength of the film [141].

Active films made from mango peel extracts were used as additives to wrap minced chicken to increase the shelf life. Studies [142] showed that Langra mango peel extract had the best antioxidant activity and antibacterial activity compared with peel extracts of different varieties of mangoes. The composition of the active film was PVA (polyvinyl alcohol)–cyclodextrin–gelatin with added Langra Mango Peel Extract. It had better mechanical properties and UV (ultraviolet) blocking capacity. The life span of the minced chicken expands to ten more days at chilled conditions storage [142].

Pumpkin residue extract

Cassava starch from *Manihot esculenta* could be used in the preparation of biodegradable films. [143] studied the effects of the additives such as Oregano Essential Oil (OEO) and Pumpkin Residue Extract (PRE) on cassava starch films. It was found that pumpkin extract had a lesser contribution to the antioxidant activity of the film when compared to oregano essential oil. The formulation-2% OEO, 3% PRE and 1.7% glycerol showed the best antioxidant activity scavenging about 60.49% of DPPH (2,2-diphenyl-1-picrylhydrazyl). The reaction mechanism of DPPH radical scavenging activity is given in Fig. 2. Although PRE doesn't contribute much in improving the antioxidant properties of the film, it was essential to prevent photo-oxidative damage. OEO and glycerol have a constructive impact on the film elongation but expressed a lower tensile strength. This film protected lipid oxidation for 3 days when tested by wrapping meat [143].

Fig. 2 Reaction mechanism of DPPH scavenging

Pumpkin oil cake

Pumpkin oil cake (PuOC) is a by-product from the oil sector; the effects of pumpkin oil cake by preparing composite films along with gelatin were noticed in [144]. Films with 40% PuOC and 60% gelatin (200 MPa) had better tensile strength than pure gelatin films (105 MPa). The swelling capacity and protein solubility were comparable with pure gelatin films. Composite films had a better elongation break. The antioxidant effect expressed by the composite films was superior to pure gelatin film. A film with 85–90% of PuOC improved the antioxidant activity up to 25% [144].

Blueberry waste

The valorization of blueberry wastes was done by incorporating it into films made of cassava starch [145]. They prepared cassava starch films with 4.8 and 12% blueberry pomace extract, and the properties of the film were tested. It was found that the aromatic compounds in the extract enhanced the UV resistance of the films. Greater the concentration of the blueberry pomace, the better will be the UV resistance of the film. Thus, blueberry pomace could be used as a bioactive compound in films that can prevent food deterioration due to UV exposure [145].

The antioxidant activity of blueberry was higher than Vitamin E and comparable to BHA (butylated hydroxyl anisole). Antihydrolysis activity was greater than BHA and similar to Vitamin E [146].

Oil palm black liquor waste

Starch-based films revealed poor mechanical and gas barrier characteristics. Bhat et al. [147] worked on extracting lignin from oil palm black liquor waste and using it to produce starch/lignin in food packaging material to overcome the problem. The films were incorporated both with extracted lignin and commercial lignin and compared. The films with extracted lignin showed better elastic modulus, tensile strength, lower waster solubility, high seal strength and comparatively lower weight loss in the thermogravimetric analysis compared to commercial lignin. But commercial lignin had lower water permeability [147].

Whey protein from dairy waste

Whey protein is a by-product of the dairy food industry. They exhibit excellent oxygen resistive property, being biodegradable, gains its importance in packaging sector. [148] studied the effect of whey protein coating on polylactic acid film. The weight of PLA/Whey film was reduced below 90% when the temperature rose beyond 250 °C. The oxygen permeability (OP) of PLA/Whey is 80cm^3 (STP) m^{-2}d^{-1} bar^{-1} is low when compared to PLA films OP 512 cm^3 (STP) m^{-2}d^{-1} bar^{-1}.

The mechanical properties of PLA are slightly better than PLA/Whey films, but the nitrogen content, organic carbon content and C/N (Carbon/Nitrogen) ratio were higher in PLA/whey films [148].

Gelatin from fish and poultry bones

Gelatin is animal-based proteins derived from various sources that differ in their properties because of the amino acid composition. One example of how amino acid composition affects the nature of polymer is the low melting temperature of fish gelatin compared to mammalian gelatin. This is because fish gelatin contains low imino acid concentrations. Similarly, the composition varies from fish to fish. Poultry farms may act as potential source material for it, i.e., from the skin and bones of poultry animals [149]. Wang et al. [150] compared the potential film-forming capabilities of a few polysaccharides and proteins. Of the proteins, gelatin showed desirable film-forming abilities. Further, the 8% concentration of gelatin showed high tensile strength and good flexibility. These films are relatively easy to synthesize. Research is done to identify different additives such as cross-linkers and plasticizers to counter their hygroscopic nature [150]. These films are used as coatings for meat to prevent the browning reaction for a considerable piece of time as they have a lower O_2 transfer rate. Extensive research is necessary to develop new methods of film preparation or better additives to improve the film properties and, as a result, their potential applications.

Xylans and mannans

Arabinoxylan from Rye endosperm and 15% micro-fibrillated cellulose had a tensile strength (TS) of 95 MPa, and elongation at break is 11% [151]. On the other hand, glucomannan from konjac tuber and 20% chitosan exhibited 88 MPa TS, elongation break is 33% [152]. These fibers could be devised as reinforcing agents with film to enhance their mechanical properties. Arabinoxylan from corn hull with 13% sorbitol has a water vapor permeability of 2 g mm m^{-2} d^{-1} kPa whereas galactoglucomannan from spruce wood with 16% sorbitol showed 0.9 g mm $m^{-2}d^{-1}$ kPa [151]. They can be executed to reduce the prepared film's water vapor transfer rates. Since these are obtained from agricultural residues, they are cheaper sources of reinforcing materials.

Orange peel oil

The Orange peel oil/zein nano (OZN)-capsules were incorporated into corn starch films and characterized [153]. Orange peels are ultrasound treated, and then atmospheric distillation is done to obtain orange peel oil. This is then made in nano-capsules along with zein. Corn starch and OZN are mixed in different proportions and made into films. When corn starch and OZN were mixed in equal proportions, it had a tensile strength of 12.19 ± 1.97 MPa, which is better than pure corn starch film (9.42 ± 1.06 MPa) [150]. At this proportion, the elongation at break was

$30.91 \pm 2.52\%$, oxygen permeability was $1.8 \pm 0.61 \times 10^{-14}$ cm^3 m^{-1} s^{-1} Pa^{-1}, and water vapor permeability $3.02 \pm 0.74 \times 10^{-11}$ g m^{-1} s^{-1} Pa^{-1}. This proportion had the best antioxidant scavenging activity of $30.16 \pm 1.69\%$ [153].

Wheat straw fibers

The wheat straw fibers (WSF) were found used in biodegradable film production and its impact on PHBV (polyhydroxy-3-butyrate-3-valerate) based composite was analyzed [139]. The thermal stability decreased significantly on the addition of WSF to PHBV. They stated this could be due to the induction of PHBV hydrolysis by degradation products of wheat straw fibers. The combination of 20 wt % WSF had a T_{peak} (degradation temperature) of 280 °C, 35 °C lesser than PHBV. Wheat straw fibers improved the hydrophilicity and thus increased the water vapor transfer rate of films. The tensile strength was higher for 20 wt % WSF in PHBV using the technique of Ball milling [139].

Conclusion

In conclusion, this review concentrates on the various sources of bio-based polymers and bioactive compounds and its production. A limited investigation has been paid to nanocomposites (structure, formation, characterization). Pectin finds application as gelling agents, emulsifiers, meat preservation, texturizer and packaging. Alginate was coated over the foods such as refined meat, carbohydrate sticks and onion rings. Collagen and aliphatic polyesters like PLA and PHB in combination with other polymers finds importance to improve the stability and shelf life of food packaging materials. Biodegradable polymers like mango peel, pumpkin cake extract, orange peel oil and wheat straw fibers satisfy the environmental concerns, but they exhibit some limitations in heat resistance, gas barrier and mechanical properties associated with the costs. These types of packaging materials need further studies, where nanotechnology field comes into picture to improve the quality of packed food in terms of antimicrobial, antioxidant and nutritional values. It gives the consumer more delight to have detailed information about the product. To expand the functions and properties of the biodegradable films, the incorporation of natural antioxidants and antimicrobial agents into polymeric matrices is necessary. The biodegradable packing materials should possess antimicrobial, antioxidant, antifungal properties along with enhanced tensile strength and prolonged shelf life with the advancements of newer technologies like starch foaming technology. Recent advances and applications of nanotechnology have given rise to antimicrobial packaging in retaliation to the drawback of food spoilage and losses. Thus, analyzing the film's properties made from biopolymers is necessary to use as a replacement for harmful plastics.

Declaration

Conflict of interest The authors declare that they have no known competing financial interests or personal-

relationships that could have appeared to influence the work reported in thispaper.

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