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# Edible films and biodegradable packaging from agricultural waste

**P. Chithrabala*, M. Ilamaran*◆, S. Kanchana**, B. Sivasankari** and K.G. Sabarinathan*****

** Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India*

*** Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India*

**** Department of Agricultural Microbiology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India*

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**Abstract**

Rising alarm over plastic contamination and long term environmental impact has spurred interest in producing biopolymers from renewable feed stocks, particularly agricultural residues. Examples of such by products cereal husks, fruit and vegetable peels and similar wastes offer abundant, low cost and eco-friendly precursors for biopolymer synthesis. This review explores the valorization of agricultural residues for making biopolymers and edible films by considering their origins, extraction and processing approaches and performance attributes. Key biopolymers recoverable from agro waste include starch, cellulose, pectin, lignin and proteins, which can be isolated by physical, chemical or enzymatic procedures. Processing techniques such as solution casting, extrusion and electro spinning enable the formation of biobased films with tailored mechanical strength, barrier performance and biodegradability. These films have applications across food packaging, pharmaceuticals, agriculture and biomedical sectors. Despite their advantages, commercialization is hindered by limitations like inferior mechanical properties relative to conventional plastics, elevated production costs, variability in feedstock quality and the absence of standardized processing protocols. Overcoming these barriers through technological innovation and enabling policy measures is essential to scale industrial deployment of biofilms. This review highlights the role of agro waste valorization in advancing circular economy models and decreasing dependence on fossil derived plastics.

## 1. Introduction

Growing concerns over the environmental impact of plastics and packaging have driven the development of sustainable alternatives. Compostable wraps with suitable mechanical properties and the ability to biodegrade in soil are one such solution (Agarwal *et al.*, 2023). Biodegradable packaging, including edible films and coatings, offers an innovative replacement for traditional plastics (Moghadas *et al.*, 2024). Agro food residues, once neglected, are now recognized as valuable feed stocks for biodegradable packaging, enhancing its functional properties (Guillard *et al.,* 2018). Edible films and coatings serve as carriers for bioactive agents, such as flavor compounds, antioxidants and antimicrobials, while forming protective barriers against contamination and spoilage, thus preserving nutritional and sensory attributes during storage (Diaz-Montes and Castro-Munoz, 2021).

Recent estimates indicate that global plastic production now exceeds 415 million tonnes per year, reflecting rapid expansion of plastic manufacturing. More than 8 billion tonnes of plastic have been produced since 1950 with nearly 80% of that becoming waste, underscoring the long term persistence of plastic pollution (Geyer *et al.*, 2017). Converting food waste into useful materials reduces pollution and diverts large amounts of organic residues from landfills. Uncontrolled decomposition of agro industrial residues contaminates water, soil and air. Agro waste is a promising feedstock for biomaterials in a circular economy because it contains proteins, phenolic compounds and fibers such as cellulose, arabinoxylan and lignin (Qazanfarzadeh *et al.*, 2022). These components can function as natural polymers or be directly incorporated into biodegradable packaging with minimal processing, reducing cost and production time (Thuppahige *et al.*, 2023).

Fruit and vegetable residues are rich in natural polymers such as pectin, which constitutes roughly 30% of an orange peel weight along with aromatic phytochemicals. This renewable resource can be converted into durable bioplastics and bio composites, addressing the demand for sustainable alternatives to petroleum based packaging (Merino *et al.*, 2023). Bioplastics and edible films mimic conventional polymers while ultimately degrading naturally under environmental conditions (Kim *et al.*, 2013).

Lipid derived polymers have recently emerged as feed stocks for 3D printing and food packaging. Fatty acids are first extracted from natural matrices before undergoing transesterification. For instance, algal lipids (Tran *et al.*, 2016) and cutin from tomato residues (Benitez *et al.*, 2018) have shown potential for producing films with strong water barrier properties because of their hydrophobic nature.

## 2. Biopolymers from agricultural waste

Biopolymers with a wide range of physicochemical roles like emulsifying, gelling, stabilizing, coagulating, forming films and

**Corresponding author: Dr. M. Ilamaran**
*Associate Professor, Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India*
**E-mail:** ilamaranmhomesci@tnau.ac.in
**Tel.:** +91-9344731868

thickening are steadily taking the place of petroleum based polymers in food applications. Living organisms synthesize biodegradable polymers through intracellular monomer conversion *via* chain growth mechanisms and enzyme catalyzed reactions (Munteanu and Vasile, 2019). Selection of suitable agro waste is typically guided by criteria such as: (i) Starch content; (ii) Cellulose, lignin and hemicellulose levels; (iii) Bioavailability and implications for food security and supply chains; (iv) Complexity of extraction and the desired material properties; (v) Biodegradability (Nunes *et al.*, 2020).

Biopolymers used for composites are generally classified based on their origin and chemical nature such as proteins, polysaccharides, and lipids, as well as their source, either plant or animal. Common examples obtained from agro waste include chitosan, cellulose, starch, xanthan gum, zein, polyhydroxy-butyrate among others (Jamwal *et al.*, 2023). Within polysaccharides, chitosan, cellulose, gums and starch are prominent; starch, owing to its affordability, versatility and transparency has become the principle polysaccharide for edible and biodegradable films (Tulamandi *et al.*, 2016).

Polymers such as poly (butylene adipate-co-terephthalate), poly (butylene succinate/adipate) and poly (∑ caprolactone) break down naturally because enzymes can cut through their carbon chains. You can find biopolymers like polylactides (PLA), polyhydroxyal kanoates (PHAs/PHBs), polyols, polyamides, bio-PET, butyl rubber and cellulose acetate on the market materials that range from smooth, flexible rubber to crisp cellulose sheets (Soares *et al.*, 2018).

PHAs are further subdivided by chain length short, medium and long-chain affecting their suitability for applications: short chains are often too stiff, crystalline and brittle for high strength uses, whereas medium chains offer reduced brittleness due to lower crystallinity and higher elongation at break (Anjum *et al.*, 2016b). While some materials fall short of sustainability targets in conventional packaging, they still play crucial roles in food logistics, preservation and safety. To comply with current food safety standards and lower environmental impact, research has focused on developing packaging materials prioritizing biodegradability, renewability and cost effectiveness (Teixeira *et al.*, 2021).

## 3. Types of biopolymers in packaging

### 3.1 Lipid based biopolymer

Blending lipids into edible films and coatings gives them a smooth gloss, helps in reducing moisture and can even reduce production costs. Films based on fats and oils are hydrophobic, providing enhanced moisture barrier properties while maintaining clarity and flexibility (Nanda *et al.*, 2021). Natural waxes rich in long chain fatty alcohols and alkanes form a tough, moisture blocking layer and are often mixed into biopolymer blends to build water vapor barriers that feel provides a smooth surface and improved barrier properties. Wax infused biopolymer films resist water vapor and dissolve less easily crucial traits for keeping packaged food crisp and fresh (Rodrigues *et al.*, 2013).

### 3.2 Chitin based biopolymer

Chitin is predominantly sourced from crustacean shells crab and shrimp and fish scales. When chitin undergoes deacetylation, its loss the acetyl groups then it turns into chitosan a substance it can also extract straight from a fungus's cell wall, rough and pale like dried coral (Duan *et al.*, 2018). Chitin and chitosan make appealing renewable sources for bioplastics because they are easily available, break down naturally to form smooth films and stay safe and compatible with living tissue (biocompatibility).

### 3.3 Microbial biopolymers

Polymers, whether formed naturally or crafted from microorganisms, hold strong promise for use in packaging coatings and thin, flexible films that gleam like clear plastic. Microbes can ferment agri food residues and by-products to produce biopolymers (Brodnjak, 2016). Among these, polylactic acid (PLA) and polyhydroxyalkanoates (PHA) have been the most intensively investigated to date (Verdini *et al.*, 2022).

**Table 1: The bioactive compounds from agricultural waste and their sources**

| Source | Bioactive compounds | Significance | References |
|---|---|---|---|
| Wheat | Gluten | Enhances solubility, foaming and emulsification properties. | Saadi *et al.*, 2021; Thammahiwes *et al.*, 2017 |
| Grapefruit peel, sugar beet, citrus and apple | Pectin | Exhibits anti-inflammatory and anticancer activity, acts as gelling and thickening agent. | Wang *et al.*, 2020; Butler *et al.*, 2023 |
| Corn stalk, raw rice straw, ground walnut shells, sugar cane and bagasse | Lignin | Provides high carbon content, thermal stability and antibacterial activity. | Linan *et al.*, 2024; Zhang *et al.*, 2019 |
| Leaves, stems and roots | Vegetable proteins | Improves water and oil absorption, supplies essential amino acids. | Ge *et al.*, 2020; Fang *et al.*, 2024 |
| Corn | Zein | Capable of encapsulating bioactive compounds. | Jaski *et al.*, 2022 |
| Lotus seeds, banana and tubers | Starch | Supports and strengthens the immune system. | Chen *et al.*, 2024; Cheng *et al.*, |

### 3.4 Proteins based biopolymers

Numerous plant and animal proteins have been applied to develop protein based materials. Major protein sources for bioplastics include wheat gluten, soy and maize derived zein materials that are abundant, cheap and renewable for manufacturing biodegradable food packaging films (Sorrentino *et al.*, 2012). Wheat gluten, a wheat milling by-product, provides good carbon dioxide and oxygen barrier properties. Soy protein bioplastics usually hold up well under tension, but they tend to lose strength in water because their polar amino acids pull in moisture like a sponge (Alvarez-Castillo *et al.*, 2021).

### 3.5 Starch based biopolymers

Most bioplastic starch comes from corn, cassava, wheat, rice, peas, tapioca and potatoes and it is used either in its natural state or after modification, sometimes mixed with synthetic polymers for extra strength. Starch based biodegradable films can be formulated from dried or fresh fruits and vegetables. Thermoplastic starch offers several advantages: it is inexpensive, easy to find, biocompatible can touch food without risk and run smoothly through standard plastic molding machines warm to the touch (Onyeaka *et al.*, 2022). Table 1 summarizes the various sources of bioactive compounds and their functional significance to produce the biodegradable packaging materials.

## 4. Methodology

Cellulose the most common polysaccharide that can be drawn not only from wood and cotton but also from high fiber plant waste like banana skins or the papery rind of an orange. Through various treatments, cellulose may be converted into micro or nanocrystalline cellulose (MCC/NCC), cellulose nanowhiskers (CNWs), cellulose microfibrils (CMFs) and cellulose nanofibrils (CNFs) (Trache *et al.*, 2020). Lignocellulosic fractions in most agricultural waste typically comprise cellulose (35 to 50%), hemicellulose (20 to 35%), lignin (15 to 25%) and other minor components.

Selection of raw materials (biopolymers)

↓

Preparation of polymer solution

↓

Incorporation of plasticizers and additives

↓

Mixing and homogenization

↓

Degassing (removal of air bubbles)

↓

Thermal treatment

↓

Film formation (casting/extrusion/molding)

↓

Shaping into uniform layers

↓

Drying/cooling under controlled conditions

↓

Biodegradable film

**Figure 1: Processing flowchart for the preparation of biodegradable films.**

### 4.1 Solvent casting

Solvent casting ranks among the oldest and most widely used ways to make thermoplastic film samples. Researchers still rely on this method to make biopolymer based biodegradable films, dissolving the material, pouring it into thin casts, then drying it until it feels smooth and paper light (Khalil *et al.*, 2018). This method can yield high quality films with uniform thickness, flatness, dimensional stability and excellent optical clarity at relatively low cost across various polymer/solvent systems (Siemann, 2005).

### 4.2 Melt extrusion

Extrusion is widely used across the agro-food industry, shaping everything from crunchy breakfast cereals to nutrient rich animal feed. Recent improvements in extrusion now have produced biodegradable active packaging, turning out films that stay strong and stable even under heat. The process integrates unit operations such as mixing, baking, kneading, shearing, molding and forming.

### 4.3 Thermal pressing

Thermal pressing involves heating and compressing a plasticized polymer blend to produce a viscoelastic mass that is then molded and cooled; final products or films are cut or formed from the cooled material. This method can be employed to produce films and containers (pots and trays) as well as adherent multilayer structures with diverse applications in food packaging (Gomez-Estaca *et al.,* 2016).

### 4.4 Compression molding

Compression molding is one of the earliest methods used by people to shape materials into different forms. It was one of the first industrial methods used to form plastic, pressing warm resin into solid, glossy molds (Frank *et al.*, 2023). In this method, the mold is first heated, then the polymer is poured into the open, hot cavity; under steady heat and heavy pressure, the material hardens and takes on every curve and edge of the mold's shape (Cristofoli *et al.*, 2023).

### 4.5 Electro spraying

Electrospinning is an efficient and cost-effective method for producing nonwoven fibers with submicron to nanoscale diameters. Food processors use a similar method called electro spraying to create tiny micro and nanoparticles, coat surfaces like a glossy chocolate shell and form thin, even films (Dhiman *et al.*, 2021).

### 4.6 Layer by layer assembly

Layer by layer electrostatic deposition (LBL) allows the fabrication of multicomponent films using relatively simple equipment and without being constrained by substrate shape (Li *et al.*, 2012). LBL has been extensively investigated for biomaterial films; its adaptability distinguishes it from traditional techniques, enabling production of materials with enhanced barrier and separation performance even under high humidity (Santos *et al.*, 2025).

### 4.7 Film preparation

Following De Paola's protocol, the films were prepared from a clear, freshly mixed film forming solution (FFS). Briefly, after combining reagents and stirring magnetically for 5 min at 25°C, the mixture was sonicated (Bandelin Sonorex, RH 102 K, Milano, Italy) for 10 min at 25°C and 35 kHz. The suspensions were heated to 80°C for 45 min to gelatinize starch and mixed at 150 rpm with an overhead stirrer (RW20, IKA, Staufen, Germany) (Ajiya *et al.*, 2018).

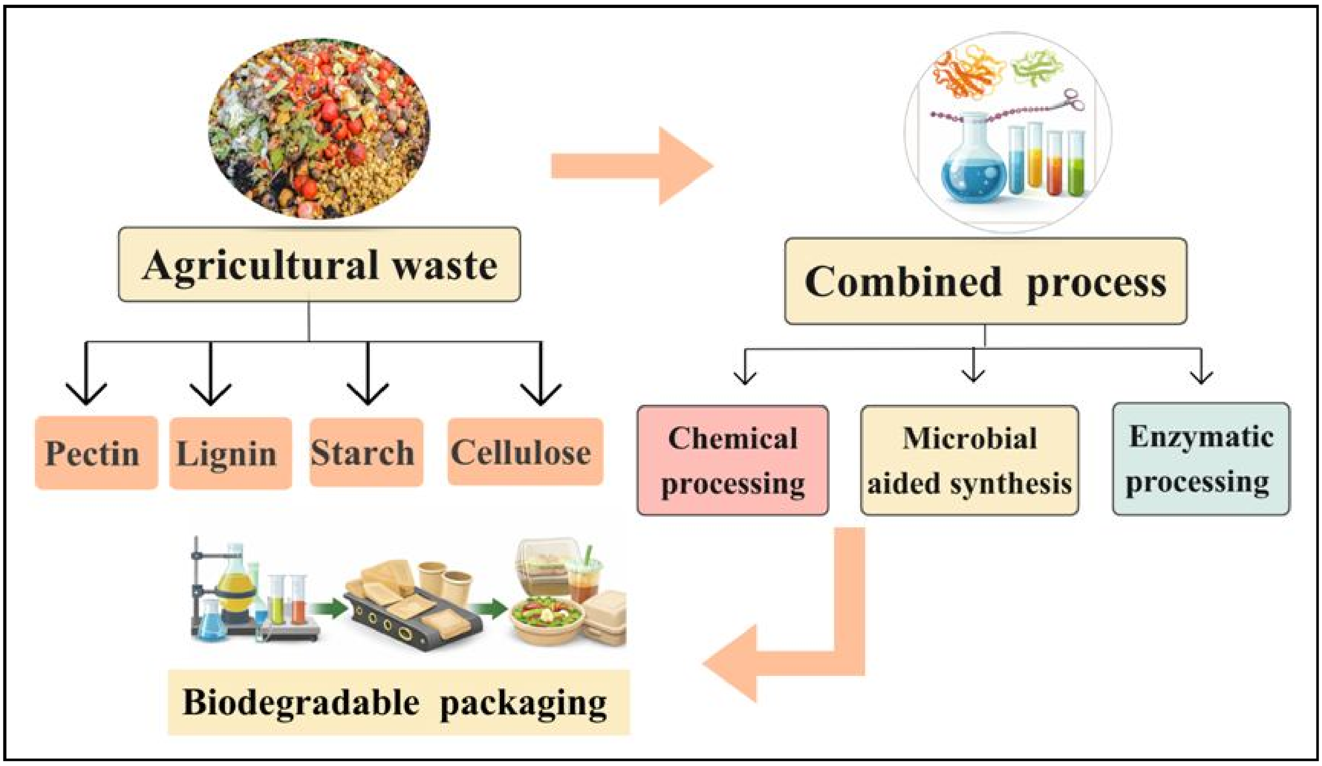


**Figure 2: Agricultural waste into biodegradable packaging material.**

Figure 2 illustrates key advancements in processing technologies, including enzymatic or deep eutectic solvent pre-treatments to enhance fiber dispersion, solvent free reactive extrusion for lignin based plastics and twin screw extrusion of fiber reinforced composites are examples of processing technology advancements that are essential for scaling up production. In this context, scaling up refers to moving from laboratory scale demonstrations to pilot and industrial scale manufacturing while preserving material performance and process efficiency (Kossalbayev *et al.*, 2025).

## 5. Properties of the biopolymers from agricultural waste

### 5.1 Physical properties

Packaging films for food require robust mechanical properties to protect and market products. Mechanical behavior under thermal and mechanical loads reflects material performance (Devi *et al.*, 2024). Tensile strength (TS) and percentage elongation at break (%) are standard metrics for evaluating these properties (Wang *et al.*, 2023). Studies on starch lauric acid films have demonstrated that ultrasonication at amplitudes up to 40% improves mechanical strength by inducing the disruption of starch granules, facilitating amylose release and promoting the uniform dispersion of lauric acid, thereby enhancing the structural integrity and homogeneity of starch lipid films (Kang *et al.,* 2019). Based on the natural polymer used, the acceptable mechanical ranges vary for food preservation films, typical targets are elongation between 5 to 30% and minimum strength of 2 to 10 MPa to maintain product shape and protection (Jiang *et al.*, 2021).

### 5.2 Degradability

A biofilm intended for packaging must biodegrade under conditions encountered in soil or composting systems heat, moisture and microbial activity breaking down at ambient or industrial composting temperatures (around 50 to 60°C) (Zhang *et al.*, 2015). Soil degradation tests of chitosan films containing sage and rosemary extracts showed that sage-containing films degraded by 95% in five days, whereas rosemary containing films reached about 99% degradability. Cellulose based polymers biodegradability and eco-friendliness make them promise for bio-based packaging (Zhao *et al.*, 2020).

### 5.3 Thermal stability

Thermo gravimetric analysis evaluates thermal stability; greater mass loss indicates poorer thermal resilience (Tavares *et al.*, 2020). The thermoplastic films made from banana peel, a small mass drop near 150°C came from free water evaporating like steam slipping off the surface while a sharper loss around 290°C marked the breakdown of starch. When banana peel nanocellulose fibers were added, the material's degradation temperature climbed roughly 15°C making it noticeably more heat stable (Chandrasekar *et al.*, 2023).

### 5.4 Oxygen permeability

Oxygen permeability depends on the packaged product and storage conditions. For food products such as fresh vegetables, fruits, dairy products and meat required oxygen permeability should be in the range below 1 to 10 $cm^3/m^2$-day-atm (Jiang, Luo *et al.*, 2021).

### 5.5 Water solubility

Edible films for packaging should have low water solubility. Increasing starch content in films significantly reduced solubility ($p<0.05$), attributed to higher concentrations of PPS forming a densely cross linked network that limits water ingress into the film matrix.

### 5.6 Water vapor transmission rate

Water is the primary factor driving food spoilage, so edible films must prevent moisture transfer between the food and the surrounding air, thereby preserving product freshness. WVTR quantifies the moisture passing through a unit area per time. Denser membrane structures reduce WVTR by creating more tortuous diffusion pathways for water molecules (Sandoval *et al.*, 2019). Table 2 summarizes the properties of the sources used for producing biodegradable packaging materials.

**Table 2: Properties of the sources used in biodegradable packaging**

| Source | Properties | Significance | Reference |
|---|---|---|---|
| Bee wax and carnauba wax | Water vapor permeability | Water vapor cannot easily pass through lipid based materials. | De Oliveira Filho *et al.*, 2021 |
| Citric acid and camellia oil | Oxygen permeability | Antioxidants reduce oxidative stress. Citric acid and camellia oil have better barrier properties. | Zhou *et al.*, 2021; Jiang, Luo, *et al.*, 2021b |
| Vegetable oils and animal fats and chitosan | Antimicrobial properties | Adding antimicrobial agents to films helps increase the shelf life of products. These agents interact with bacteria and prevent their growth. | Akyuz *et al.*, 2018 |
| Lignin, ginger and cinna-mon bee wax | Antioxidant properties | Antioxidants are being incorporated as bio active compounds into the polymeric matrix to prevent oxidation. | Devi *et al.*, 2022 |

## 6. Applications

In recent years, more people have started reusing agro food residues, uncovering chances to create high value products like natural fibers or bio based coatings with real economic promise. As a result, more agro food leftovers are being turned into bio-based materials for packaging like fruit peels transformed into sturdy, compostable wraps. In 2021, the global food packaging market was valued at USD 346.5 billion. The bioplastics sector is projected to grow by 36% from 2020, reaching USD 2.87 million by 2025 (Cruz *et al.*, 2025). In 2022, Asia produced about 41% of global bioplastics output, with Europe at 26.5%, North America at 18.9% and South America at 12.6%. The cellulose fraction in sugar palm nano-fibrillated cellulose (SPNFCs) influenced mechanical behavior: higher cellulose loadings (0.1 to 1.0 wt %) enhanced strength (Ilyas *et al.*, 2019). Modified coffee grounds have been employed to produce bio based films because virgin materials limited hydrophobicity reduces compatibility with synthetic polymers (Moustafa *et al.*, 2019).

Photobleaching of corn starch blueberry powder biopolymers enabled intelligent packaging films: photobleaching altered luminance values so films served as colorimetric indicators of food spoilage turning red under basic and blue under acidic pH (Luchese *et al.*, 2017). Tests showed that lemon and lime peels reach an optimal tensile strength of 48 MPa. The high-strength and solid texture of these eco-friendly composites stem from a dense network of natural fibers (cellulose, lignin and hemicellulose) within the plant waste, which are tightly bound together by strong hydrogen interactions (Navas *et al.*, 2015).

The polysaccharides are a long chain biopolymer composed of monosaccharides, which are smaller repeating units of carbohydrates connected by glycoside linkages. Because of their hydrocolloid nature and capacity for gelatinization, polysaccharide components like chitosan, starches (corn, cassava, sago, tapioca and potato) and gums (guar, xanthan and carrageenan) can be utilized to create edible packaging. Polysaccharide based films have good oxygen gas barrier qualities but their main drawback is that they are not very resistant to moisture (Falguera *et al.*, 2011).

Due to the non-toxic nature, safety for human consumption, biodegradability and capacity to prolong the shelf-life of food goods, edible packaging has recently gained appeal in both scientific and food packaging application (Benbettaieb *et al.*, 2018). By creating a semipermeable protective layer around the fruit's surface, edible film application increases the fruit's shelf-life by lowering phenol oxidation, respiration, evapotranspiration rate and altering the gaseous environment ($O_2$ and $CO_2$). Additionally, the fruit coating seals the tiny fissures on the fruit's pericarp, causing the stomata and lenticels to close, delaying the onset of physiological conditions and enzymatic reactions (Tokatl and Demirdoven, 2019).

Plant based proteins (pea, soybean, wheat gluten, zein) used to make protein component-based edible films. In general, the edible films made of proteins have strong mechanical and gas barriers (Valenzuela *et al*., 2012). Due to their hydrophilic nature, these films are more flexible than coatings based on polysaccharides, although they often have poor moisture barrier qualities. Lipid based edible films and coatings typically have no polymeric matrix. Compared to polysaccharide or protein based films, lipid based films have a superior moisture barrier because they are highly hydrophobic (Valencia Chamorro *et al*., 2010).

## 7. Trends and barriers

In 2022, Asia accounted for around 41% of global bioplastic production, compared with Europe (26.5%), North America (18.9%) and South America (12.6%). The biorefinery concept aims to convert a single biomass feedstock into multiple products; sustainability is achieved when waste is minimized. By producing a range of intermediate and end products without resource loss or adverse environmental impact, biorefineries maximize biomass value (Zhu, 2014). Using readily available agro food waste, biorefineries can generate eco-friendly, cost-effective and valuable products.

A film is usually a thin solid sheet made through one or more processing methods, that's used to wrap or seal food like the clear layer clinging to a sandwich. In contrast, coatings are liquid mixtures spread right onto food brushed on sprayed in a fine mist or dipped until the surface glistens (Hassan *et al.*, 2017). Because biopolymeric systems are nontoxic, biodegradable and act as barriers, they offer multiple advantages: inhibiting microbial growth (Chitosan and plant extracts) and limiting oxidation (Green tea extract for fresh sausage preservation) (Hamann *et al.*, 2022). Pectin based coatings have shown efficacy in preserving fruits and vegetables by enhancing surface moisture retention (Rohasmizah and Azizah, 2022). Research on zein based films revealed that adding sunflower extract reduced water vapor permeability and increased plasticization, extending wheat bread shelf-life (Mouzakitis *et al.*, 2022).

Historically, the high cost of bio based polymers has impeded commercial uptake due to limitations in production processes. Advances in microbial synthesis pathways (anaerobic/aerobic, mixed cultures) and the availability of inexpensive carbon rich feedstocks have reduced costs for PHA production for medical and other commercial uses (Luckachan and Pillai, 2011). Edible films struggle to work as reliable packaging since their strength and barrier protection fall short; researchers are turning to nanotech and layered designs to fix that, adding tiny particles that can stiffen the sheet like a crisp leaf. Another hurdle comes from how easily they draw in water, clinging to every drop (Sun *et al.*, 2021).

Thermal processing techniques are limited to thermoplastic polymers that can tolerate heat. Common coating application methods include spraying, dipping, brushing, panning and fluidized bed processing. Low yields from current lab scale extraction and production of certain biomaterials from food waste restrict commercial viability and scale up. Common shortcomings of bio based materials include high permeability and moisture uptake (Abotbina *et al.*, 2022). High fiber content can worsen interfacial adhesion in composites, leading to increased water absorption, matrix porosity and reduced performance (Cardoso *et al.*, 2019). Strategies to boost yields focus on optimizing production and processing. Integrating multi feedstock bio refinery designs to co-produce diverse products from the same biomass is one route to economically address low yields.

## 8. Conclusion

Growing global populations have made agro waste management increasingly challenging. Converting these residues into useful products can save both environmental resources and considerable costs. Advances in this field have accelerated alongside consumer demand for environmentally friendly food packaging. Agro food waste from diverse sources can be extracted, purified and converted into packaging components. Significant research has targeted crop residues, processing waste and animal by-products. Agricultural processing, handling and manufacturing generate large volumes of waste, posing environmental and economic problems that call for alternative recycling and valorization approaches. It is now critical to design composite materials as low cost packaging alternatives with improved properties to enable large scale, economical production. Petroleum based plastics dominate current food packaging markets but are neither biodegradable nor eco-friendly taking years to decompose. Biodegradable and edible materials, which break down more rapidly under microbial and environmental action are promoted as solutions.

In this review, inexpensive lab scale biodegradable and edible films were produced from readily available household ingredients gelatin, soy protein, corn starch and papaya as potential substitutes for commercial plastics to reduce waste. Developments in electrospinning/electrospray technologies, incorporation of nano fibrillated cellulose and cellulose reinforcement have driven interest in biofilms for packaging.

To deploy biopolymers in agricultural and construction contexts, manufacturing techniques that balance tensile/flexural strength, biodegradability and environmental impact are required. Diverse agro wastes can be converted into fillers and packaging materials that enhance reinforcement or barrier functions, but they must be properly extracted and purified before use. Industry and academia face major challenges in the coordinated collection, storage, preservation and pre-processing of feedstock. Legislative measures are urgently needed to enable widespread use of agro waste for environmental sustainability.

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## Conflict of interest

The authors declare no conflicts of interest relevant to this article.

## References

**Abotbina, W.; Sapuan, S. M.; Ilyas, R. A.; Sultan, M. T. H. and Alkbir, M. F. M. (2022).** Preparation and characterization of black seed/cassava bagasse fiber reinforced cornstarch based hybrid composites. Sustainability, **14**(19):12042. https://doi.org/10.3390/su141912042

**Agarwal, A.; Shaida, B.; Rastogi, M. and Singh, N. B. (2023).** Food packaging materials with special reference to biopolymers properties and applications. Chemistry Africa, **6**(1):117-144.

**Ajiya, D. A.; Jikan, S. S. B.; Talip, B. A.; Matias-Peralta, H. M.; Badarulzaman, N. A. and Yahya, S. (2018).** Physical properties of edible films based on tapioca starch as affected by the glycerol concentration. International Journal of Current Research in Science Engineering and Technology, **1**(1):410. https://doi.org/10.30967/ijcrset.1.s1.2018.410-415

**Akyuz, L.; Kaya, M.; Ilk, S.; Cakmak, Y. S.; Salaberria, A. M.; Labidi, J. and Sargin, I. (2018).** Effect of different animal fat and plant oil additives on physicochemical, mechanical, antimicrobial and antioxidant properties of chitosan films. International Journal of Biological Macromolecules, **111**:475-484.

**Alvarez-Castillo, E.; Bengoechea, C.; Felix, M. and Guerrero, A. (2021).** Protein based bioplastics from biowastes: sources, processing, properties and applications. In: Springer eBooks. pp:137-176. https://doi.org/10.1007/978-981-16-1823-9_5

**Anjum, A.; Zuber, M.; Zia, K. M., Noreen, A., Anjum, M. N. and Tabasum, S. (2016b).** Microbial production of polyhydroxyalkanoates (PHAs) and its copolymers: A review of recent advancements. International Journal of Biological Macromolecules, **89**:161-174. https://doi.org/10.1016/j.ijbiomac.2016.04.069.

**Benbettaieb, N.; Debeaufort, F. and Karbowiak, T. (2018).** Bioactive edible films for food applications: Mechanisms of antimicrobial and antioxidant activity. Critical Reviews in Food Science and Nutrition, **59**(21):3431-3455. https://doi.org/10.1080/10408398.2018.1494132

**Benitez, J. J.; Castillo, P. M.; Del Rio, J. C.; Leon-Camacho, M.; Dominguez, E.; Heredia, A.; Guzman-Puyol, S.; Athanassiou, A. and Heredia-Guerrero, J. A. (2018).** Valorization of tomato processing by-products: fatty acid extraction and production of bio-based materials. Materials, **11**(11):2211. https://doi.org/10.3390/ma11112211.

**Brodnjak, U. V. (2016).** Microorganism based biopolymer materials for packaging applications: A review. Journal of Composites and Biodegradable Polymers, **4**(1):32-40. https://doi.org/10.12974/2311-8717.2016.04.01.5.

**Butler, I. P.; Banta, R. A.; Tyuftin, A. A.; Holmes, J.; Pathania, S. and Kerry, J. (2023).** Pectin as a biopolymer source for packaging films using a circular economy approach: Origins, extraction, structure and films properties. Food Packaging and Shelf-Life, **40**:101224.

**Cardoso, T.; Esmerino, L. A.; Bolanho, B. C.; Demiate, I. M. and Danesi, E. D. G. (2019).** Technological viability of bio-based films formulated with cassava by-product and spirulina platensis. Journal of Food Process Engineering, **42**(5). https://doi.org/10.1111/jfpe.13136.

**Chandrasekar, C. M.; Krishnamachari, H.; Farris, S. and Romano, D. (2023).** Development and characterization of starch based bioactive thermoplastic packaging films derived from banana peels. Carbohydrate Polymer Technologies and Applications, **5**:100328. https://doi.org/10.1016/j.carpta.2023.100328.

**Chen, K.; Wei, P.; Jia, M.; Wang, L.; Li, Z.; Zhang, Z. and Shi, L. (2024).** Research progress in modifications, bioactivities and applications of medicine and food homologous plant starch. Foods, **13**(4):558.

**Cheng, H.; Chen, L.; McClements, D. J.;Yang, T.;Zhang, Z.; Ren, F. and Jin, Z. (2021).** Starch-based biodegradable packaging materials: A review of their preparation, characterization and diverse applications in the food industry. Trends in Food Science and Technology, **114**:70-82.

**Cristofoli, N. L.; Lima, A. R.; Tchonkouang, R. D. N.; Quintino, A. C. and Vieira, M. C. (2023).** Advances in the food packaging production from agri food waste and by-products: Market trends for a sustainable development. Sustainability, **15**(7):6153. https://doi.org/10.3390/su15076153.

**Cruz, B.; Vaitsi, A.; Domingos, S.; Possidónio, C.; Luís, S.; Portugal, E.; Loureiro, A.; Padmanabhan, S. and Farias, A. R. (2025).** Unpacking online discourse on bioplastics: Insights from reddit sentiment analysis. Polymers, **17**(6):823. https://doi.org/10.3390/polym17060823.

**De Oliveira Filho, J. G.; Albiero, B. R.; Cipriano, L.; de Oliveira Nobre Bezerra, C. C.; Oldoni, F. C. A.; Egea, M. B. and Ferreira, M. D. (2021).** Arrowroot starch based films incorporated with a carnauba wax nanoemulsion, cellulose nanocrystals and essential oils: A new functional material for food packaging applications. Cellulose, **28**(10):6499-6511.

**Devi, L. S.; Jaiswal, A. K. and Jaiswal, S. (2024).** Lipid incorporated biopolymer based edible films and coatings in food packaging: A review. Current Research in Food Science, **8**:100720. https://doi.org/10.1016/j.crfs.2024.100720.

**Devi, L. S.;Kalita, S.; Mukherjee, A. and Kumar, S. (2022).** Carnauba wax-based composite films and coatings: Recent advancement in prolonging postharvest shelf-life of fruits and vegetables. Trends in Food Science and Technology, **129**:296-305.

**Dhiman, A.; Suhag, R.; Singh, A. and Prabhakar, P. K. (2021).** Mechanistic understanding and potential application of electro spraying in food processing: A review. Critical Reviews in Food Science and Nutrition, **62**(30):8288-8306. https://doi.org/10.1080/10408398.2021.1926907.

**Diaz-Montes, E. and Castro-Munoz, R. (2021).** Edible films and coatings as food-quality preservers: An overview. Foods, **10**(2):249. https://doi.org/10.3390/foods10020249

**Duan, B.; Huang, Y.; Lu, A. and Zhang, L. (2018).** Recent advances in chitin based materials constructed *via* physical methods. Progress in Polymer Science, **82**:1-33. https://doi.org/10.1016/j.progpolymsci.2018.04.001

**Falguera, V.; Quintero, J. P.; Jimenez, A.; Munoz, J. A. and Ibarz, A. (2011).** Edible films and coatings: Structures, active functions and trends in their use. Trends in Food Science and Technology, **22**(6):292-303. https://doi.org/10.1016/j.tifs.2011.02.004

**Fang, B.; Peng, Z.; Chen, B. and Rao, J. (2024).** Unconventional sources of vegetable proteins: Technological properties. Current Opinion in Food Science, **57**:101150.

**Frank, R.; Wittmann, L; Kleffel, T.; Roth, B.; Graichen, K. and Drummer, D. (2023).** Investigating the integration of nonwoven carbon fibers for mechanical enhancement in compression molded Fiber-Reinforced polymer bipolar plates. Polymers, **15**(19):3891. https://doi.org/10.3390/polym15193891

**Ge, J.; Sun, C. X.; Mata, A.; Corke, H.;Gan, R. Y. and Fang, Y. (2021).** Physicochemical and pH-dependent functional properties of proteins isolated from eight traditional Chinese beans. Food Hydrocolloids, **112**:106288.

**Geyer, R.; Jambeck, J. R.; and Law, K. L. (2017).** Production, use, and fate of all plastics ever made. Science Advances, **3**(7):1700782. https://doi.org/10.1126/sciadv.1700782

**Gomez-Estaca, J.; Gavara, R.; Catala, R.; Hernandez-Munoz, P. (2016).** The potential of proteins for producing food packaging materials: A review. Packag. Technol. Sci., **29**:203-224.

**Guillard, V.; Gaucel, S.; Fornaciari, C.; Angellier-Coussy, H.; Buche, P. and Gontard, N. (2018).** The next generation of sustainable food packaging to preserve our environment in a circular economy context. Frontiers in Nutrition, **5**. https://doi.org/10.3389/fnut.2018.00121.

**Hamann, D.; Puton, B. M. S.; Comin, T.; Colet, R.; Valduga, E.; Zeni, J.; Steffens, J.; Junges, A.; Backes, G. T. and Cansian, R. L. (2022).** Active edible films based on green tea extract and gelatin for coating of fresh sausage. Meat Science, **194**:108966. https://doi.org/10.1016/j.meatsci.2022.108966

**Han, J. H. (2013).** A review of food packaging technologies and innovations. Elsevier eBooks, pp:3-12. https://doi.org/10.1016/b978-0-12-394601-0.00001-1

**Hassan, B.; Chatha, S. a. S.; Hussain, A. I.; Zia, K. M. and Akhtar, N. (2017).** Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review. International Journal of Biological Macromolecules, **109**:1095-1107. https://doi.org/10.1016/j.ijbiomac.2017.11.097

**Ilaz-Montes, E.; Gutierrez-Macias, P.; Orozco-Alvarez, C. and Castro-Munoz, R. (2020).** Fractionation of *Stevia rebaudiana* aqueous extracts *via* two-step ultrafiltration process: Towards rebaudioside a extraction. Food and Bioproducts Processing, **123**:111-122.

**Ilyas, R.; Sapuan, S.; Ibrahim, R.; Abral, H.; Ishak, Zainudin, E.; Atikah, M.; Nurazzi, N. M.; Atiqah, A.; Ansari, M.; Syafri, E.; Asrofi, M.; Sari, N. H. and Jumaidin, R. (2019).** Effect of sugar palm nanofibrillated cellulose concentrations on morphological, mechanical and physical properties of biodegradable films based on agro waste sugar palm (*Arenga pinnata* (Wurmb.) Merr) starch. Journal of Materials Research and Technology, **8**(5):4819-4830. https://doi.org/10.1016/j.jmrt.2019.08.028

**Jamwal, V.; Mittal, A. and Dhaundiyal, A. (2023).** Valorization of agro industrial waste in composite films for sustainable packaging applications. Materials Today Proceedings, **113**:94-100. https://doi.org/10.1016/j.matpr.2023.08.042

**Jaski, A. C.; Schmitz, F.; Horta, R. P., Cadorin, L.; Da Silva, B. J. G.; Andreaus, J. and Zimmermann, L. M. (2022).** Zein a plant based material of growing importance: New perspectives for innovative uses. Industrial Crops and Products, **186**:115250.

**Jiang, L.; Han, Y.; Meng, X.;Xiao, Y. and Zhang, H. (2021).** Cellulose nanocrystals reinforced Zein/Catechin/β-Cyclodextrin inclusion complex nanoparticles nanocomposite film for active food packaging. Polymers, **13**(16):2759. https://doi.org/10.3390/polym13162759

**Jiang, L.; Luo, Z; Liu, H.; Wang, F.; Li, H.; Gao, H. and Zhang, H. (2021).** Preparation and characterization of chitosan films containing lychee (*Litchi chinensis* Sonn.*)* pericarp powder and their application as active food packaging. Foods, **10**(11):2834. https://doi.org/10.3390/foods10112834

**Kang, X.; Liu, P.; Gao, W.; Wu, Z.; Yu, B.; Wang, R.; Cui, B.; Qiu, L. and Sun, C. (2019).** Preparation of starch lipid complex by ultrasonication and its film forming capacity. Food Hydrocolloids, **99**:105340. https://doi.org/10.1016/j.foodhyd.2019.105340

**Khalil, H. P. S.A.; Banerjee, A.; Saurabh, C. K.; Tye, Y. Y; Suriani, A. B.; Mohamed, A., Karim, A. A.; Rizal, S. and Paridah, M. T. (2018).** Biodegradable films for fruits and vegetables packaging application: Preparation and properties. Food Engineering Reviews, **10**(3):139-153. https://doi.org/10.1007/s12393-018-9180-3

**Kim, Y. T.; Min, B. and Kim, K. W. (2013).** General characteristics of packaging materials for food system. In: Elsevier eBooks, pp:13-35. https://doi.org/10.1016/b978-0-12-394601-0.00002-3

**Kossalbayev, B. D.; Belkozhayev, A. M.; Abaildayev, A.; Kadirshe, D. K.; Tastambek, K. T.; Kurmanbek, A. and Toleutay, G. (2025).** Biodegradable packaging from agricultural wastes: A comprehensive review of processing techniques, material properties and future prospects. Polymers, **17**(16): 2224. https://doi.org/10.3390/polym17162224

**Linan, L. Z.; Fakhouri, F. M.; Nogueira, G. F.; Zoppe, J. and Velasco, J. I. (2024).** Benefits of incorporating lignin into starch based films: A brief review. Polymers, **16**(16):2285.

**Luchese, C. L.; Sperotto, N.; Spada, J. C. and Tessaro, I. C. (2017).** Effect of blueberry agro-industrial waste addition to corn starch based films for the production of a pH-indicator film. International Journal of Biological Macromolecules, **104**:11-18. https://doi.org/10.1016/j.ijbiomac.2017.05.149

**Luckachan, G. E. and Pillai, C. K. S. (2011).** Biodegradable polymers a review on recent trends and emerging perspectives. Journal of Polymers and the Environment, **19**(3):637-676. https://doi.org/10.1007/s10924-011-0317-1

**Merino, D.; Bellassi, P; Paul, U. C.; Morelli, L. and Athanassiou, A. (2023).** Assessment of chitosan/pectin rich vegetable waste composites for the active packaging of dry foods. Food Hydrocolloids, **139**:108580. https://doi.org/10.1016/j.foodhyd.2023.108580

**Miehle, E; Haas, M; Bader-Mittermaier, S. and Eisner, P. (2022).** The role of hydration properties of soluble dietary fibers on glucose diffusion. Food Hydrocolloids, **131**:107822.

**Moghadas, H. C.; Chauhan, R. and Smith, J. S. (2024).** Application of plant oils as functional additives in edible films and coatings for food packaging: A review. Foods, **13**(7):997.

**Moustafa, H.; Youssef, A. M.; Darwish, N. A and Abou-Kandil, A. I. (2019).** Eco-friendly polymer composites for green packaging: Future vision and challenges. Composites Part B Engineering, **172**:16-25. https://doi.org/10.1016/j.compositesb.2019.05.048

**Mouzakitis, C; Sereti, V.; Matsakidou, A.; Kotsiou, K.; Biliaderis, C. G. and Lazaridou, A. (2022).** Physicochemical properties of zein based edible films and coatings for extending wheat bread shelf-life. Food Hydrocolloids, **132**:107856. https://doi.org/10.1016/j.foodhyd.2022.107856

**Munteanu, S. B. and Vasile, C. (2019).** Vegetable additives in food packaging polymeric materials. Polymers, **12**(1):28. https://doi.org/10.3390/polym12010028

**Nanda, S.; Patra, B. R.; Patel, R.; Bakos, J. and Dalai, A. K. (2021).** Innovations in applications and prospects of bioplastics and biopolymers: a review. Environmental Chemistry Letters, **20**(1):379-395. https://doi.org/10.1007/s10311-021-01334-4

**Navas, C. S.; Reboredo, M. M. and Granados, D. L. (2015).** Comparative study of agro industrial wastes for their use in polymer matrix composites. Procedia Materials Science, **8**:778-785. https://doi.org/10.1016/j.mspro.2015.04.135

**Nunes, L. A.; Silva, M. L.; Gerber, J. Z. and De a Kalid, R. (2020).** Waste green coconut shells: Diagnosis of the disposal and applications for use in other products. Journal of Cleaner Production, **255**:120169. https://doi.org/10.1016/j.jclepro.2020.120169

**Onyeaka, H.; Obileke, K.; Makaka, G. and Nwokolo, N. (2022).** Current research and applications of starch based biodegradable films for food packaging. Polymers, **14**(6):1126. https://doi.org/10.3390/polym14061126

**Qazanfarzadeh, Z.; Ganesan, A. R.; Mariniello, L.; Conterno, L. and Kumaravel, V. (2022).** Valorization of brewer's spent grain for sustainable food packaging. Journal of Cleaner Production, **385**:135726. https://doi.org/10.1016/j.jclepro.2022.135726

**Rahman, S.; Gogoi, J.; Dubey, S. and Chowdhury, D. (2023).** Animal derived biopolymers for food packaging applications: A review. International Journal of Biological Macromolecules, **255:**128197. https://doi.org/10.1016/j.ijbiomac.2023.128197

**Ren, Y.; Wu, Z.; Shen, M.; Rong, L.; Liu, W.; Xiao, W. and Xie, J. (2021).** Improve properties of sweet potato starch film using dual effects: cCombination mesona chinensis benth polysaccharide and sodium carbonate. Lwt, **140:**110679.

**Riaz, A.; Lagnika, C.; Luo, H.; Dai, Z.; Nie, M.; Hashim, M. M. and Li, D. (2020).** Chitosan based biodegradable active food packaging film containing Chinese chive (*Allium tuberosum*) root extract for food application. International Journal of Biological Macromolecules, **150**:595-604.

**Rodrigues, D. C.; Caceres, C. A.; Ribeiro, H. L.; De Abreu, R. F.; Cunha, A. P. and Azeredo, H. M. (2013).** Influence of cassava starch and carnauba wax on physical properties of cashew tree gum based films. Food Hydrocolloids, **38**:147-151. https://doi.org/10.1016/j.foodhyd.2013.12.010

**Rohasmizah, H. and Azizah, M. (2022).** Pectin based edible coatings and nanoemulsion for the preservation of fruits and vegetables: A review. Applied Food Research, **2**(2):100221. https://doi.org/10.1016/j.afres.2022.100221

**Saadi, S.; Saari, N.; Ghazali, H. M.; Abdulkarim, S. M.; Hamid, A. A. and Anwar, F. (2022**). Gluten proteins: Enzymatic modification, functional and therapeutic properties. Journal of proteomics, **251:**104395.

**Sandoval, D. C. G.; Sosa, B. L.; Martinez-Avila, G. C. G.; Fuentes, H. R.; Abarca, V. H. A. and Rojas, R. (2019).** Formulation and characterization of edible films based on organic mucilage from mexican opuntia ficus indica. Coatings, **9**(8):506. https://doi.org/10.3390/coatings9080506

**Santos, T. F.; Santos, C. M.; Rao, H. J.; Sanjay, Nascimento, J.; Souza, D.; Gapsari, F.; Raharjo, R. and Siengchin, S. (2025).** Progress in bio-fibers, bio-films, bio-polymers, and bio-composites for biobased food packaging *via* bibliometric approach. Food Chemistry Advances, pp:100936. https://doi.org/10.1016/j.focha.2025.100.

**Siemann, U. (2005).** Solvent cast technology: A versatile tool for thin film production. In Springer eBooks, pp:1-14. https://doi.org/10.1007/b107336.

**Soares, R. M.; Siqueira, N. M.; Prabhakaram, M. P. and Ramakrishna, S. (2018).** Electrospinning and electrospray of bio-based and natural polymers for biomaterials development. Materials Science and Engineering, **92**:969-982. https://doi.org/10.1016/j.msec.2018.08.004

**Sorrentino,A.; Gorrasi, G. and Vittoria, V. (2012).** Permeability in clay/polyesters nano-bio composites. In: Green Energy and Technology, pp:237-264. https://doi.org/10.1007/978-1-4471-4108-2_9

**Sun, X.; Wang, J.; Dong, M.; Zhang, H.; Li, L. and Wang, L. (2021).** Food spoilage, bioactive food fresh keeping films and functional edible coatings: Research status, existing problems and development trend. Trends in Food Science and Technology, **119**:122-132. https://doi.org/10.1016/j.tifs.2021.12.004

**Tavares, K. M.; De Campos, A.; Luchesi, B. R.; Resende, A. A.; De Oliveira, J. E. and Marconcini, J. M. (2020).** Effect of carboxymethyl cellulose concentration on mechanical and water vapor barrier properties of corn starch films. Carbohydrate Polymers, **246**:116521. https://doi.org/10.1016/j.carbpol.2020.116521

**Teixeira, S. C.; De Fatima Ferreira Soares, N. and Stringheta, P. C. (2021).** Desenvolvimento de embalagens inteligentes com alteração colorimétrica incorporadas com antocianinas: uma revisão crítica. Brazilian Journal of Food Technology, **24**. https://doi.org/10.1590/1981-6723.03321.

**Thammahiwes, S.; Riyajan, S. A. and Kaewtatip, K. (2017).** Preparation and properties of wheat gluten based bioplastics with fish scale. Journal of cereal science, **75**:186-191.

**Thuppahige, V. T. W.; Moghaddam, L., Welsh, Z. G.; Wang, T. and Karim, A. (2023).** Investigation of critical properties of Cassava (*Manihot esculenta*) peel and bagasse as starch rich fibrous agro industrial wastes for biodegradable food packaging. Food Chemistry, **422**:136200. https://doi.org/10.1016/j.foodchem.2023.136200

**Tokatlý, K. and Demirdoven, A. (2019).** Effects of chitosan edible film coatings on the physicochemical and microbiological qualities of sweet cherry (*Prunus avium* L.). Scientia Horticulturae, **259**:108656. https://doi.org/10.1016/j.scienta.2019.108656

**Trache, D.; Tarchoun, A. F.; Derradji, M.; Hamidon, T. S.; Masruchin, N.; Brosse, N. and Hussin, M. H. (2020).** Nanocellulose: From fundamentals to advanced applications. Frontiers in Chemistry, **8**. https://doi.org/10.3389/fchem.2020.00392

**Tran, D.; Lee, H. R.; Jung, S.; Park, M. S. and Yang, J. (2016).** Lipid extracted algal biomass based biocomposites fabrication with poly(vinyl alcohol). Algal Research, **31**:525-533. https://doi.org/10.1016/j.algal.2016.08.016

**Tulamandi, S.; Rangarajan, V.; Rizvi, S. S.; Singhal, R. S.; Chattopadhyay, S. K. and Saha, N. C. (2016).** A biodegradable and edible packaging film based on papaya puree, gelatin, and defatted soy protein. Food Packaging and Shelf-Life, **10**:60-71. https://doi.org/10.1016/j.fpsl.2016.10.007

**Valencia Chamorro, S. A.; Perez Gago, M. B.; Del Rio, M. A. and Palou, L. (2010).** Effect of antifungal hydroxypropyl Methylcellulose Lipid edible composite coatings on penicillium decay development and postharvest quality of cold stored "Ortanique" mandarins. Journal of Food Science, **75**(8):418-26. https://doi.org/10.1111/j.1750-3841.2010.01801.x

**Valenzuela, C.; Abugoch, L. and Tapia, C. (2012).** Quinoa protein-chitosan-sunflower oil edible film: Mechanical, barrier and structural properties. LWT, **50**(2):531-537. https://doi.org/10.1016/j.lwt.2012.08.010

**Verdini, F.; Tabasso, S.; Mariatti, F.; Bosco, F.; Mollea, C.; Gaudino, E. C.; Cirio, A. and Cravotto, G. (2022).** From agri food wastes to polyhydroxyalkanoates through a sustainable process. Fermentation, **8**(10):556. https://doi.org/10.3390/fermentation 8100556

**Wang, D.; Wang, B.; Jin, X.; Peng, Y., Zhao, J.; Zhang, M. and Chen, Q. (2024).** Microwave-enzyme-assisted extraction of pectin from feijoa *(Acca sellowiana*) fruit: Extraction optimization, physicochemical and functional properties. Lwt., **204**:116445.

**Wang, F.; Xie, C.; Tang, H.; Hao, W.; Wu, J.; Sun, Y.; Sun, J.; Liu, Y. and Jiang, L. (2023).** Development, characterization and application of intelligent/active packaging of chitosan/chitin nanofibers films containing eggplant anthocyanins. Food Hydrocolloids, **139**:108496. https://doi.org/10.1016/j.foodhyd.2023.108496

**Westlake, J. R.; Tassie, A.; Kotoulas, K. T.; Chaloner, E.; Laabei, M.; Sarda, L.; Ghandi, R.; Burrows, A. D. and Xie, M. (2025).** Mushroom derived chitosan as an alternative feedstock for active packaging films: Performance and biodegradation. ACS Food Science and Technology. https://doi.org/10.1021/acsfoodscitech.5c00200

**Zhang, W.; Chen, J.; Chen, Y.; Xia, W.; Xiong, Y. L. and Wang, H. (2015).** Enhanced physicochemical properties of chitosan/whey protein isolate composite film by sodium laurate modified $TiO_2$ nanoparticles. Carbohydrate Polymers, **138**:59-65. https://doi.org/10.1016/j.carbpol.2015.11.031

**Zhang, X.; Liu, W.; Liu, W. and Qiu, X. (2020).** High performance PVA/lignin nanocomposite films with excellent water vapor barrier and UV-shielding properties. International Journal of Biological Macromolecules, **142**:551-558.

**Zhao, L.; Duan, G.; Zhang, G.; Yang, H.; He, S. and Jiang, S. (2020).** Electrospun functional materials toward food packaging applications: A review. Nanomaterials, **10**(1):150. https://doi.org/10.3390/nano10010150.

**Zhou, Y.; Wu, X.; Chen, J. and He, J. (2021).** Effects of cinnamon essential oil on the physical, mechanical, structural and thermal properties of cassava starch based edible films. International Journal of Biological Macromolecules, **184**:574-583.

**Zhu, L (2014).** Biorefinery as a promising approach to promote microalgae industry: An innovative framework. Renewable and Sustainable Energy Reviews, **41**:1376-1384. https://doi.org/10.1016/j.rser.2014.09.040



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