ISSN Print: 2664-6536
ISSN Online: 2664-6544
Impact Factor: RJIF **5.4**
IJBB 2025; 7(1): 89-94
www.biosciencejournal.net
Received: 09-12-2024
Accepted: 14-01-2025

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Proteins: A biodegradable biopolymer for edible films and coating

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DOI: https://www.doi.org/10.33545/26646536.2025.v7.i1b.100

Abstract
Proteins, as natural biopolymers, are becoming very popular in the field of the development of biodegradable EF(edible films) and coatings, especially in the food industry. Increasing environmental concerns over plastic waste, protein-based materials present a suitable alternative for food packaging and preservation. Our review explores the properties, sources, applications, and benefits of protein-based films, including whey, soy, gelatin, corn, and casein proteins. These proteins exhibit excellent film-forming abilities, providing barriers to moisture, oxygen, and also enhances the shelf life in turn the quality of food products. Protein films are not only edible, but reduce food waste and offer potential nutritional benefits. Protein-based films face challenges such as water sensitivity, limited mechanical strength, and higher production costs compared to synthetic polymers despite having so many advantages. The current research aims to address these limitations by incorporating crosslinking agents, blending with other biopolymers, and adding bioactive compounds for enhanced functionality. Overall, protein-based biodegradable films and coatings represent an innovative promising solution to the ever increasing demand for sustainable packaging alternatives, though further advancements are needed for broader adoption.

Keywords: Proteins, natural biopolymers, biodegradable edible films (EF), food packaging

Introduction

Proteins

Protein are the polypeptides chains of amino acids inter-linked with peptide bond and disulphide bridges. Proteins exists in two forms either globular or fibrous protein. Globular proteins have spherical or ellipsoidal shape because the polypeptide chain folds itself which makes it soluble in aqueous media (Acids, bases and salts) as well as water soluble. Fibrous protein have rod shaped twisted linear polypeptide chain which make them water insoluble but they function as a structural material for various animal tissue.

On the basis of biological function and origin, proteins display different molecular characteristics and this difference helps to identify the property of protein individually to form best film forming material. So far researchers have concluded solution like zein protein, whey protein soy protein and gluten protein as the best fit. All these proteins undergo denaturation either by heat acids base or solvent to form film. Denaturation of proteins leads to the extended structure these structures interlink with each other through hydrogen bonding, ionic hydrophobic and covalent bonding. Films formed from this interaction are stronger, although they have slightly little high transmission rate and rigid in texture.

Proteins forms soluble dispersion in ethanol or ethanol-water mixture have been widely used till now as polymer for developing edible films and they have shown good mechanical and permeability property alone as well as in blend with other polymers. It has been reported that the polymers having hydrogen and ionic linkages shows tremendous oxygen barrier but more prone to moisture, as protein have such linkages so they have good oxygen permeability at less humidity.

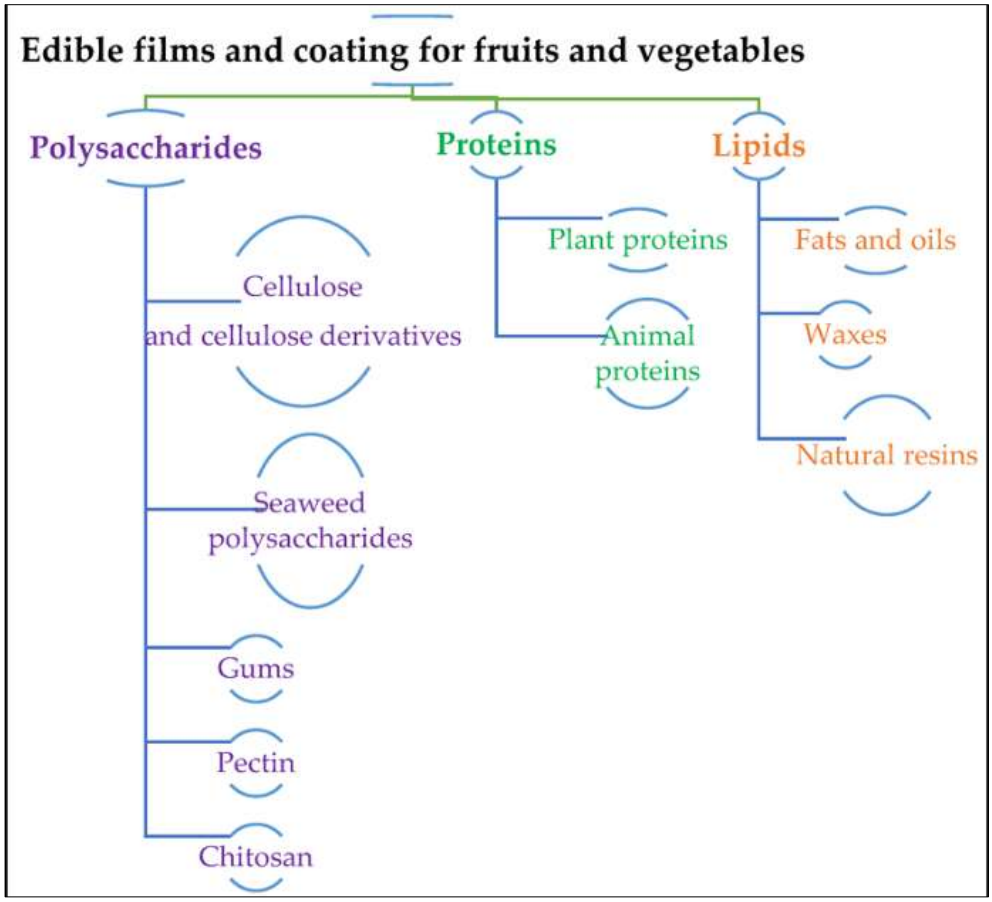


Fig 1: Classification of natural polymers used in edible films and coatings (Adapted from Wu, Y., Wu, H. et. al.2017)

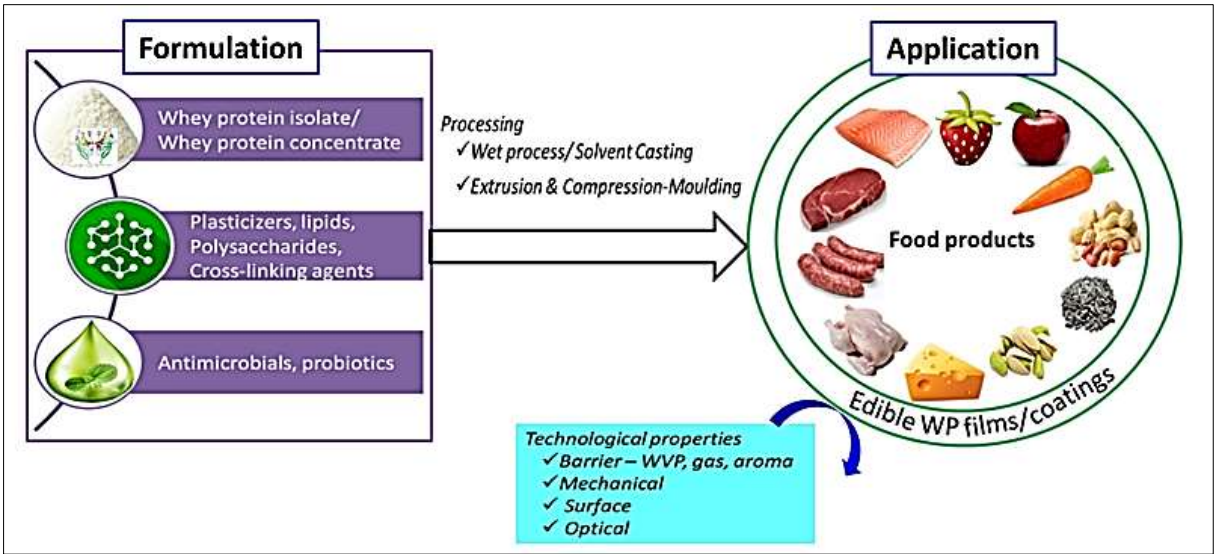


Fig 2: Formulation and application process for Edible WP films/coatings adapted from Kandasamy *et al*. 2021 [17]

Zein Protein

Zein protein is found mainly in corn maize and is a large by product of oil and bio ethanol production. It is hydrophobic in nature i.e. it dissolves in ethanol it is because of the non-polar amino acids which makes zein protein hydrophobic and most potent biodegradable material for film formation Zein protein till now is being used as a traditional coating material in confectionary industries. Zein protein films have proved to have good barrier properties towards moisture, vapour and are also a very good carrier for various active compounds like antioxidants and antimicrobials.

Whey Protein

These proteins are obtained as a by-product during the processing of cheese, the raffinate collected over the top of cheese is rich in β-Lactoglobulin which constitutes to whey proteins. Whey proteins has so far extensively used for edible films and coating as they have good film forming capability (Kaya and Kaya, 2000) [22]. Films from whey proteins are hydrophilic in nature due to which they have greater tendency to moisture and water permeability. Many researchers have incorporated different essential oils and fatty acids in these films to overcome these permeability limitations (Mc Hugh and Korchta 1994) [19]. Whey proteins

are now a day's consumed as a good source of protein by many athletes and also used in the formulation of baby foods as an essential dietary source

Table 1: The application of Whey Protein (WP)-based edible films and coatings (WPC) on packaging food. Adapted from (Kandasamy, et. al. 2021) [17]

Whey Protien Coating(WPC) Film and Coating Composition	Food Products	Function
Whey Protien Coating-pullulan + beeswax	Milk	permeability of water vapor improves
WPI + natamycin/chitooligosaccharides/lactic acid	Cheese	Reduce moisture loss Inhibit pathogens
WPC	Banana	Reduces ripening rate to many afolds
WPC	Apples	Respiration is reduced
WPC	Strawberry	Rehydration is reduced
WPC + sodium montmorillonite nanoparticles + sodium metabisulfite	Eggs	weight loss reduces and foam stability increases
WP + cinnamon/ cumin/thyme essential oils (1-2.5%)	Fresh beef	viable bacterial counts reduces
WP + *Lactobacillus rhamnosus* GG + sodium alginate	Bread	Increase cell viability of *L. rhamnosus* GG. Retention of sensory properties.
WPC+ sea weed extract	Fresh poultry meat	lipid oxidation inhibits
WP-alginate + lactoperoxidase	Chicken thigh meat.	antibacterial activity against *Enterobacteriaceae* spp increases

Wheat Gluten

Gluten is the wheat protein made up of polypeptide molecules which are also called as globular protein. It is comprised mainly of two parts gliadin and glutenin and are responsible for imparting cohesiveness and elasticity to the dough. Gliadin is ethanol soluble and glutenin is water soluble. On whole gluten films are formed on the drying of ethanol solution and during this drying process the native disulphide bonds of gluten breaks down by heat and new disulphide are formed which leads to the structure of gluten film.

Gluten itself possess plasticity component but its plasticity can be increased on addition of glycerol/glycerine. The films formed from gluten protien are strong clear homogenous and provide good moisture and water barrier property. There was a research where minimally processed fruits and vegetables were coated with gluten films and it was seen that the respiration rate lowered and even controlled and also freshness of fruits and vegetables remain intact for a longer period of time (Tanada-Palmu and Grosso 2005) [33].

Table 2: Protein-Based Edible Films and Coatings. Adapted from (Liyanapathiranage, A. et. al. 2023) [18]

Films/Coatings material	Properties	Uses
Casein	Processing convenience of emulsion preparation in amphipathic dispersion systems.	coatings and (EF) edible films
Whey protein	For foaming, gelling agent, thickening agent, emulsification, and water-binding. It inherits good mechanical, odorless, flexible, and transparent characteristics with moderate water vapor permeability and excellent oxygen gas barrier.	Edible films (EF) and coatings Edible blends
Collagen	Provides oxygen-carbon dioxide barrier properties and excellent mechanical support. Have proven acceptable films with mechanical, optical properties and great tensile strength	Edible films (EF) and coatings Blends for edible films and coatings
Gelatin/Chitosan blends	Antioxidant and antimicrobial edible films and coatings	Edible films (EF) and coatings

Lipids

Lipids are the hydrophobic materials which are usually added with the polysaccharides and proteins to increase the water barrier property depends on the efficiency of the lipid (Mehyar *et al*., 2012) [26]. Lipids alone cannot form the stable film but they are mostly used as a coating material on fruits and vegetables to lower the respiration rates and enhance the shelf life of fruits and vegetables. These coating materials are mostly waxes, resins, carnauba, candelilla, beeswax (Rhim and Shellhammer, 2005) [32]. Now a day's researchers are using vegetable oils and essential oils in the edible films to enhance hydrophobicity, essence, aroma, digestibility when coated or wrapped over the food product and is generally recommended safe for use.

Table 2: Lipids splay an important role too in edible films and edible coatings. Adapted from (Liyanapathiranage, A. et. al. 2023) [18]

Lipids	Sources
Oils, Fats, shortening and margarine	(a) Hydrogenated or trans-esterified oils Margarine. (b) Various native fats and oil from animals, vegetables, and seeds egs: butter from dairy, lard, sunflower, mustered, olive, almond, peanut, coconut, palm, cocoa, etc. (c) Mono, di and tri-glycerides Fractionated, concentrated, or reconstituted oils and fats.
Essential oils and liquorices	Various essential oils from an extract from animals, vegetables, flowers, and fruits; Citrus, ginger, rose, mint, etc.
Waxes	(a) Waxes from synthetic sources; mineral, microcrystalline, paraffins, oxidized-non-oxidized polyethylene wax. (b) Waxes from natural vegetables, animals, insects and Beeswax, genuine rice bran wax, carnauba wax, candelilla wax and laurel wax

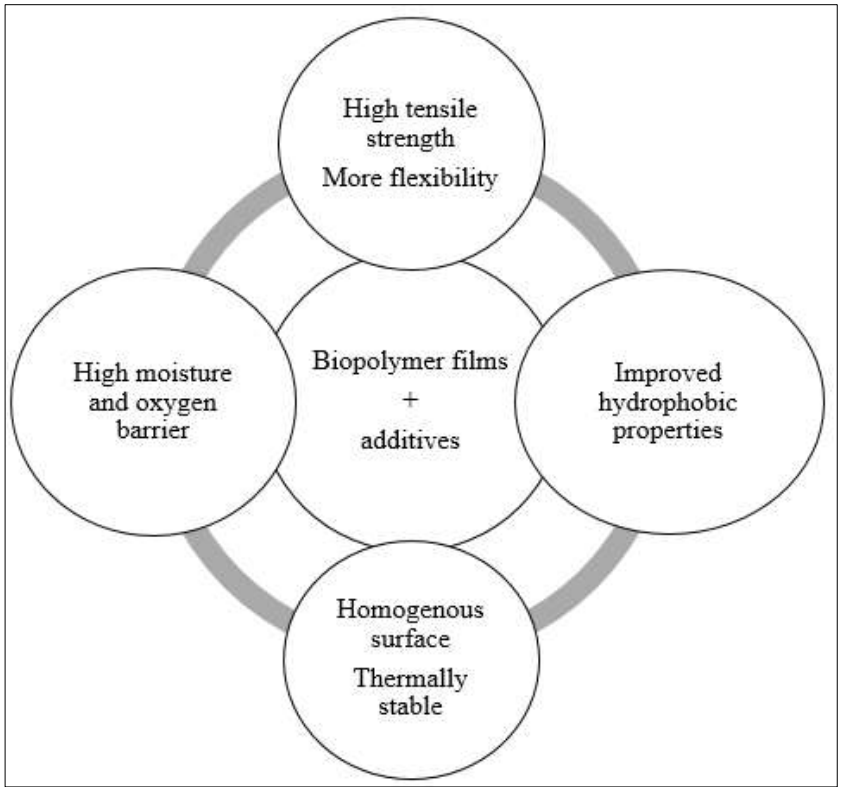


Fig 3: Properties of biopolymer films when in combinations with good additives.

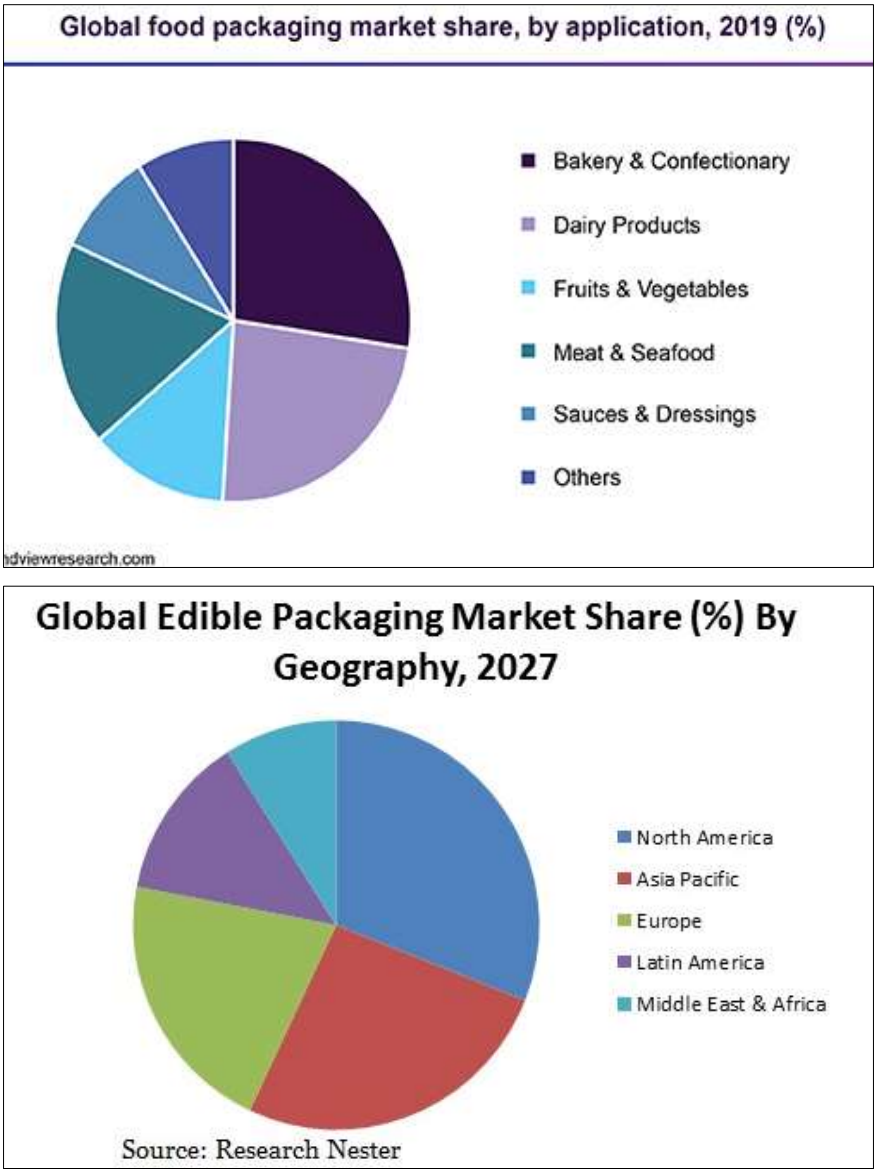
Applications of (EF) Edible films in global markets

Edible films have shown a great influence in commercial use, as they are considered as the best and suitable carriers for the bio active materials but due to its weak mechanical and barrier properties on comparison to synthetic packaging, its use have been limited (Azeredo *et al*., 2009) [2]. So, researchers have now overcome this limitation also by incorporating such components which will enhance its mechanical and barrier property.

Many researchers have so far believed that the markets for edible films and coatings is expected to grow higher in coming years because of the unhealthy life style and rising diseases with the usage of synthetic packaging. As the edible film and coatings comes into the category of green packaging, so USEPA (United States Environmental Protection Agency) has advised a plan for the reduction of municipal wastage (Dangaran, Tomasula and Qi 2009) [15]. The plan is to develop such a packaging material which will minimize the environmental toxic waste and makes it convenient for reuse or compost. Also, the packaging material should be able to minimize the food spoilage by increasing the shelf-life of the food product. In both the conditions the edible film and coatings fits the best.

Source: www.marketsandmarkets.com/Market-Reports/edible-packaging-market-248057967

Fig 4: Estimated Market for Edible films & coatings globally



Source: www.grandviewresearch.com/industry-analysis/food-packaging-market
www.researchnester.com/reports/edible-packaging-market/1165

Fig 5: Market share of Food packaging globally

Similarly, Europe, European legislation 2004/1935/EC sets some framework regarding packaging material and approved the active packaging concept with the intention of adding active agents in the packaging material. With this concept the European Union and all the state members of legislation formed a single market to minimize trade barriers. The concept approved by EU legislation was that no such material should be present in the packaging material such that when it come in contact with the food material it should not cause any chemical reaction which can lead to enzymatic or organoleptic changes in the food product. So all the regulations of 1935/2004/EC legislation were revoked and approved only the innovative concept of packaging i.e. (EF) Edible Films and coatings. As far as the components which can be added in the edible film formulation are only approved food additives and their Overall migration limits (OMLs) and specific migration limits (SMLs) were specified.

Conclusion

Food packaging and preservation have found an eco-friendly and innovative solution, Protein-based biodegradable coatings and films. Since they are obtained from renewable natural resources, such as whey, soy, and gelatin, these offer greater advantages of bio-degradability, edibility, and improved food quality. They offer extended shelf life by serving as effective barriers to contaminants and moisture, meanwhile also contributing to sustainability by reducing plastic waste. Though, water sensitivity, limited mechanical strength, and higher production costs are still challenges one faces, which may hinder large-scale implementation. Ongoing research into enhancing the properties of protein films, through blending, crosslinking, and the incorporation of bioactive agents, holds the promise of overcoming these barriers. Finally, protein-based coatings and films could revolutionize the food packaging industry, providing a practical and environmentally responsible alternative to traditional plastics.

Acknowledgement

Author acknowledges Ramjas College, University of Delhi, India, for providing necessary environment in completion of this work.

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