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7. Applications of Agro-Wastes Based Edible Films and Coatings to Improve the Shelf Life of Fortified Foods

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Abstract:

Demand for edible and biodegradable packaging has grown recently among consumers and food industries. When it comes to extending the shelf life of food items without compromising its nutritional, biological, or sensory qualities, edible packaging is thought of as an alternative to synthetic polymers. It aids in weight loss, decreasing lipid oxidation, slowing respiration, and preventing food products from enzymatic browning such as fruits and vegetables.

This review delves into the preparation, types, functional properties and health benefits of edible films and coatings. Agro-wastes are thought to be a natural source of secondary plant metabolites, like flavonoid and phenolic compounds along with high fibre and pectin contents.

Thus, it is utilized as fortifying agent in the formulation of value-added food products that elevates the functional properties of the food. However, it contains special qualities that allow them to be used to create biodegradable packaging to broaden the potential applications of agro-wastes in the food industries. As a result, edible coating and films can be formulated from the agro-waste products on a commercial scale to extend the shelf life of food items.

Keywords:

Agro-waste, biodegradable, fortified, edible film, shelf-life.

7.1 Introduction:

The quality of food with the extension of its shelf life is found to be developed by the end evolution of novel packaging systems **(Kumar *et al.,* 2021).** However, this packaging technique is called active food packaging which is prepared from polymeric raw material that is further incorporated with certain active ingredients like antioxidants, antimicrobials, oxygen scavengers, moisture absorbers, and ethylene scavengers **(Kumar *et al.,* 2021).** As per research, the combination of both packaging and synthetic antioxidants is beneficial for extending the shelf-life of the food product. Edible films are considered as the thin layer of edible material, which is incorporated between the food components and is consumed as a part of food products. However, the material utilized in the development of films comprised of appropriate food grade may not affect the organoleptic role of the food products. These strategies are evaluated by incorporating the edible biopolymers in combination with the components obtained from aqueous plant extract, and the particles present naturally are produced by agro-industrial residues **(Lourenco *et al.,* 2020).** However, these by-products and residues from agro-industrial operations have also drawn attention toward the utilization of naturally occurring active molecules. This is because they offer a practical and affordable means of getting strong antioxidants and antimicrobials, as well as the opportunity to value those residues that are still vital sources of functional compounds and are typically discarded **(Lourenco *et al.,* 2020).**

In recent years, the development of different varieties of packaging has been trending across countries. However, the application of edible films and coatings consists of multiple remarkable benefits that have gained attention for their cost-effectiveness. Edible films are considered to be a material that can be easily digestible by the human body and are biodegradable items. Moreover, these edible coatings are regarded as liquid forms of edible coatings. Edible films are generally thin layered wrapping sheets that are covered over the food item and the coatings are sprayed all around the food surface **(Paidari *et al.,* 2021).** In several food packaging industries, the focus was more on the substances having antimicrobial properties which replace the utilization and incorporation of antibiotics in the packaging materials to extend the shelf life. The coating aims to control the physiological changes of the fruit and reduce the loss of water. Therefore, substances with certain antioxidative properties, antimicrobial agents, and color pigments can be added for the preservation of fruits and vegetables **(Gurler, 2022).** The edible films constitute limited barrier and mechanical characteristics. However, the researchers are focusing on the addition of another essential component in these films such as the incorporation of lipophilic components namely, the essential oils eg; lemon, oregano, and thyme essential oil. These oils show antimicrobial properties that are added to the protein and polysaccharide-based film. Moreover, lemongrass oil is loaded with antimicrobial components **(Gaspar & Braga 2023).** Essential oils that are derived from agriculture waste as a source of bioactive compounds added in biodegradable coatings. Apart from that, these enriched coatings act as a barrier against microbial spoilage and gases that elevate the shelf life of the product **(Khalid *et al.*, 2023).**

The agro-waste such as pulp, peel, bagasse, husk, oil cakes, etc., contributes towards 30-50% of total food weight. These waste products constitute essential bioactive components like polyphenols, flavonoids, and tannins that have vital antimicrobial potential for the packaging system. Moreover, the fortification of a biodegradable polymer matrix with these compounds increases the functional properties of the food **(Ismail *et al.*, 2012).** Recent research focus on employing the vital polyphenolic pigments obtained from the agro-waste residue for the production of biopolymeric films **(Bhargava *et al.*, 2020).** As per the studies, the motive of edible films and coatings is utilized for extending the shelf life of food by inhibiting the exchange of lipids, CO2, O2, and volatile molecules. However, the edible coating which is obtained from fruit and vegetable residue constitutes bioactive components with antimicrobial properties that preserve perishable food products **(Merino *et al.*, 2021).**

7.2 Functional Properties of Edible Films:

7.2.1 Physical properties:

- **Optical properties:** It involves the improvement of sensory attribute especially the product appearance. However, the optical characteristics of edible film constitute opacity, glossiness including colour effects. The calories considered as significant parameter for the acceptability of a coated food product, such as vegetable and fruits. (**Yadav *et al.*, 2023).** Therefore, the edible coating should not impart any colour on the surface of the product. As per studies, the measurement of colour is done through

ASTM E308 method by CIE lab scale method. It is used to measure the L* (lightness/darkness) including the b* (yellow/blue) and a* (red/green) **(Kurek *et al.*, 2014).**

- **Thickness:** The thickness is considered as an important characteristic for the edible films which further affects the mechanical strength, microstructure, barrier properties, structure and uniformity of the edible films. During the drying of edible film, the thickness of edible film can be attributed to various drying kinetics and retractability of the film **(Kokoszka *et al.*, 2010; Yadav *et al.*, 2023).**

7.2.2 Antioxidative properties:

Environmental concerns have leads to the packaging industry switching from using petroleum-based and synthetic materials to eco-friendly materials like fruit peels to produce edible films and coatings. Natural compounds are increasingly being used in the formulation of edible packaging material due to their antioxidant and antibacterial properties. This approach aims to reduce the risks associated with synthetic chemicals in food products. Plant materials are a significant source of bioactive substances such as polyphenols, flavonoids and phenolic acid which are responsible for antioxidant properties. Any material that has the ability to delay, slow down, or stop the onset of rancidity or other oxidation-related degradation processes is considered an antioxidant.

They are added to food items in order to prevent lipid oxidation, which leads to unpleasant tastes and smells and forms harmful aldehydes that make the product unfit to be consumed by humans. Recently, a variety of bioactive materials have been isolated from fruit processing by-products, which may find application in the formation of edible films **(Ribeiro *et al.*, 2021; Yadav *et al.*, 2023)**. Antioxidant-containing coatings and films serve as protective barriers and prolong the shelf life of food, making them a natural and biodegradable substitute for chemical preservatives. It can prevent food components from deteriorating, thereby improving food safety and quality. Studies have shown that coating fresh-cut fruits with an edible antioxidant-containing coating significantly decrease browning while boosting the antioxidant content of foods **(Eça *et al.*, 2014).**

7.3 Preparation of Edible Films and Coating:

The development of the edible films is primarily done by the two methods that are, (i) wet method based on solvent casting (ii) dry method that are extrusion based or compression molding. Firstly, the edible bi-polymeric material is coated on the base material and then kept it for getting dried till it becomes a desired film **(Tharanathan, 2003).** It is examined that during the process of drying, the polymer solubility decreases due to the solvent evaporation.

7.3.1 Solvent casting method:

Solvent casting is used as film processing technique. These are considered to be complicated method based on solvent system. Therefore, the stable colloidal systems which need to be prepared based on the solubility parameters of the polymers. However, emulsion stabilizers and oil including wax-based surfactants are incorporated to maintain the uniformity of the films **(Galus & Kadzi, 2015).** Additionally, the levelling and wetting agents are utilised to control the surface tension, wetting and surface tension like pinholes, bubbles and defoaming agents to prevent the aeration of colloids. The process of solidification is important for the quality of edible coating and films which is done through precise drying method as the drying helps to transform the fluid into the solid-state transition **(Bhattacharya, 2013).**

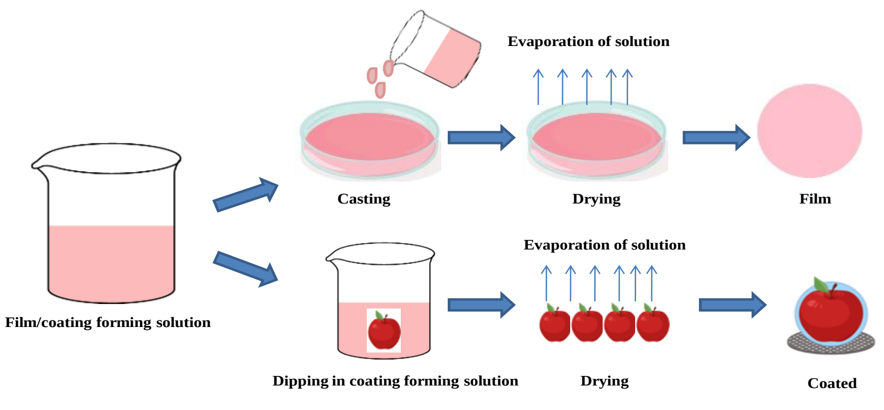

Figure .7.2: Edible film development techniques.

7.3.2 Melt Extrusion method:

The process of melt extrusion involves the steps of melt blending, formulation, cooling and storage, extrusion which are applied for the preparation of edible films **(Izquierdo, 2008).** Basically, the operating condition and the extruder temperature are examined through the rheological and thermal properties of polymers.

However, the incorporation of plasticizers and process aids are done to elevate the polymer melt flow during the method of extrusion. The degree of crystallization of polymeric matrix determines the quality and clarity of the film. Although, the polymeric matrix changed into polymeric state during the process of re-crystallization under the melt condition **(Pavlath, 2009).** The polymers show impact onthe optical properties and alsocontrols the transparency and clarity of films. In addition to it, the extruder parameters and the rotor speed **(Liyanapathiranage *et al.*, 2023).**

7.4 Types of Edible Film and Coatings:

Edible films comprise of three important components polysaccharides, lipids and proteins. The protein that mainly utilized in edible films is whey, casein, corn zein, wheat gluten, soy and collagen. The lipids that are utilised for the films and coating are waxes, unsaturated fatty acid and acylglycerol. However, the film contains both lipid and hydrocolloid parts. As per studies, the plasticizers incorporated to the film framing improves the property of edible films **(Gurler, 2022)**

7.4.1 Pectin based edible films:

Pectin belongs to the group of polysaccharides found in fruits and vegetable such as citrus peel and apple pomace. However, it is an anionic polysaccharide with structure of (1→4)-linked α-d-galacturonic acid unit. Pectin is used as a thickening agent, gelling in product, stabilizing agents in different food products **(Espitia *et al.*, 2014).** The pectin edible films obtained through casting method constitute excellent mechanical characteristics and also act as a barrier to oxygen, aroma and oil. As per studies, these are associated with polyvalent cation that offers good compatibility with other biopolymers **(Gao *et al.*, 2019).**

The films are effective in terms of food protection and are utilised for packaging purposes of certain fruits and vegetable like walnuts, carrot, berries, apricot, guava, melon, tomatoes, guava etc., Previous research has also revealed that certain mints, marjoram and essential oils are incorporated in the pectin-based matrix to get appropriate functionalities to these materials **(Aimasi *et al.*, 2020).**

7.4.2 Lipid based edible films:

Lipids are obtained through naturally occurring resources. However, due to their certain properties, these are used for the coating of different food items **(Shahidi, 2020).** Coatings that are made through lipids those are shiny in appearance. Generally, the main components of these materials are extracted from plants residue. Moreover, the other materials of the lipid's category are the essential oils. As these are basically hydrophobic and it constitutes antibacterial activities due to the presence of terpens and terpenoids **(Paidari *et al.*, 2021).**

Some other methods for compositesare the film forming methods with the bilayer and multilayer films.As per studies, in lipid hydrocolloid composites, the fraction of hydrocolloid is responsible for moisture absorbance whereas, the lipids contribute to moisture absorption.Lipid functionalization are utilised for the improvement of the film forming ability and enhance theadherence of films and coating on the food items. Apart from it, lipids act as a texturing agent, antioxidants, emulsifiers, antimicrobial agents, enzymes for the process of coating **(Liyanapathiranage *et al.*, 2023).**

7.4.3 Essential oils-based films:

Essential oil is regarded as volatile compounds that are gained from the natural resource like plant which further exhibit antimicrobial activities. Moreover, the presence of essential oils in edible films and coating prevents microbial growth, lipid oxidation, chemical reactions and end endogenous enzyme activities. The natural essential oils improve the antimicrobial, mechanical, sensory and antioxidative property of the edible film and coatings in vegetable and fruits. However, the incorporation of essential oils with sesquiterpenes and monoterpenes in edible films and coatings which further enhances the shelf life of fresh fruit items.

The essential oil consists of active compounds like thymol, carvacrol, cinnamaldehyde, eugenol, 1,8-cineole and various herbs and spices which has greater antioxidative and antimicrobial properties **(Liyanapathiranage *et al.*, 2023).**

The addition of essential oils in edible coatings is responsible for increase in their functional properties which is further considered as a novel method for improving the shelf life of the food items.

The coating through the essential oil is mainly produced from biological components. In addition to this, the edible coating with the essential oil were found to improves the efficiency of coatings 29.8% against the loss of moisture **(Chhikara & kumar, 2021).**

7.5 Fortification of Edible Films Through Agro-Waste Residue:

The development of edible films with the naturally occurring bioactive components including essential oils, carotenoids, polyphenol and curcumin are basically derived from the agriculture waste residue. However, these essential ingredients are further utilised for their antimicrobial and antioxidant property.

The incorporation of these vital nutrient impacts the mechanical and functional properties of the edible films **(Tongnuanchan and Benjakul 2014)**. Development of edible films can also be done through single and multilayer category of active ingredients that enhances the functional properties. These incorporation focuses on ingredients especially for protecting the food product against degradation of food product and increases its shelf life **(Chen *et al.*, 2021)**.

7.5.1 Incorporation of Bioactive Compounds for Edible Film Fortification:

The film matrix is constructed through the certain food components such as lipids, proteins and polysaccharides. However, the fortification of film matrices are done through the essential active component like antioxidant and antimicrobial that further elevates its functional properties. Therefore, the interaction of these films with the natural active ingredients helps in the preservation of the food product by extending the shelf life of the food item **(Chen *et al.*, 2022).**

These ingredients are often used for their antioxidant, antimicrobial, coloring, flavoring, and/or nutritional effects. It should be noted that the incorporation of these active ingredients may also impact the structural organization and functional properties of the films. For instance, studies have shown that essential oils not only have antioxidant and anti- microbial effects when incorporated into edible films, they also modify their mechanical and barrier properties (Tongnuanchan and Benjakul 2014). It is therefore import- ant to establish the impact of active ingredients on all the properties of edible films during the formulation process.

In some cases, active ingredients are simply mixed with the film-forming materials prior to film formation (S□ Anchez Aldana et al. 2015). In other cases, the active ingredients must be encapsulated within colloidal particles before they are mixed with the film-forming materials (Wu et al. 2015). The strategy utilized depends on the miscibility of the active ingredients with the film-forming solution. Edible films can be fortified with single or multiple types of active ingre- dients to obtain the desirable functional attributes, such as an antioxidant and an antimicrobial (Espitia et al. 2014)

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7.5.2 Incorporation of *Moringa Oleifera* Leaf Extract in The Papaya Edible Film*:*

Incorporation of *Moringa oleifera* leaf extract with the ascorbic acid in the papaya based edible films containing naturally vital components is preferred to be reliable substitute over the chemical additives. *Moringa oleifera* leaf contains high concentration of phenolic and flavonoid components with strong antioxidative action **(Rodríguez *et al.,* 2020)**. It belongs to the family of *Moringaceae* family.

It is filled with high concentration of vitamins, minerals and digestable proteins. **Otoni *et al.,* (2014)** examined that incorporation of cinnamaldehyde nanoemulsions with papaya puree edible coatings showed the high antimicrobial activity against the certain pathogenic microbes such as *Salmonella enterica, Staphylococcus aureus, Escherichia coli and L. monocytogenes*. Apart from it, the film based on khorasan wheat starch fortified with moringa extract presented UV blocking action as well as high antioxidant activity **(Rodríguez *et al.,* 2020)**.

7.5.3 Incorporation of Mushroom Waste in Chitosan Based Edible Films:

Mushroom is regarded as an appropriate alternative for the non-animal source chitosan production. Chitosan in particular are renewable biopolymers present naturally in abundant form. Moreover, it is biocompatible and polycationic polysaccharide that shows high filmogenic and antimicrobial activity.

The stalk bases obtained from brown mushroom namely, *Agaricus bisporus* were utilised to elevate the concentration of Vitamin D by the treatment of UV-B lights. However, the chitin is recovered from these vegetable residues and converted into chitosan through *N-deacetylation*.

Therefore, the mushroom *(Agaricus bisporus)* waste residue can be utilised for the production of nutritionally fortified form of chitosan-based film. In addition to this, the industrial waste of high-quality mushroom can be incorporated for the production of Vitamin D including chitosan-based film **(Sainz *et al.,* 2017).**

7.5.4 Incorporation of Orange Peel Powder in The Edible Film:

Orange is a commercial citrus fruit belonging to the family *Rutaceae* which constitute rich nutrient content such as beta carotene, pectin, folate, Vitamin C including essential minerals. In addition to it, the peel of orange possesses high antimicrobial activity and prevent the oxidative stress with the edible film **(Moosavy *et al.*, 2017).** As per th researches, the role of aromatic oils in the orange peel with antioxidant shows high fatty material stability during the time of storage and prevent deterioration of fatty material. The orange peel showed the stability in the coating polymer against oxidation due to the presence of essential oil in the orange peel **(Anbari *et al.*, 2019).**

7.5.5 Incorporation of Date Palm Fruit Waste in The Edible Film:

The date palm fruit waste extract (DPFW) is incorporated with chitosan and polyethylene glycol composites. As per the research, the ethanolic extract of date palm waste residue possess the high antimicrobial activity against the food borne pathogens.

The films also constitute good tensile strength including the reliable flexibility. However, the freshness of strawberry wrapped in the film containing date palm fruit waste extract is maintained. In addition to it, the film shows the wide range of potential in food packaging as it enhances the longevity of freshly prepared food products. Therefore, these film materials fortified with date palm waste residue can be beneficially utilized for packaging perishable fruits and vegetables **(Zidan *et al.*, 2023).**

7.6 Health Effects:

Edible film and coating were prepared in alteration to synthetic and chemical materials that causes negative impact on human health. However, the edible coatings are utilised for the preservation purpose especially for the phenolic content, essential pigments and antioxidant. As per research, the edible coatings are incorporated with bioactive components such as probiotics that are beneficial to human health. Therefore, the presence of certain probiotic strains in the food coating is termed as functional food **(Pham *et al.*, 2023).** In addition to this, paraffins and waxes are regarded as safe coating for vegetables and fruits.

Although it is reported that the starch-based biopolymer and cellulose monomers are safe in terms of human health.The nanocellulose that are utilised in edible coatings is basically a non-toxic component at the concentration of 0-50 mg/mL in human body **(Liyanapathiranage *et al.*, 2023).**

7.7 Conclusion:

The incorporation of agro waste residue in edible films and coatings presents a promising way in the field of sustainable packaging and food preservation. Through innovative research and experimentation suggested that these bio-based materials offer numerous advantages such as biodegradability, low cost, and antimicrobial properties. By exploiting the natural properties of certain agro-waste, such as its high fiber content and natural antioxidants, researchers have been able to create films and coatings that not only extend the shelf life of food products but also contribute to reducing food waste and environmental pollution. However, more research is needed to optimize the formulation and processing methods to improve the mechanical and barrier properties of these films and coatings for wide-ranging industrial applications by incorporating agriculture waste residue such as vegetable stalk, fruit peel, plant extract, husk of coconut etc., In conclusion, the investigation of agro-waste as a beneficial asset for the development of edible films and coatings represents as an important step toward achieving sustainability in the food packaging industries.

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