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Edible films and coatings - Recent developments in sustainable bio based packaging of foods

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ABSTRACT

Edible coatings or films in food industry have received huge attention in the recent years with the plastic ban and plastic disposal problems, increasing consumer demands and awareness. Biopolymers like polysaccharides, lipids, proteins, gums along with carriers like antioxidants, antimicrobial agents and additives are used considering their functionality and properties to add onto the safety of food. It is non-toxic, contributes to the pollution reduction leading to zero wastage as they need not be disposed but consumed along with the food packed. The development of films from mung bean protein isolate, films from composite mixture of alginates, calcium chloride and oregano oil the ethanolic propolis extract(EPE)a waxy resin from bees which was incorporated to cassava beeswax films, post harvest losses reduction by application of guar gum coating and silk fibroin protein based films are the recent developments in the area of edible films and coatings. The edible films and coatings, its component classification, recent research developments with its application in food packaging industry are summarized in this review. Application of smart packaging in edible films still needs to be an area of research and would be major breakthrough in food packaging industry

Keywords: edible films, edible coatings, food packaging, antifungal, anti microbial, recent developments

INTRODUCTION

Food packaging is an important step in supply chains and plays an essential role in the protection of food after final processing. Edible films and coatings are one of the emerging strategies for optimization of food-quality .The use of edible films and coatings based on natural polymers, bio plastics and food grade additives has been constantly increasing in the last few years.(Pooja Saklani et.al, 2019) The plastic ban , non- decomposable nature of certain papers, increasing consumer concerns and environmental pollution have necessitated the development of such alternatives to petrochemicals used in conventional plastics used for packaging. Conventional plastics are those produced from fossil fuels like coal, petroleum, natural gases are commonly preferred because of low cost of production, light weight, easy to use, excellent barrier properties and mechanical properties leading to protection of foods and convenience of users. But, plastics pollution poses the most important threat to humanity including all species on earth especially a study says by 2050 there will be more plastic in oceans than species (Romjue. A ,2019). When the life of plastic is considered at every stage, there is heavy chemical burden in plastic life; there are heavy toxic chemicals at each stage which also results in leakage of these when exposed to foods when packed or to the environment when it is disposed. (Yusuf et.al,2020). The hotter plastics get; the more leakage occurs or even exposure to sunlight can cause this effect. A testing conducted in 159 drinking water samples from different continents showed that 83% of those contained plastic and is also a serious promoter of climate change contributing to greenhouse effect (Yust, M.M. ,2019). It is studied that 13% of climate change carbon budget will be contributed by plastics in 2050 [Laville, S. (2019). A plastic bag takes 25 years to break and plastic bottle takes 450 years to breakdown completely which adds to the land pollution over this huge time period.

Another material is paper used as paper wraps considered as biodegradable, recyclable and suitable for thermal incineration accounts to 41% largest share of volume of packaging materials including all types of packaging and not only food. In Europe, 72% of all paper and cardboard is recycled, but not all paper containing food residues or an additional plastic layer or aluminium barrier layer then it is difficult to recycle and in some cases impossible to recycle. Paper and cardboard need more water, raw materials and energy in their production than plastic and are not moisture resistant leading to their limited usage at excess costs. So various researches have been undertaken to develop alternatives to these with the same functionality along with zero wastage.

One such alternative in recent years possessing all characteristics and properties of such conventional packaging materials from fossils are the biobased packaging materials. Applications of this sustainable mode of packaging especially the edible forms of packaging have significantly increased with the go green trend of the society. The issue of sustainability is crucial, encouraging politics, huge industry to develop these sustainable alternatives for safeguarding resources for the coming generations, focusing on biodegradable and bio-renewable materials. Bio-based films are suitable for a variety of food packaging applications as they have almost the same gas barrier and mechanical properties as petrochemical-based plastic films. All new types of bio-based films are more permeable to water vapour than the conventional plastic films available in market, which can also be a weakness or strength depending on the requirements of food packaging. Bio based polymers especially the edible forms of polymers are considered. Bio-based packaging films is suitable for many products such as dairy products, ready to eats, biscuits, beverages and even fresh produce such as meat, fruits and vegetables. It can be organic, biodegradable, renewable, edible and also compostable. Biobased materials are those sourced from biomass/ renewable materials such as grains, vegetables, potatoes, sugarcane, palm, starch and even vegetable oil. Edible forms of packaging like edible films and coatings are gaining importance in the field of bio based packaging materials.

EDIBLE FILMS

In the biobased packaging and polymers, edible films and coatings are considered as one of the emerging areas for optimization of foods compared to the counter synthetic films as they can be an integral part of food which can be eaten together and have received considerable attention because of their advantages compared to synthetic films. Although edible coatings and films have similar definitions there is a difference as edible films are applied to the surface and prepared separately whereas coatings are applied directly onto the food surfaces (Cordeiro, 2012). Though edible films and coatings cannot replace traditional packaging entirely but the food protection can be improved by combining these edible films as primary layers along with secondary non- edible layers usually required for handling and transport (Cordeiro, 2012). The films or coatings are produced from renewable, edible elements and therefore are more degradable than other polymeric materials (Trinetta, 2016)

Edible films and coatings are materials used to extend the shelf life and protect foods by being in close contact with them, they can be further removed or eaten together with foods packed – raw or processed. They are thin layers on surface of foods acting as an immediate protective layer. These are also dried to be put into direct contact as wrappings, pouches, casings, bags or even capsules in later processing stages.

From edible materials like proteins, polysaccharides and lipids, edible films are prepared as continuous matrices. These materials form as films or edible coatings on food or occur in between food components. They are also carriers of active ingredients. They are considered both a packaging and a food component satisfying properties like good sensory characteristics, excellent barrier and mechanical properties, biochemical, physical, and microbial stability with safety and non-polluting nature of product.

The matter of concern is to apply simple technology at low processing cost in large industries. The addition of bioactive compounds and food additives are to preserve the quality, safety and sensory properties of foods along with extended shelf life. Researches efforts are attempted to optimize the composition of film and coatings material in order to be efficient and effective in real and pragmatic food systems used everyday.

There is a wide range of usage of edible films like wrapping foods by being in close contact with them owing to individual protection of meat, fish, fruits and vegetables based on the organoleptic, mechanical, gas, moisture barrier properties of film. Polysaccharides like cellulose, gums, starch, dextrin and proteins like gluten, casein, gelatine based films have good mechanical and organoleptic properties, whereas wax based films like bee wax, carnauba wax and other lipid derivative films also have excellent water vapour barrier properties.

Recently, Edible wrapping acts as a replacement and provides fortification of the natural layers at the outer surfaces of product which prevents losses due to moisture, gas aromas and restricts the solute movements out from the food and selectively controls exchange of essential gases like ethylene, CO_2 and O_2 which are involved in the respiration of food product (Embuscado & Huber, 2009).

Plant or animal based proteins and celluloses are the most common choice of base materials in development of such edible films. These polymers have advantages in their commercial usage like biocompatibility, moisture and gas barrier properties, stability and mechanical integrity, non toxic and non-pollutant but most importantly are carriers for antioxidant or antimicrobial additives which help to extend food shelf life and thus prevent from microbial contamination.

Edible films and coatings can be used for ingredients and components of foods, agriculture produce, pharmaceuticals, packing of raw or processed foods and also nutraceuticals in various forms like soluble strips, flexible thin or transparent pouches, macro and microcapsules, and as a cover for hard particles. These films are usually produced by two basic techniques.

The first technique known as solution casting which is wet solvent processing developed over one hundred years ago. Here, the solutions are spread onto levelled acrylic, silicon or teflon plates which further moves to drying process at ambient or controlled conditions of hot air supply and relative humidity, infrared and microwave energy (Dangaran and Tomasula, 2009). In recent years' extrusion is used for the manufacture of these polymers and films and has become the dominant production method for manufacturing films. In the process of extrusion elevated temperature and high shear is applied to soften and melt the resins of polymer which allows to form a cohesive film matrix (Dangaran and Tomasula, 2009).

Antioxidant edible films can prevent food oxidation, the development of off-flavors and nutritional losses, whereas antimicrobials can prevent spoilage from food-borne bacteria and organoleptic deterioration by microorganism proliferation. Edible films are obtained from food-grade suspensions and are usually melded as solid sheets onto inert surfaces.

EDIBLE COATINGS

Edible coatings EC are defined as soluble formulations applied on food surfaces such that it forms a thin layer of edible film directly on the surface of food or between different layers of the food components and prevents the migration of moisture, light, oxygen, and solute into the food (Bourtoom, 2008; Monteiro Cordeiro de Azeredo, 2012).

EC fabrication materials can be classified into three categories: hydrocolloids; lipids; and composite materials, consisting of a combination of different hydrocolloids and lipids to complement each other and overcome their respective drawbacks. The selection of the coating materials and their additives is not only based on technological applications but also their effectiveness of cost, market value, sensory attributes, quality and barrier properties and consumer acceptance.

More recently, the use of edible coatings has been further promoted by coating functional bioactive compounds like natural antimicrobial compounds, antioxidants, minerals, and vitamins, which improves the safety of food by preserving its quality and delivering health benefits to the consumers [Maria Leena.et.al,2020]. Because of their very high efficiency to reduce the occurrence of deteriorative processes like oxidation antimicrobial coatings have been recently studied and widely used for extending the shelf life of fish and meat products, value-added fruit and vegetables [Valdés, A.et.al,2017]. Edible coatings can be applied to the food surfaces by several methods mainly spraying, dipping, spreading, and thin-film hydration [Ju,J.et.al,2019]. Recently studies have been conducted to assess the effect of edible coatings on preserving the quality of foods and increasing the shelf life of fresh produce or cut fruits and vegetables [Maringgal, B.et.al, 2020].

The coating efficiency in protection of foods depends on the following factors

(i) method of application of coating

(ii) concentration and nature of coating ingredients

(iii) the uniform wetting property and spreading onto the surface

(iv) the adhesion, cohesion, and durability of coating to the food

(v) the capability to act as barriers against water or oils permeation, and gas or vapor transmission [Krochta.et.al,2019, Paul.et.al,2020]

Owing to their wide availability and regulatory activity alginates are widely used in edible coatings. Calcium chloride is important in fruit and vegetable preservation where fruits and vegetables are dipped in calcium chloride solutions post harvest. This showed softening and delay in decaying process when combined with heat treatment. Essential oils (EOs) as natural antimicrobial agents in edible coatings has received increasing attention to control the process of decaying and extends the storage life of perishable foods [Donsi.et.al,2016,Fathi.M.et.al,2019)

CLASSIFICATION OF EDIBLE COMPONENTS USED FOR FILMS AND COATINGS

Table 1 : Edible components classification

COMPONENTS	PROCESS/FUNCTION	EXAMPLES
MAIN COMPONENT Biopolymers Type-1	Polymers directly extracted/removed from biomass like polysaccharides, proteins ,gums and lipids	polysaccharides such as starch, potato, maize, wheat, rice and its derivatives proteins from animals or plants like casein, zein, whey, collagen, gelantine and soya gluten lipids like cross-linked tri-

		glycerides, waxes, triglycerides, acetylated monoglycerides, free fatty acids, sucrose esters, and shellac resin others include gums like guar, locust bean ,alignates carrageenan, pectins and its derivatives
Biopolymers Type-2	Polymers produced by classical chemical synthesis using renewable biobased monomers which are formed by fermentation of carbohydrates.	Polylactic acid is a biopolyester which is polymerised from monomers of lactic acid
Biopolymers Type 3	Polymers produced by microorganisms or genetically modified bacteria.	PHA, bacterial cellulose, Xanthum
Solvents	To be used in combination with the biomaterials	Water and Ethanol
Additives Type-1	To improve or modify the basic functionality of the material	Plasticizers, crosslinking agents, emulsifiers, and reinforcements
Additives Type-2	To improve the quality, stability, and safety of packaged foods	Antioxidants, antimicrobials, color agents, flavours, and nutraceuticals

(Source: Pablo.R.Salgoda.et.al.,2015)

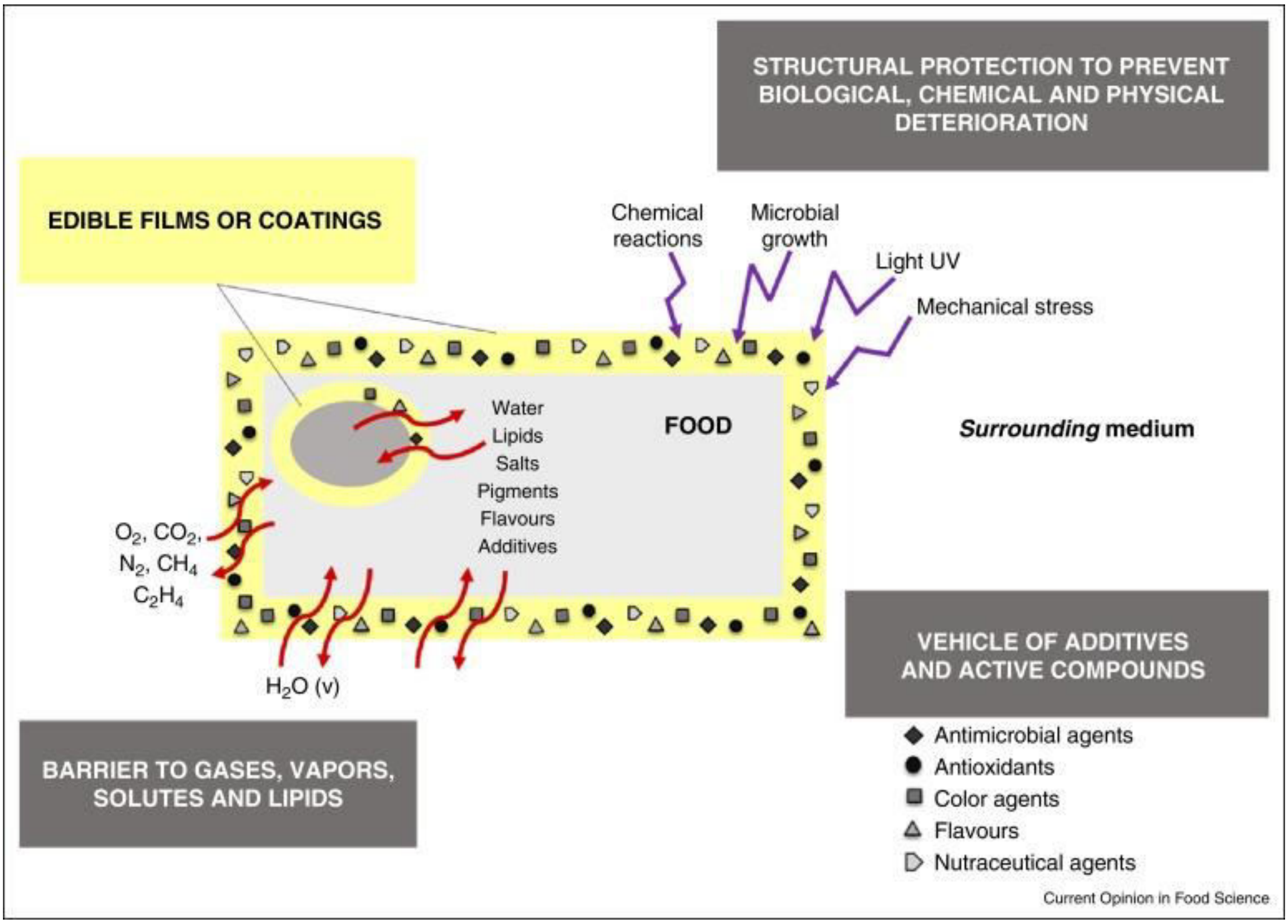

Fig 1: Function of edible films and coatings (Source- Pablo.R.Salgodaet.al,2015)

RECENT DEVELOPMENTS IN EDIBLE FILMS AND COATINGS

Postharvest losses cause 40%–50% wastage of globally produced fruits and vegetables. Among the many methods like irradiation, chemical treatment, heat treatment and storage methods like controlled atmospheric storage and modified atmospheric storage to reduce spoilage of fresh fruits and vegetables application of edible coating is one of the most effective methods to reduce spoilage of fresh fruits and vegetables. Here, gum arabic (GA) is applied as edible coating and its potential to reduce fresh food losses in persimmons, a perishable climacteric fruit was studied and was found to extend the storage life by maintaining quality attributes of it. The studies resulted in significantly lower weight loss and less membrane leakage. The concentrations of H2O2 and MDA were also found to be much lower. It suppressed the polygalacturonase, pectin methylesterase (PME) activity and cellulose activities which resulted in reduced fruit softening. GA-coated fruits showed substantially higher superoxide dismutase (SOD) activity, catalase (CAT) activity, peroxidase (POX) activity and ascorbate peroxidase (APX) activity. Similarly, these coated persimmon fruits also explicitly showed higher values of total phenolic content, ascorbic acid content, good antioxidant activity and with reduced total soluble solids and low ripening index throughout the storage. So this study concludes 10% gum arabic coating application to fruit is optimum to maintain the quality of persimmon fruit during the period of postharvest storage at ambient temperatures. (Muhammad Shahzad Saleem.et.al,2020)

Silk fibroin (SF) structural protein extracted from Bombyxmori silkworm cocoons is a polymer which obtained the Self-Designated Generally Recognized as Safe (GRAS) status by the US Food and Drug

Administration for the development of edible coatings and films. Here SF was applied as edible coating to prolong the shelf-life of climacteric fruit apple which continues to ripen post harvest through respiration and ethylene production. It showed outstanding mechanical properties and stability, non-toxic nature, compostibility and biodegradability, good transparency and most importantly edibility. Polymorphism is a property of SF which enables the protein to be stable in dry conditions with different secondary molecular structures like random coil or beta sheet. Polymorphism is controlled by alcohol treatment or water annealing process and thus modulates the mechanical and gas barrier properties that are regulated by formulating blends and mixtures of SF with other polymers. Multilayered structures and polymer blending can be used to obtain synergistic effects in membrane manufacturing and to regulate transport process by leveraging the intrinsic properties of each constituents. SF can also be mixed in suspension with other biopolymers to form miscible biopolymer blends with good mechanical properties and biodegradation kinetics. Similarly, SF can be suspended with polymers like poly vinyl alcohol, PVOH) to form blends which are immiscible. A coating with SF: PVOH in the weight ratio 1:1 was applied, preserved and studied which showed minimum water vapor permeability and less weight loss and color changes of SF coated fresh-cut apples over 14 days of storage at 4 °C and were found to be much lower than the uncoated control samples taken. Ascorbic acid was also added along with the coating material to obtain the oxygen scavenging property to the active food coating. (Elisabetta Ruggeri.et.al,2020)

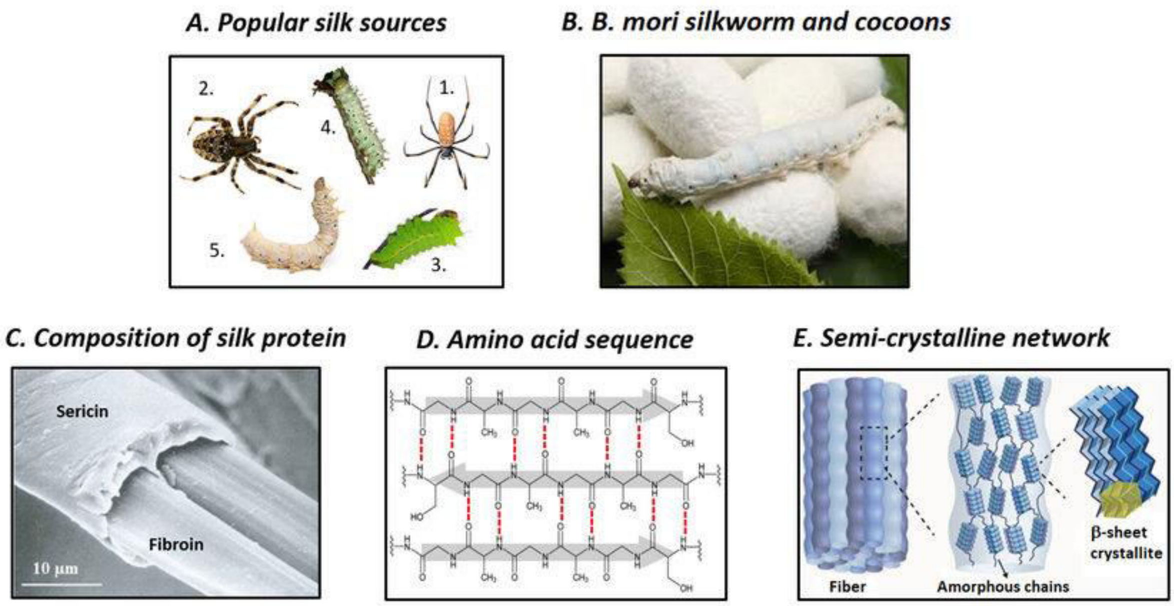

Fig 2: Silk fibroin source and structure of protein (Thang Phan et.al,2019)

A study with a blend of chitosan and pullulan in the ratio 50:50 enriched with pomegranate peel extract was coated on litchi fruit and its quality, shelf life and sensory characteristics for a period of 18 days at room temperature and relative humidity (23 ± 3ºC ,40- 45%) and at cold temperature and relative humidity (4 ± 3ºC, RH- 90-95%). The recorded results showed significant reduce in the physiological weight loss, TSS, acidity, browning and increase in the antioxidant activity was noticed in litchi fruit during both the storage conditions compared to control litchi. The coated fruit showed decreasing weight loss at room temperature as compared to the control only on 18th day of storage. The results of the sensory evaluation confirmed that the treatment of chitosan: pullulan blend edible coating could be effective to prolong the shelf life of litchi at both storage condition. The 50:50 composition of chitosan: pullulan was found to be the optimum ratio for preservation of quality and extending the post-harvest shelf life of the litchi fruit under the mentioned storage conditions. This study suggests the application of chitosan: pullulan blend as edible coating to be considered for commercial application of fruits, vegetables either as a whole or fresh-cut during the storage period. (Nishant Kumar.et.al,2020)

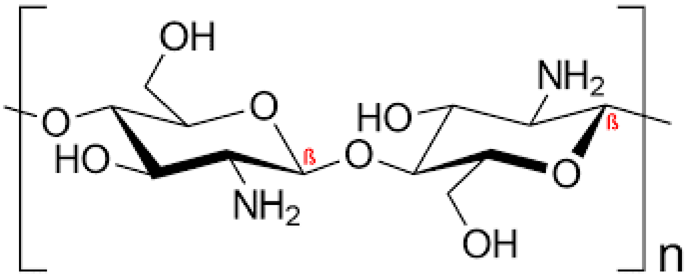

Fig 3: Structure of chitosan (sourced from Wikipedia)

Edible film using mung bean protein was prepared and studied at different concentrations of protein isolate and 5% mung bean protein isolate edible film showed maximum tensile strength 1.31±0.5 MPa and 62±0.03% elongation at break. The film also showed minimum solubility rate which is a desired characteristic and moreover the film was found to be a uniform homogeneous continuous surface without pores or cracks. The study shows this film can be used as films for wrapping fruit since it showed higher tensile strength and elongation at break and desirable low solubility than other control films. (ZarZar Oo.et.al,2020)

In this study cassava starch (2-4%w/v) and beeswax(0.5–0.9%w/w) composed edible films with addition ethanolic propolis extract to improve anti microbial and barrier properties of cassava starch was optimized using three-factor Box-Behnken response surface experimental design .Higher starch content showed higher thickness of film and water vapor permeability values , higher concentrations of beeswax produced films with low water vapor transmissions and moisture content values ,increase in EPE content reduced the lightness and thus formed light yellow opaque films. Assessment of antifungal activity of films with 4.0 mL of expanded polyethylene (EPE) against Aspergillus niger showed good activity. FTIR analysis showed small microstructural changes in starch molecules on addition of cassava, beeswax and ethanolic propolis compounds. Films were found to be more soluble in acidic solutions than alkaline solutions and had low values of water vapor permeability and water solubility when compared to other lipid source films. Propolis addition on the cassava starch-beeswax based film proved antimicrobial activity against Aspergillus niger. This film can be useful as a biodegradable packaging material to maintain the quality of food products and extending shelf life without deteriorative changes for minimally processed fruits and vegetables. (Luis D. Pérez-Vergaraa.et.al,2020)

Two formulations of edible films were prepared using whey protein isolate with and without probiotic *Lactobacillus casei*as a fruit cover for cherry tomatoes and Thompson grapes and was studied. The addition of the probiotic culture had no effect on the density (1.272-1.303 g/cm3) and water vapor permeation (0.28-0.35 g.mm/m2.day.kPa) but was yellowish, thicker (16.18 vs 13.15 µm), more soluble (42.8 vs 34.8%) and exhibited higher tensile strength, 23.3 vs 12.6 N but lower elongation at break of 45.4%. Scanning Electron Microscopy images showed higher number of orifices and agglomerates in all superficial extension. The application of this film did not give a positive impact on the shelf life of tomatoes but reduced the mass loss and TSS of grapes. The film with probiotic culture showed lower TSS values in tomatoes and grapes and also higher mass loss in grapes. So it was found that the whey film with probiotic can be successfully applied to grapes to extend shelf life and a positive effect on the ripening process of the tomatoes and grapes owing to lower TSS values. (Izaura B. Dianina.et.al,2019)

Edible films of pectin and whey protein containing antimicrobials with cinnamic acid, cinnamon leaf essential oil and Cinnamon bark powder for significant anti-microbial activity against food borne pathogens like Escherichia coli, Staphylococcus aureus and Listeria monocytogenes. The edible films were further structurally characterized for the transparency of visible and UV light; functional group was characterized using characterized using FTIR analysis It provides information related to the interaction between the functional groups of antimicrobial agent with biofilm polymers. The anti microbial potential was examined using agar diffusion technique wherein the results showed cinnamon essential oil as the most efficient antimicrobial agent against pathogenic microbes when compared to cinnamic acid and bark powder which can be used as an effective packaging material. (Deepansh Sharma.et.al,2017)

To improve storage of tomatoes using edible coatings which are based on alginates cross-linked with calcium chloride containing oregano essential oil(OEO) which is a nano emulsion acting as a natural anti-microbial. The solution was optimized using response surface methodology to obtain a thin and uniform coating layer on the surface of tomatoes by sequential dipping in a 0.5% w/w sodium alginate solution and in a 2.0% w/w calcium chloride solution and enriched by incorporating oregano essential oil as emulsion and lecithin as natural emulsifier. The nano emulsion improved the wettability of tomato skin but did not did not affect the coating thickness. It also promoted surface adhesion by interaction with hydrophobic tomato skin. This developed edible coatings successfully prolonged the shelf life of tomato by reducing the growth of endogenous microbial flora (yeasts, molds) over a period of 14 days at room temperature in comparison with the control, with indicates better performance. (Annachiara Pirozzi et.al,2020)

CONCLUSION

The concept of edible packaging materials touches a new horizon in packaging industry. The wide range of properties of films helps to alleviate many problems encountered with foods. Film-forming ability and stability of natural ingredients are considered in the production of edible films. Reduced gas transfer rates, durability, non-toxicity and barrier properties are essential for the optimization of edible coating formulation to protect and extend the shelf life of foods. There are several advantages listed by eminent scientists, researchers and scholars but the obstacle arise in developing films at the most cost effective and efficient method in comparison with the synthetic polymers. Some of the most recent developments in the area of edible packaging in food industry are reviewed in this paper and more developments are yet to happen in the near future as this is one of the most promising and emerging field in the packaging industry.

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