



Carrier Materials for Encapsulation of Bio-active Components of Food

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ABSTRACT

The food contains many bioactive compounds like pigments, flavours, enzymes, vitamin etc. those are susceptible to degradation due to light, heat and oxygen. Encapsulation is one of the best methods to extend the shelf life these bioactive components. In encapsulation, choosing of encapsulating or carrier materials is important step. This review paper gives insight on different carrier materials can be used encapsulation of bioactive components of food materials. The different encapsulation materials i.e. carbohydrates, protein and lipid based are discussed in the paper. This review can be useful for the researchers and industrial people to choose best encapsulating materials for their bioactive components.

Keywords: Encapsulation, Carrier materials, encapsulating materials, Carbohydrate, Protein, Lipid

INTRODUCTION

Now a day, the awareness of consumers towards eating and its health benefits to maintain good health is increasing. Preventing illness by diet is a unique opportunity for innovative so-called functional foods¹. These products often present new challenges to the food technologist. Existing and new ingredients need to be incorporated into food systems, in which they slowly degrade and lose their activity, or become hazardous, by oxidation reactions. Ingredients can also react with components present in the food system, which may limit bioavailability, or change the colour or taste of a product. In many cases, microencapsulation can be used to overcome these challenges.

Microencapsulation is the envelopment of small solid particles, liquid droplets or gases in a coating². Microcapsules are small (1–1000 µm) and can have many morphologies. In general, one can distinguish between mononuclear capsules, which have one core enveloped by a shell, and aggregates, which have many cores embedded in a matrix.

The shell or matrix materials are usually polymers. These carrier materials are commonly referred to as the internal phase, the core material, the filler or the fill. The encapsulation material is known as the external phase, the shell, coating or membrane³. Bioactive compounds in foods are chemically unstable.

These compounds are undergoes degradation, migration, transformation and they may lose their bioactivity during storage, food processing or food packaging or transportation⁴.

Carrier materials can be made from a variety of polysaccharides (i.e. cellulose, starch, chitin alginates, pectin), proteins (i.e. gelatine, corn zein, wheat gluten, soy protein, casein, keratin, collagen, whey), lipids (i.e.

wax and oil based coating, fatty acids and mono-glycerides, resins and rosins, emulsions, composite bilayer coating consisting of polysaccharides, protein and lipids).

The paper will be focused on different carrier materials used for encapsulation of bioactive food components.

Carrier/Encapsulating Materials of Different Origins

Encapsulant materials like proteins, carbohydrates and lipids are depicted in Table 1, which may be used in alone or in combination to improve efficiency. The materials chosen as encapsulants are typically film forming, pliable, odourless, tasteless and non-hygroscopic. Solubility in aqueous solvent or ability to exhibit a phase transition, such as melting or gelling, are sometimes attractive, depending on the processing requirements for production of the microencapsulated ingredient and for when it is incorporated into the food product. Other additives, such as emulsifiers, plasticisers or defoaming agents, are sometimes included in the formulation to tune the final product's characteristics. The encapsulant materials may also be modified by physical or chemical means in order to achieve the desired functionality of the microencapsulation matrix. The choice of encapsulant materials is therefore dependent on a number of factors, including its physical and chemical properties, its compatibility with the target food application and its influence on the sensory and aesthetic properties of the final food product⁵⁻⁶.

Carbohydrates Based Encapsulating Materials

The ability of carbohydrates to form gels and glassy matrices has been exploited for microencapsulation of bioactive⁷⁻⁸. Starch and starch derivatives have been widely used for the delivery of sensitive ingredients through food⁹. Chemical modification has made a number of starches more suitable as encapsulating for oils by increasing their lipophilicity and improving their



emulsifying properties. Starch that was hydrophobically modified by octenyl succinate anhydride had improved emulsification properties compared to the native starch¹⁰⁻¹¹. Acid modification of tapioca starch has been shown to improve its encapsulation properties for carotene, compared to native starch or maltodextrin¹². Physical modification of starches by heat, shear and pressure has also been explored to alter its properties¹³, and the modified starch has been used in combination with proteins for microencapsulation of oils¹⁴. Carbohydrates used for microencapsulation of carotene, from sea buckthorn juice by ionotropic gelation using furcellaran beads, achieved encapsulation efficiency of 97%¹⁵. Interest in using cyclodextrins and cyclodextrin complexes for molecular encapsulation of lipophilic bioactive cores is on-going, especially in applications where other traditional materials do not show good activity, or where the final application can accept the cost of this expensive material. The majority of marketable applications for cyclodextrins have been for flavour encapsulation and packaging films¹⁶. Proteins are used as encapsulating agents because of their excellent solubility in water, good gelforming, film-forming and emulsifying properties¹⁷⁻¹⁸.

Polysaccharides used for coatings food materials which includes cellulose, starch derivatives, pectin derivatives, seaweed extracts, exudates gums, microbial fermentation gums and chitosan. Polysaccharides are generally very hydrophilic resulting in poor water vapor and gas barrier properties. Although coatings by polysaccharide polymers may not provide a good water vapour barrier, these coatings can act as sacrificing agents retarding moisture loss from food products¹⁹⁻²⁰.

Cellulose and its Derivatives

Cellulose is composed of repeating unit of D-glucose which are linked together by β -1, 4 glycosidic bonds. In the structure of cellulose, the hydroxymethyl groups of anhydroglucose residues are alternatively located above and below the plan of the polymer backbone. The polymeric chains and a highly crystalline structure of cellulose resist solvation in aqueous media. Water solubility can be increased by treating cellulose with alkali to swell the structure, followed by reaction with chloroacetic acid, methyl chloride or propylene oxide to yield carboxymethyl cellulose (CMC), methyl cellulose (MC), hydroxypropyl cellulose (HPMC) or hydroxypropyl cellulose (HPC) (Figure 1B-1E). MC, HPMC, HPC and CMC film possess good film-forming characteristic; films are generally odourless and tasteless, flexible and are of moderate strength, transparent, resistance to oil and fats, water-soluble, moderate to moisture and oxygen transmission¹⁹.

MC is the most resistant to water and it is the lowest hydrophilic cellulose derivatives²⁰ however, the water vapour permeability of cellulose ether film is still relatively high. MC and HPMC have the ability to form thermally induced gelatinous coating; they have been used to retard oil absorption in deep frying food

products²⁰⁻²¹. MC could be applied as coating on confectionery products as barrier to lipid migration²². A number of researchers have investigated composite films composed of MC or HPMC and various kinds of solids, such as beeswax and fatty acids^{20,23-27}. Many of these have water vapour permeability comparable to low density polyethylene (LDPE). These composite films were all polymer-lipid bilayer formed from aqueous ethanolic solutions of cellulose ether fatty acids²⁸.

Chitin and Chitosan

Chitin is the second most abundant naturally occurring biopolymer and is found in the exoskeleton of crustaceans, in fungal cell walls and other biological materials²⁹. It is mainly poly (β -(1-4)-2-acetamide-D-glucose), which is structurally identical to cellulose except that secondary hydroxyl on the second carbon atom of the hexose repeat unit is replaced by an acetamide group (Figure 2A). Chitosan is derived from chitin by deacetylation in the presence of alkali. Therefore, chitosan is a copolymer consisting of (β -(1-4)-2-acetamido-D-glucose and (β -(1-4)-2-acetamide-D-glucose units with the latter usually exceeding 80% (Figure 2B). Chitosans are described in terms of the degree of deacetylation and average molecular weight and their importance resides in their antimicrobial properties in conjunction with their cationicity and their-forming properties³⁰. Chitosan can form semi-permeable coatings, which can modify the internal atmosphere, thereby delaying ripening and decreasing transpiration rates in fruits and vegetables. Films from aqueous chitosan are clear, tough, flexible and good oxygen barriers³¹⁻³². Carbon dioxide permeability could be improved by methylation of polymers. Butler³³ observed that films from chitosan were rather stable and their mechanical and barrier properties changed only slightly during storage. Chitosan coatings are usually used on fruit and vegetable products like strawberries, cucumbers, bell peppers as antimicrobial coating³⁴⁻³⁵, and on apples, pears, peaches and plums as gas barrier³⁶⁻³⁷.

Starch

Starch is a polymeric carbohydrate made up of anhydrous glucose units. Starch is polysaccharides composed of a linear chain molecule termed amylose and a branched polymer of glucose termed amylopectin³⁸. Starches are mostly used in food industry. They have been used to produce biodegradable films to partially or entirely replace plastic polymers because of its low cost and renew ability, and it has good mechanical properties³⁹. High amylose starch such as corn starch is a good source for films formation; free-standing films can be produced from aqueous solution of gelatinized amylose and drying. Normal corn starch consists of approximately 25% amylose and 75% amylopectin. Mutant varieties of corn are produced which contain starch with up to 85% amylose (Whistler and Daniel, 1985). Mark⁴⁰ reported that films produced from high amylose corn starch (71% amylose) had no detectable oxygen permeability at RH levels less



than 100%. This was true for both unplasticized and plasticized (16% glycerol) films⁴¹. This result is surprising in light of the fact that addition of plasticizers and absorption of water molecules by hydrophilic polymers increase polymer chain mobility and generally lead to increased gas permeability⁴². Partial etherification of high-amylose starch with propylene oxide, to yield the hydroxypropylated derivative, improves water solubility.

Agar

Agar is a hydrophilic colloid consisting of a mixture of agarose and agarpectin that have the ability to form reversible gels simply by cooling a hot aqueous solution. Agar gel melts on heating and resets on cooling. Typical gel temperatures of agar for 1.5% solution are in the range 35-45°C⁴³ because of its ability to form very hard gels at very low concentrations and the simplicity of the extraction process⁴⁴, agar has been used extensively as a gelling agent in the food industry. However, in despite its biodegradability and its enormous gelling power, agar has been few used as edible film due to a poor aging. Indeed, both photo-degradation and fluctuations in ambient temperature and humidity alter agar crystallinity, leading to formation of micro-fractures and polymer embrittlement⁴⁵⁻⁴⁶. However, it was reported that agar-based film displays a better moisture barrier properties than cassava starch film⁴⁷. The influence of agar on the structure and the functional properties of emulsified edible films have been recently studied by Phan⁴⁸. Gelled agar chains can stabilize film-forming emulsion to create a macro network. This macro network entraps flattened lipid particles improving barrier performance by increasing tortuosity. The mechanical properties of agar-hydrogenated vegetable oil emulsified films are comparable with some protein and Low-density polyethylene (LDPE) films.

Alginate

Alginate is an indigestible biomaterial produced by brown seaweeds (Phaeophyceae, mainly Laminaria) therefore it may also be viewed as a source of dietary fibre. Alginate has a potential to form biopolymer film or coating component because of its unique colloidal properties, which include thickening, stabilizing, suspending, film forming, gel producing, and emulsion stabilizing⁴⁹⁻⁵⁰. An attractive feature of alginate solutions is the gelling capacity in presence of Calcium. Edible films prepared from alginate form strong films and exhibit poor water resistance because of their hydrophilic nature⁵¹⁻⁵³. The water permeability and mechanical attributes can be considered as moderate compared to synthetic films⁵⁴.

Alginate edible-films are appropriated to load additives and antibacterial compounds. Good results are obtained applying probiotics⁵⁵ and oil compounds such as garlic oil⁵⁶ and oregano oil⁵⁷.

A mixture of starch and alginate to form edible film has been studied by Wu⁵⁸ achieving to improve the mechanical properties of film.

Carrageenan

Carrageenans are water-soluble polymers with a linear chain of partially sulphated galactans, which present high potentiality as film-forming material. These sulphated polysaccharides are extracted from the cell walls of various red seaweeds (Rhodophyceae). Different seaweeds produce different carrageenans. The positions and numbers of sulfate ester groups are important because they are, together with the anhydrogalactose bridge, responsible for carrageenan functionality and determine a classification in three major types: κ , ι and λ . κ - and ι -carrageenans contain the 3,6-anhydro units and are used as gelling agents because of their property to produce thermo-reversible gels on cooling below the critical temperature. λ -Carrageenan, with only sulfated galactose groups and no anhydrogalactose bridge, is a thickening polymer⁵⁹. The use of carrageenan as edible films and coatings already covers various fields of the food industry such as application on fresh and frozen meat, poultry and fish to prevent superficial dehydration⁶⁰, sausage-casings⁶¹, dry solids foods, oily foods⁶², etc. Carrageenan film formation includes this gelation mechanism during moderate drying, leading to a three-dimensional network formed by polysaccharide double helices and to a solid film after solvent evaporation⁶³⁻⁶⁴. Recently, carrageenan films were also found to be less opaque than those made of starch⁶⁵.

Gums

Gums in edible-forming preparation are used for their texturizing capabilities. All gums are polysaccharides composed of sugars other than glucose. Gums are differentiate in three groups⁶⁶ exudates gums (gum Arabic; mesquite gum), the extractive gums (come from endosperm of some legume seeds or extracted from the wood: guar gum) and the microbial fermentation gums (xanthan gum). In edible-forming preparations, guar gum is used as a water binder, stabilizer and viscosity builder. Gum arabic, owing to its solubility in hot or cold water, is the least viscous of the hydrocolloid gums. Xanthan gum is readily dispersed in water; hence high consistency is obtained rapidly in both hot and cold systems. A blend of guar gum, gum arabic and xanthan gum provided uniform coatings with good cling and improved adhesion in wet batters⁶⁷⁻⁶⁸. The coating based from mesquite gum preparation and applied to Persian limes provided a lowest physiological weight loss, best dark shade green colour retention and unaltered physicochemical parameters to Persian limes. The mesquite gum forms films with excellent water vapour barrier properties when small amounts of lipids are added in their formulation⁶⁹. Film-forming polymers based on gum Arabic, showed to be an inhibitor of after-cooking darkening of potatoes⁷⁰.

Pectin

Pectin is a heterogeneous grouping of acidic structural polysaccharides, found in fruit and vegetables and mainly prepared from citrus peel and apple pomace. This



complex anionic polysaccharide is composed of β -1, 4-linked d-galacturonic acid residues, wherein the uronic acid carboxyls are either fully (HMP, high methoxy pectin) or partially (LMP, low methoxy pectin) methyl esterified. Commercial extraction causes extensive degradation of the neutral sugar-containing side chains. With Chitosan, HMP or LMP forms excellent films. Indeed, the cationic nature of chitosan offers the possibility to take advantage of the electrostatic interactions with anionic polyelectrolytes, such as pectin⁷¹⁻⁷². The effect of antimicrobial plant essential oils such as oregano, lemon grass, or cinnamon oil at different concentrations, on physical properties of apple puree-pectin based edible coatings was reported by Rojas-Grau⁷³. It is also interesting to point out the application of LMP based edible coatings as a pre-treatment in osmotic dehydration for obtaining better dehydration efficiency⁷⁴⁻⁷⁵ finally recently an investigation demonstrated the prevention of crumb ageing of dietetic sucrose-free sponge cake when a pectin-containing edible film was used. This sponge cake had better preserved freshness, especially up to the fifth day of storage⁷⁶.

Protein Based Encapsulant Materials

Protein-based microcapsules can be easily rehydrated or solubilised in water, which often results in immediate release of the core. Proteins are often combined with carbohydrates for microencapsulation of oils and oil-soluble components. In the manufacture of encapsulated oil powders, encapsulation efficiency was higher when the encapsulation matrix was a mixture of milk proteins and carbohydrates, compared to when protein was used alone⁹⁶. Soy protein-based microcapsules of fish oil have been cross-linked using transglutaminase to improve the stability of the encapsulated fish oil⁹⁷. Protein-based hydrogels are also useful as nutraceuticals delivery systems⁹⁸. The release properties of protein-based hydrogels and emulsions may be modulated by coating the gelled particles with carbohydrates. A model-sensitive core, paprika oleoresin, was encapsulated in microspheres of whey proteins and coated with calcium alginate to modify the core's release properties⁹⁹. Whey protein-based hydrogels with an alginate coating altered the swelling properties of the gelled particles. The stability of these particles was improved at neutral and acidic conditions both in the presence and absence of proteolytic enzymes¹⁰⁰. Lipids are generally used as secondary coating materials applied to primary microcapsules or to powdered bioactive cores to improve their moisture barrier properties¹⁰¹.

In their native states, proteins generally exist as either fibrous proteins, which are water insoluble and serve as the main structural materials of animal tissues, or globular proteins, which are soluble in water or aqueous solutions of acids, bases or salts and function widely in living systems.

Fibrous proteins are fully extended and associated closely with each other in parallel structures, generally through

hydrogen bonding, to form fibers. The globular proteins fold into complicated spherical structures held together by a combination of hydrogen, ionic, hydrophobic and covalent (disulfide) bonds¹⁰². The chemical and physical properties of these proteins depend on the relative amounts of the component amino acid residues and their placement along the protein polymer chain. Several globular proteins, including wheat gluten, corn zein, soy protein, and whey protein, have been investigated for their film properties. Protein films are generally formed from solutions or dispersions of the protein as the solvent/carrier evaporates. The solvent/carrier is generally limited to water, ethanol or ethanol-water mixtures¹⁰³. Generally, proteins must be denatured by heat, acid, base, and/or solvent in order to form the more extended structures that are required for film formation. Once extended, protein chains can associate through hydrogen, ionic, hydrophobic and covalent bonding. The chain-to-chain interaction that produces cohesive films is affected by the degree of chain extension and the nature and sequence of amino acid residues. Uniform distribution of polar, hydrophobic, and/or thiol groups along the polymer chain increase the likelihood of the respective interactions. Increased polymer chain-to-chain interactions resulted in films that are stronger but less flexible and less permeable to gases, vapours and liquids¹⁰³. Polymers containing groups that can associate through hydrogen or ionic bonding result in films that are excellent oxygen barriers but are susceptible to moisture¹⁰⁴. Thus, protein films are expected to be good oxygen barriers at low relative humidity. Various types of protein have been used as edible films. These include gelatin, casein, whey protein, corn zein, wheat gluten, soy protein, mung bean protein, and peanut protein¹⁰⁵.

Gelatin

Gelatin is obtained by controlled hydrolysis from the fibrous insoluble protein, collagen, which is widely found in nature as the major constituent of skin, bones and connective tissue. Gelatin is composed of a unique sequence of amino acids. The characteristic features of gelatin are high content of the amino acids glycine, proline and hydroxyproline. Gelatin also has a mixture of single and double unfolded chains of hydrophilic character¹⁰⁶. At approximately 40°C, gelatin aqueous solutions are in the sol state and form physical, thermoreversible gels on cooling.

During gelation, the chains undergo a conformational disorder–order transition and tend to recover the collagen triple-helix structure¹⁰⁷.

Gelatin films could be formed from 20-30% gelatin, 10-30% plasticizer (glycerin or sorbitol) and 40-70% water followed by drying the gelatin gel¹⁰⁸.

Gelatin is used to encapsulate low moisture or oil phase food ingredients and pharmaceuticals.

Such encapsulation provides protection against oxygen and light, as well as defining ingredient amount or drug



dosage. In addition, gelatin films have been formed as coatings on meats to reduce oxygen, moisture and oil transport¹⁰⁹.

Zein

Zein is the most important protein in corn. It is a prolamin protein and therefore dissolves in 70–80% ethanol¹⁰⁻¹¹¹⁻¹¹². Zein is a relatively hydrophobic and thermoplastic material. The hydrophobic nature of zein is related to its high content of non-polar amino acids¹¹³. Zein has excellent film forming properties and can be used for fabrication of biodegradable films. The zein bio-film is formed through the development of hydrophobic, hydrogen and limited disulfide bonds between zein chains¹¹⁴. Edible films can be formed by drying aqueous ethanol solution of zein¹¹⁵. Formation of films is believed to involve development of hydrophobic, hydrogen and limited disulfide bonds between zein chains in the film matrix¹¹⁶. The resulting films are brittle and therefore require plasticizer addition for increasing flexibility¹¹⁷. Zein films are relatively good water vapor barriers compared to other edible films¹¹⁴. Water vapor barrier properties can be improved by adding fatty acids or by using a cross-linking reagent. But when cross-linking agents are used the edibility of those films is of concern¹¹⁸. Zein coating have also shown an ability to reduce moisture and firmness loss and delay color change (reduce oxygen and carbon dioxide transmission) in fresh tomatoes¹¹⁹.

Gluten

Gluten is a general term for water-insoluble proteins of wheat flour which is composed of a mixture of polypeptide molecules, considered to be globular proteins. Cohesiveness and elasticity of gluten give integrity to wheat dough and facilitate film formation. Wheat gluten contains the prolamine and glutelin fractions of wheat flour proteins, typically referred to as gliadin and glutenin, respectively. While gliadin is soluble in 70% ethanol, glutenin is not¹²⁰. Although insoluble in natural water, wheat gluten dissolves in aqueous solutions of high or low pH at low ionic strength¹²¹. Edible films can be formed by drying aqueous ethanol solution of wheat gluten. Cleavage of native disulfide bonds during heating of film-forming solutions and then formation of new disulfide bonds during film drying are believed to be important to the formation of wheat gluten films structure, along with hydrogen and hydrophobic bonds¹²⁰. Addition of plasticizer such as glycerin in gluten films is necessary to improve film flexibility (Gennadios). However, increasing film flexibility by increasing sorbitol content reduces film strength, elasticity and water vapor barrier properties confirmed the effect of wheat gluten purity on film appearance and mechanical properties, i.e., a greater purity gluten results in a stronger and clearer films¹²². Herald investigated the effect of plasticizer size of wheat gluten; films prepared from spray-dried wheat gluten were stronger than films from flash-dried which had larger sized particles¹²³. When used as a coating on

grade A-quality shell eggs, the egg quality was maintained for 30 days. Tensile strength of gluten films can be improved by using a cross-linking agent such as glutaraldehyde, or heat curing at 80°C (Gennadios and Weller, Koelsch determined the influence of relative humidity on carbon dioxide sorption in wheat gluten films. The results showed that the permeability was based on the rise of CO₂ solubility and diffusivity with the increase in RH. The increase in the water content of wheat gluten improves the affinity between carbon dioxide and the protein matrix, leading to outstanding sorption values for high RH¹⁰⁵⁻¹⁰⁶.

Soy Protein

The protein content of soybeans (38-44%) is much higher than the protein content of cereal grain (8-15%). Most of the protein in soybeans is insoluble in water but soluble in dilute neutral salt solutions. Thus, soy protein belongs to the globulin classification¹²⁵. Soy protein is globular in nature and is further classified into 2S, 7S, 11S and 15S fraction according to relative sedimentation rates¹²⁵. The principal components are the 7S (conglycinin) and (glycinin) fractions, both of which have a quaternary (subunit) structure¹²⁶. Soy protein is high in asparagine and glutamine residues. Both conglycinin and glycinin are tightly folded proteins. While the extent of disulfide cross-linking of conglycinin is limited due to only two to three cysteine groups per molecule, glycinin contains 20 intramolecular disulfide bonds¹²⁷. Alkali and heating both cause dissociation and subsequent unfolding of glycinin due to disulfide bond cleavage¹²⁷. Edible films based on soy protein can be produced in either of two ways: surface film formation on heated soymilk or film formation from solutions of soy protein isolate (SPI)¹²⁸. Soymilk is produced by grinding soybeans with water followed by separation of milk from extracted soybeans. To form films from both soymilk and SPI, (a) heating of film solutions to disrupt the protein structure, cleave native disulfide bonds and expose sulfhydryl groups and hydrophobic groups, and then (b) formation of new disulfide, hydrophobic and hydrogen bonds during film drying are believed to be important to the formation of soy protein film structure¹²⁹⁻¹³⁰. The use of soy protein in the formation of films or coatings on food products has been investigated¹³¹⁻¹³⁵.

Whey Protein

Whey protein isolate produces totally water-soluble coatings but heat denatured solutions of whey protein isolate produce coatings in which the protein is insoluble. Industrially produced whey protein concentrate (WPC) have a protein content between 25 and 80% whereas the whey protein isolate (WPI) have protein content above 90%¹³⁶⁻¹³⁷. Whey proteins have been the subject of intense investigation over the past decade or so¹³⁸. Whey proteins can produce transparent, flexible, colourless and flavourless films, with poor moisture barrier¹³⁹⁻¹⁴⁰. Moreover protein-based films possess a good aroma barrier¹³⁸⁻¹⁴¹, and low oxygen permeability¹⁴². Whey



protein films produced without addition of any plasticizers are very brittle therefore the addition of plasticizers provides flexibility to the films but also increases their water vapour permeability. Increased concentration of plasticizers in edible whey protein films will decrease tensile strength and Young's modulus, but increase elongation. The water vapour permeability can also be improved by the incorporation of hydrophobic materials such as lipids¹⁴⁴. However, the incorporation of lipid materials into edible film formulations into films could adversely affect the sensory characteristics of films. The incorporation of antimicrobial agents into edible coating formulations is needed to obtain stronger inhibitory effect against microbial growth. Optimization of edible whey protein films containing sorbitol, beeswax and potassium sorbate concentrations for mechanical and optical properties was reported by Ozdemir and Floros¹⁴⁵. Recently WPI and mesquite gum (MG) are shown totally compatible to form solutions and films. Indeed, the incorporation of different amounts of MG on the WPI allowed to obtain composite films with improved flexibility without increasing plasticizer content and consequently without affecting negatively other characteristics such as water vapour permeability¹⁴⁶.

Lipid based Encapsulant Materials

Lipids can also be incorporated in an emulsion formulation to form a matrix or film around the bioactive core. The increasing demand for food-grade materials that will perform under the different stresses encountered during food processing has spurred the development of new encapsulant materials. Understanding the glass transition temperature of various polymers (e.g. proteins and carbohydrates) and their mixtures is also becoming important as this can influence the stability of the encapsulated core. The low water mobility and slow oxygen dispersal rates in glassy matrices can improve stability of bioactives¹⁵³. It is possible to exploit thermally induced interactions between proteins and polysaccharides and then to use the modified materials for encapsulation. Hydrogels formed by heat treatment of lactoglobulin chitosan have been investigated, and it has been suggested that under controlled conditions these complexes may be useful for microencapsulation of functional food components¹⁵⁴. Maillard reaction products formed by interactions between milk proteins and sugars or polysaccharides have been used as encapsulant matrices to protect sensitive oils and bioactive ingredients¹⁵⁵.

Lipid compounds utilized as protective coating consist of acetylated monoglycerides, natural wax, and surfactants. The most effective lipid substances are paraffin wax and beeswax. The primary function of a lipid coating is to block transport of moisture due to their relative low polarity. In contrast, the hydrophobic characteristic of lipid forms thicker and more brittle films.

Consequently, they must be associated with film forming agents such as proteins or cellulose derivatives¹⁵⁶.

Generally, water vapor permeability decreases when the concentration of hydrophobic phase increases. Lipid-based films are often supported on a polymer structure matrix, usually a polysaccharide, to provide mechanical strength.

Waxes and Paraffin

Paraffin wax is derived from the distillate fraction of crude petroleum and consists of a mixture of solid hydrocarbon resulting from ethylene catalytic polymerization. Paraffin wax is permitted for use on raw fruit and vegetable and cheese. Carnauba wax is an exudate from palm tree leaves (*Coccothrinax crinita*). Beewax (white wax) is produced from honeybees. Candelilla is obtained from the candelilla plant. Mineral oil consists of a mixture of liquid paraffin and naphthenic hydrocarbon¹⁵⁷. Waxes are used as barrier films to gas and moisture (skin on fresh fruits) and to improve the surface appearance of various foods (e.g., the sheen on sweets). If applied as a thick layer, they must be removed before consumption (certain cheese); when used in thin layers, they are considered edible. Waxes (notably paraffin, carnauba, candelilla and bee wax) are the most efficient edible compounds providing a humidity barrier.

Acetoglyceride

Acetylation of glycerol monostearate by its reaction with acetic anhydride yields 1-stearoaceticin. This acetylated monoglyceride displays the unique characteristic of solidifying from the molten state into a flexible, wax-like solid¹⁵⁸. Most lipids in the solid state can be stretched to only about 102% of their original length before fracturing. Acetylated glycerol monostearate, however, can be stretched up to 800% of its original length¹⁵⁹, water vapor permeability of this film is much less than that of polysaccharide films with the exception of methyl cellulose or ethyl cellulose. Acetylated monoglyceride coatings have been used on poultry and meat cuts to retard moisture loss during storage²⁰.

Shellac Resins

Shellac resins are a secretion by the insect *Laccifer lacca* and are composed of a complex mixture of aliphatic alicyclic hydroxyl acid polymers. This resin is soluble in alcohols and in alkaline solutions. Shellac is not a GRAS substance; it is only permitted as an indirect food additive in food coatings and adhesives. It is mostly used in coatings for the pharmaceutical industry and only few studies have been reported on foods (Hernandez, 1994). Rosins which are obtained from the oleoresins of the pine tree are residues left after distillation of volatiles from the crude resin. Resin and its derivatives are widely used in coating for citrus and other fruits.

These coatings were designed primarily to impart high-gloss at the time of inspection by the buyer, usually after application of the coating.

When coatings are applied to fruit, they form an additional barrier through which gases must pass.



Because coatings differ in gas permeance and ability to block openings in the peel, they have different effects on gas exchange¹⁶⁰.

Citrus fruits with shellac and wood resin-based coatings generally have lower internal O₂, higher internal CO₂ and

higher ethanol content than fruits with wax coatings¹⁶⁰. High ethanol content, in turn, is an indication of off-flavor¹⁶¹⁻¹⁶³.

Shellac- and wood resin-based coatings also tend to increase prevalence of post-harvest pitting¹⁶¹.

Table 1: Encapsulating Materials for Food Application

Encapsulant Materials		
Carbohydrates	Proteins	Lipid and Waxes
Cellulose and derivatives		
Chitin and Chitosan		
Starch	Gelatin	
Agar	Corn zein	Waxes and paraffin
Alginate	Wheat gluten	Acetoglycerides
Carrageenans	Soy protein	Shellac resins
Gums	Whey Protein	
Pectins		

Table 2: Carbohydrate based Encapsulating Materials and their Applications

Encapsulant Materials	Uses	References
Cellulose and its derivatives	Applied on some fruits and vegetables	77
Chitin and chitosan	Encapsulation of essential oils	78
Starch	Encapsulation of pigments	79
	1. Anthocyanin and lycopene	
	Encapsulation of antimicrobials agent in	80
	1. Green tea extract(gram positive bacteria)	
	Encapsulation of flavouring compounds from	81
	1. Peppermint	
	2. Limonene and β - unsaturated aldehydes	82
	3. Pandan leaf extract	83
Agar	Encapsulation of flavours	84
Alginate	Encapsulation of antioxidant agents in fruits	
	1. N-acetylcystein and glutathione	
	2. ascorbic acid and citric acid	85
	3. Tea polyphenols	86
	Encapsulation of antimicrobials agent in	87
	1. Cinnamon, palmarosa and lemongrass oils	
	2. Lemongrass, oregano oil and vanillin	88-89
	Encapsulation of flavours	90-92
	1. Linoleic acid and isoleucine	
	Encapsulation of probiotics	54
	1. Bifidobacterium lactis	
2. Lactobacillus acidophilus	93	
3. Lactobacillus acidophilus	94	
4. Lactobacillus rhamnosus	95	
5. Lactobacillus acidophilus	96	
Carrageenans	application on fresh and frozen meat	60
	poultry and fish, sausages-casting	61
	dry solid foods, oily foods	62
Gums	Applied on potatoes	69
Pectins	Edible coating for fruits	70

Table 3: Protein based Encapsulant Materials

Encapsulant Material	Uses	References
Gelatin Protein	Encapsulation of antimicrobial agents applied on fish	147
Corn zein Protein	Encapsulation of flavonoids 1. Catechin, flavone or quercetin	148
Wheat Gluten protein	Applied on egg shell	149
Soy Protein	Applied layer on fruits and vegetables	150
Whey Protein	Encapsulation of antioxidant agents 1. Oregano oil in fresh beef	151
	2. Sunflower oil, lemon and orange oil flavour	152

Table 4: Lipids based Encapsulant Materials

Encapsulant Material	Uses	References
Waxes and Paraffin	Applied on fruits	165, 166
Acetoglyceride	Coating used on poultry and meat cuts	20
Shellac Resins	Applied on fruits	160

CONCLUSION

The bioactive components of food are undergoes into different changes due to heat, light and oxygen.

The decomposition of these components may be overcome by the encapsulation.

Various encapsulating materials are used for encapsulation of bioactive components of foods.

These materials are mainly based on carbohydrate, protein and lipids.

These materials can be used for encapsulation to prevent oxidation and decomposition which was occurred due to heat and light.

This paper will be beneficial to research scientist and R & D persons to find out the best encapsulating materials for bioactive food components.

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