EDIBLE COATINGS and FILMS to IMPROVE FOOD QUALITY

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Preface

RESEARCH into edible coatings and films has been intense in recent years, with all indications that interest will continue. Motivations for developments in this field come from several directions. Consumer interests in health, food quality, convenience, and safety continue to increase, presenting food processors with new challenges to which edible coating and film concepts offer potential solutions. Consumers and processors alike have found new and renewed commitment to reducing the environmental consequences of packaging. By acting as barriers to moisture or oxygen, edible coatings can conceivably reduce the complexity and, therefore, improve recyclability of packaging. In some cases, edible films may be able to replace synthetic packaging films. Furthermore, food scientists and engineers have isolated new materials that present new opportunities in the formation and properties of edible coatings and films. In many cases, these materials are quite abundant in nature and have previously been regarded as surplus or waste. In some cases, these materials are being combined in new and creative ways to achieve heretofore unattainable coating and film properties.

With the explosion of interest and information in the area of edible coatings and films in recent years, a book that summarizes progress to this point was needed. Thus, *Edible Coatings and Films to Improve Food Quality* brings together some of the many researchers presently contributing to this field. The intent of the book is to achieve a number of goals, including introducing newcomers to this field, describing materials appropriate for use, summarizing properties, reviewing methods for application, describing approaches for mathematical modeling, and summarizing present and potential uses. Authors were asked to develop topics in a comprehensive manner, with the result that each chapter stands alone and as an important contributing element in the total book. Some overlap, therefore, occurs between chapters, but usually with the result of increased clarification due to the different contexts of each chapter. In addition to the review of the editors, each chapter was anonymously reviewed by experts in the chapter area to further insure accuracy and comprehensive presentation of subject matter.

The thanks of the editors go to the many researchers in this field who developed the information covered in the book, the authors who wrote the chapters, and Technomic Publishing Co., Inc. for their encouragement, patience, and support of this project.

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CHAPTER 1

Edible Films and Coatings: Characteristics, Formation, Definitions, and Testing Methods

I. GREENER DONHOWE[1]
O. FENNEMA[2]

INTRODUCTION

ALTHOUGH the use of edible films in food products may seem new, food products were first enrobed in edible films and coatings many years ago. During the twelfth and thirteenth centuries, dipping of oranges and lemons in wax to retard water loss was practiced in China (Hardenberg, 1967). In England, during the sixteenth century, "larding," coating food products with fat, was used to prevent moisture loss in foods (Labuza and Contrereas-Medellin, 1981). Currently, edible films and coatings find use in a variety of applications, including casings for sausages, chocolate coatings for nuts and fruits, and wax coatings for fruits and vegetables. The technical challenges involved in producing stable foods suggest that edible films and coatings could be used to an even greater extent than they are currently. However, technical information concerning edible films is far from adequate, leaving the food scientist with the formidable task of developing a film for each food application.

The information presented in this chapter and subsequent ones will enable the food scientist to more readily develop edible films and to more thoroughly understand the fundamentals responsible for the physical properties of edible films.

RATIONALE FOR USING EDIBLE FILMS

Edible films can help meet the many challenges involved with the

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marketing of foods that are nutritious, safe, of high quality, stable, and economical by serving one or more of the functions listed in Table 1.1.

Edible films can be used as barriers to gases and water vapor. For this purpose they can be positioned either on the surface of the food, e.g., as a coating on fruits, or within the food, where they separate components of markedly different water activity.

In the first instance, the function is to restrict loss of moisture from the fruit to the environment or to lessen absorption of oxygen by the fruit and thereby slow respiration (Kester and Fennema, 1986). In the latter instance, the film may serve to stabilize water activity gradients and preserve different textural properties possessed by different food components. For example, an edible film could be used to separate the crisp component of a pizza from the moist semi-solid component.

Edible films can also be used as protective coatings for food ingredients that are susceptible to oxidation. Polysaccharide coatings on nutmeats serve this purpose (Murry and Luft, 1973).

Lessening migration of lipids is another potential application for edible films. Migration of fats and oils can be a problem in the confectionery industry, especially in products involving chocolate. For example, if oil from a peanut butter filling migrates into a chocolate coating, this will have an adverse effect on the properties of the chocolate (Nelson and Fennema, 1991; Paulinka, 1986).

Edible films and coatings can also improve the mechanical-handling properties, or structural integrity of a food product. In foods composed of many discrete particles, such as a pizza topping, an edible film could be used to secure these components in place during product distribution. Coatings can also provide some physical protection for food products

TABLE 1.1. Possible Uses of Edible Films and Coatings.

Use	Appropriate Types of Film
Retard moisture migration	Lipid, composite[a]
Retard gas migration	Hydrocolloid; lipid, or composite
Retard oil and fat migration	Hydrocolloid
Retard solute migration	Hydrocolloid, lipid, or composite
Improve structural integrity or handling properties	Hydrocolloid, lipid, or composite
Retain volatile flavor compounds	Hydrocolloid, lipid, or composite
Convey food additives	Hydrocolloid, lipid, or composite

[a]A composite film consists of lipid and hydrocolloid components combined to form a bilayer or conglomerate.

which are susceptible to injury during transport, such as fresh fruits and vegetables.

Food additives, such as flavors, antimicrobial agents, antioxidants, and colors can be incorporated into edible films and used to control location or rate of release of these additives in a food.

Additionally, edible films may offer an alternative to the commercial packaging materials used for food products. Using edible films for this purpose would likely reduce the packaging waste associated with processed foods.

Although it is clear that edible films and coatings have many potential applications in food, they have not, with few exceptions, been widely utilized by the food industry.

FILM COMPONENTS

Components of edible films and coatings can be divided into three categories: hydrocolloids, lipids, and composites. Suitable hydrocolloids include proteins, cellulose derivatives, alginates, pectins, starches, and other polysaccharides. Suitable lipids include waxes, acylglycerols, and fatty acids. Composites contain both lipid and hydrocolloid components. A composite film can exist as a bilayer, in which one layer is a hydrocolloid and the other a lipid, or as a conglomerate, where the lipid and hydrocolloid components are interspersed throughout the film. Specific types of film components will be discussed only briefly, since this information is covered in depth in Chapters 9–11.

HYDROCOLLOIDS

Hydrocolloid films can be used in applications where control of water vapor migration is not the objective. These films possess good barrier properties to oxygen, carbon dioxide, and lipids. Most of these films also have desirable mechanical properties, making them useful for improving the structural integrity of fragile products. Water solubility of polysaccharide films is advantageous in situations where the film will be consumed with a product that is heated prior to consumption. During heating, the hydrocolloid film or coating would dissolve, and ideally, would not alter the sensory properties of the food.

Hydrocolloids used for films and coatings can be classified according to their composition, molecular charge, and water solubility. In terms of composition, hydrocolloids can be either carbohydrates or proteins. Film-forming carbohydrates include starches, plant gums (for example alginates, pectins, and gum arabic), and chemically modified starches.

Film-forming proteins include gelatin, casein, soy protein, whey protein, wheat gluten, and zein. It should be noted, however, that great differences exist in how easily films of good integrity can be formed from these substances.

The charged state of a hydrocolloid can be useful for film formation. Alginates and pectins require the addition of a polyvalent ion, usually calcium, to facilitate film formation. They, as well as proteins, are susceptible to pH changes because of their charged state. For some applications, an advantage can be gained by combining hydrocolloids of opposite charge such as gelatin and gum arabic.

Although hydrocolloid films generally have poor resistance to water vapor because of their hydrophilic nature, those which are only moderately soluble in water, such as ethylcellulose, wheat gluten, and zein do provide somewhat greater resistance to the passage of water vapor than do the water-soluble hydrocolloids. The dependence of permeability on solubility is more thoroughly discussed in Chapter 7.

LIPIDS

Lipid films are often used as barriers to water vapor, or as coating agents for adding gloss to confectionery products. Their use in a pure form as free-standing films is limited, because most lack sufficient structural integrity and durability.

Waxes are commonly used for coating fruits and vegetables to retard respiration and lessen moisture loss. Formulations for wax coatings vary greatly and the compositions are often proprietary. Acetylated monoglycerides are frequently added to wax formulations to add pliability to the coating.

Shellac coatings, when formed on a supporting matrix, provide effective barrier properties to gases and water vapor (Hagenmaier and Shaw, 1991). Coatings to sucrose fatty acid esters reportedly are effective moisture barriers for maintaining the crispness of snack foods (Kester et al., 1990) and for extending the shelf-life of apples (Drake et al., 1987).

Although fatty acids and fatty alcohols are effective barriers to water vapor, their fragility requires that they be used in conjunction with a supporting matrix.

Many lipids exist in a crystalline form and their individual crystals are highly impervious to gases and water vapor (Fox, 1958). Since the permeate can pass between crystals, the barrier properties of crystalline lipids are highly dependent on the intercrystalline packing arrangement. Lipids consisting of tightly packed crystals offer greater resistance to diffusing gases than those consisting of loosely packed crystals. Also, crystals oriented with their major planes normal to permeate flow provide better barrier properties than crystals that are oriented differently (Fox, 1958).

Lipids existing in a liquid state or having a large proportion of liquid components offer less resistance to gas and vapor transmission than those in a solid state (Kamper and Fennema, 1984a; Kester and Fennema, 1989a, 1989b), indicating that molecular mobility of lipids detracts from their barrier properties.

The barrier properties of lipids having crystalline properties can be influenced both by tempering and by polymorphic form (Kester and Fennema, 1989e, 1989f).

COMPOSITES

Composite films can be formulated to combine the advantages of the lipid and hydrocolloid components and lessen the disadvantages of each. When a barrier to water vapor is desired, the lipid component can serve this function while the hydrocolloid component provides the necessary durability. Properties of lipid-hydrocolloid bilayer films have been studied extensively in the authors' laboratory (Greener and Fennema, 1989a, 1989b; Kester and Fennema, 1989a–1989f; Kamper and Fennema, 1984a, 1984b). Composite films consisting of a conglomerate of casein and acetylated monoglycerides have been studied by Krochta et al. (1990). These films can be used as coatings for processed fruits and vegetables. A composite film of gum acacia and glycerolmonostearate was reported to have good water vapor barrier properties at a 43.8–23.6% relative humidity gradient (Martin-Polo and Voilley, 1990).

FILM ADDITIVES

The functional, organoleptic, nutritional, and mechanical properties of an edible film can be altered by the addition of various chemicals in minor amounts. Plasticizers, such as glycerol, acetylated monoglyceride, polyethylene glycol, and sucrose are often used to modify the mechanical properties of a film. Incorporation of these additives may, however, cause significant changes in the barrier properties of the film. For example, the addition of hydrophilic plasticizers usually increases the water vapor permeability of the film.

Other types of film additives often found in edible film formulations are antimicrobial agents, vitamins, antioxidants, flavors, and pigments.

FILM FORMATION

Many techniques have been developed for forming films directly on food surfaces, or as separate, self-supporting films.

COACERVATION

Coacervation involves separation of a polymeric coating material from a solution by heating, altering pH, adding solvents, or altering the charge on the polymer involved (Deasy, 1984; Bankan, 1973). In simple coacervation, only one soluble polymer is involved (Deasy, 1984; Bankan, 1973). In complex coacervation, at least two oppositely charged macromolecules are combined to yield an insoluble mixed polymer by the mechanism of charge neutralization (Glicksman, 1982).

Coacervation may also be classified according to the type of phase separation: aqueous or nonaqueous. Aqueous phase separation requires a hydrophilic coating such as gelatin or gelatin–gum acacia that is deposited on a water-insoluble core particle. Nonaqueous phase separation usually involves a hydrophobic coating that is deposited on a core which may be either water-soluble or water-insoluble (Dziezak, 1988).

Although coacervation has been used extensively in the pharmaceutical industry, especially for encapsulation, few applications have developed in the food industry. This is probably the result of costly equipment; the lack of food-grade status for some encapsulating materials; and with flavor encapsulation, difficulty incorporating adequate flavor concentrations in microcapsules (Dziezak, 1988).

SOLVENT REMOVAL

For film-forming materials dispersed in aqueous solutions, solvent removal is a necessity for solid film formation. Rate and temperature of drying has been found to influence the resulting crystallinity and mechanical properties of cellulosic films (Greener, 1992; Reading and Spring, 1984).

SOLIDIFICATION OF MELT

Solidification of the melt by cooling is a common technique for preparing lipid films. Similar to the rate of solvent removal, the rate of cooling plays an important role in the overall physical properties of the resulting film. The rate of cooling influences the predominant polymorphic state, as well as degree of recrystallization in the solidified film. Kester and Fennema (1989e) reported that the water vapor and oxygen resistances of lipid films were dependent on the polymorphic state. After the initial solidification, the barrier properties of lipid films to water vapor and oxygen are further altered by tempering (Kester and Fennema, 1989f; Landmann et al., 1960).