Protein Functionality in Food Systems

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JOHN EDWARD KINSELLA
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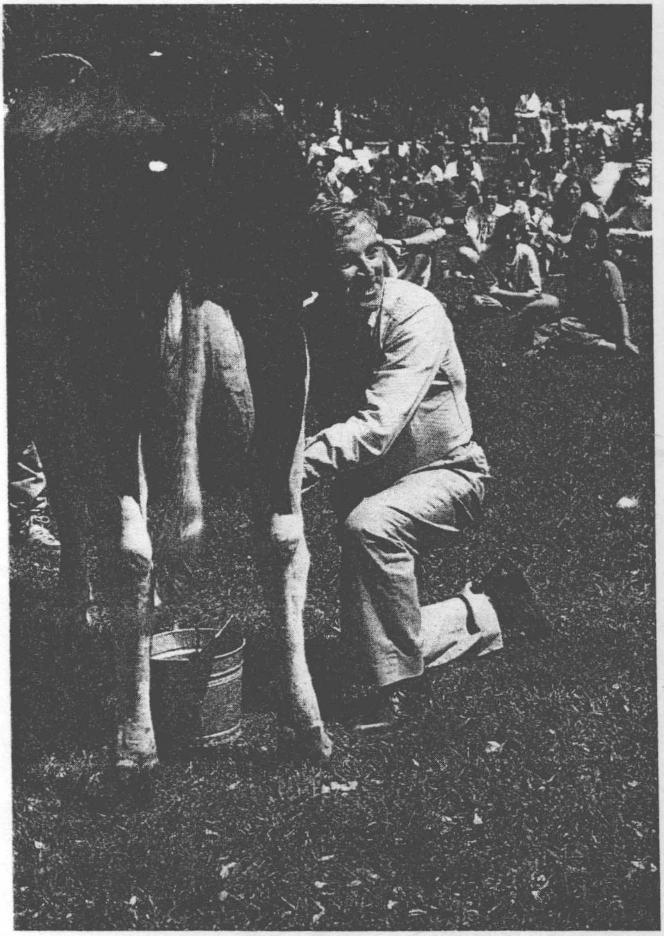

We think not a friend lost because he is gone into another room, nor because he is gone into another land, and into another world no man is gone, for that Heaven which God created and this world are all one.

William Penn

Dr. John E. Kinsella's contribution to the study of protein functionality is revealed in the reference list of nearly every chapter of this book. Among the contributors are several of John's former graduate students and postdoctoral scholars. All considered him a valued colleague. In recognition of this, we dedicate this book to his memory.

Preface

The Institute of Food Technologists (IFT) and the International Union of Food Science and Technology (IUFoST) sponsor an annual, 2-day Basic Symposium, held in conjunction with the IFT Annual Meeting. The Basic Symposium deals in depth with fundamental aspects of selected topics of interest to food scientists, with some applications of the fundamental concepts to the solution of problems facing the food scientist and the food industry.

This symposium, Protein Functionality in Food Systems, the 17th in the series, took place July 9 and 10, 1993, prior to IFT's 53rd Annual Meeting in Chicago. This topic was selected by the Basic Symposium Committee to help meet the demands of the food industry, to enhance the teaching of advanced courses in proteins, and to serve as reference material on protein functionality in food systems.

Aside from their biological activity and their obvious role in nutrition, proteins contribute significantly to the technological and organoleptic characteristics of foods. The *functional properties* of food proteins include solubility, viscosity, gelation, emulsification, and foam formation. Additionally, proteins exhibit the ability to form films and glasses, and contribute to color and flavor. Egg white, gelatin, soy protein, whey protein, and caseinates are all utilized as functional food ingredients.

The chapters in this book feature the latest information on fundamental structure–function relationships, protein-separation technologies, computer-aided techniques for predicting quality parameters of products directly from ingredient proteins, interactions of proteins with other food components, modification of proteins for improved functionality, special protein formulations, and novel applications. These chapters provide not only a sound basis for understanding basic principles involved in food protein functionality, but also valuable fundamental information to creatively develop unique food products utilizing proteins as novel ingredients.

The help provided by present and former Basic Symposium Committee members—Patricia Kendall, Colorado State University; John Rushing, North Carolina State University; Rakesh Singh, Purdue University; Frank Flora, USDA-CSRS; Richard McDonald, FDA; Henry Schwartzberg, University of Massachusetts; Elsa Murano, Iowa State University; Anna Resurrecction, University of Georgia; Ralph Waniska, Texas A&M University; Fred Wolfe, University of Alberta, and Barbara Klien, University of Illinois—in organizing the symposium is gratefully acknowledged.

The symposium organizers thank David Lineback, 1992–93 IFT President, Daniel E. Weber, IFT Executive Director, John B. Klis, Director of Publications, Anna May Schenck, Associate Scientific Editor, and all the other IFT staffers for their support. Most of all, the Basic Symposium Committee members and the co-chairs gratefully acknowledge the contribution of the speakers. Without their dedication, expertise, and hard work, publication of these proceedings would not have been possible.

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Structure-Function Relationship of Food Proteins

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INTRODUCTION

Food preferences by human beings are often based on sensory attributes such as appearance, color, flavor, and texture. Proteins play several functional roles in the expression of sensory attributes of various foods. The curd-forming properties of casein micelles and soy proteins, the foaming, whipping, and heat-setting properties of egg white, the water-binding, emulsifying, and texture-forming behavior of meat proteins are important in many food products such as cheese, diary products, meat products, bakery, ice cream, etc. Traditionally, proteins of animal origin, e.g., milk, egg, and meat proteins, have been used in conventional and fabricated foods. The use of plant proteins, although cheap and abundant, in food products is very limited mainly because of lack of desirable functional performance of these proteins in foods. The major impediment to increasing the utilization of plant proteins in formulated foods is the lack of proper understanding of the molecular bases for protein functionality in foods.

The functional role of a protein that contributes to the sensory quality of the food product does not arise from a single physicochemical property, rather it is a manifestation of a complex interaction of multiple properties. For example, egg white possesses multiple functionalities, such as foaming, emulsification, heat setting, and binding/adhesion, which make it the most desirable protein in many food applications. Therefore, for a protein to perform well in a food system, it should possess multiple functionalities. This requirement further complicates proper understanding of the structure-function relationship of food proteins.

The important functional properties of proteins that are relevant to food systems are given in Table 1.1. These are fundamentally related to their physicochemical and structural properties, such as size, shape, amino acid composition/sequence, net charge, charge distribution, hydrophobicity/hydrophilicity ratio, secondary, tertiary, and quaternary structural arrangements, number of microdomain structures, and adaptability of domain structures or the structure of the whole molecule to changes in environmental conditions.

Many physicochemical properties that directly affect functional behavior of proteins are ultimately related to amino acid sequence. The amino acid sequence dictates the three-dimensional structure of a protein and thereby its thermodynamic stability, charge distribution pattern on the protein surface, symmetric or asymmetric distribution of hydrophilic and hydrophobic patches on the surface, and the topography of the protein surface. The folding of a protein is dictated by the thermodynamic requirement that a majority of the hydrophobic residues be buried inside and a majority of the hydrophilic and charged residues be located on the surface so that the global free energy of the molecule is at the lowest possible level. In most proteins, while almost all the hydrophilic and charged residues are located on the surface, not all hydrophobic residues are completely buried in the interior because of steric constraints imposed by the polypeptide chain. In many globular proteins, including several food proteins, about 40–50% of the protein surface is occupied by hydrophobic patches (Lee and Richards, 1971). The distribution pattern of these hydrophobic patches (cavities) influences the shape of the molecule as well as the topography of the protein surface. In food proteins, the mode of distribution of nonpolar and polar patches on the protein surface significantly influences several functional properties such as solubility, the tendency to form oligomeric and micellar structures, and surface-active properties. For instance, in α_s- and β-caseins all the serinephosphate residues and a majority of carboxyl groups are segregated at the N-terminal segment, and the remaining

TABLE 1.1 Functional Roles of Food Proteins in Food Systems

Function	Mechanism	Food system	Protein source
1. Solubility	Hydrophilicity	Beverages	Whey proteins
2. Viscosity	Water binding, hydrodynamic size, shape	Soups, gravies, salad dressing	
3. Water binding	H-bonding, ion hydration	Meat sausages, cakes, breads	Muscle proteins, egg proteins
4. Gelation	Water entrapment and immobilization, network formation	Meats, gels, cakes, bakeries, cheese	Muscle proteins, egg and milk proteins
5. Cohesion/ Adhesion	Hydrophobic, ionic and H-bonding	Meats, sausages, pasta, baked goods	Muscle proteins, egg proteins, whey proteins
6. Elasticity	Hydrophobic bonding, disulfide cross-links	Meats, bakery	Muscle proteins
7. Emulsification	Adsorption at interfaces, film formation	Sausages, bologna, soup, cakes, dressing	Muscle proteins, egg proteins, milk proteins
8. Foaming	Interfacial adsorption, film formation	Whipped toppings, ice cream, cakes, desserts	Egg proteins, milk protein
9. Fat and flavor binding	Hydrophobic bonding, entrapment	Simulated meats, bakery, doughnuts	Milk proteins, egg proteins

Source: Kinsella et al., 1985.

two thirds of the molecules are highly hydrophobic (Swaisgood, 1982). This asymmetric distribution of charged and hydrophobic residues in the amino acid sequence provides these caseins with detergent-like characteristics.

The solubility of a protein under a given set of conditions is the thermodynamic manifestation of the equilibrium between protein-protein and protein-solvent interactions. It is related to the net free energy change arising from interaction of hydrophobic and hydrophilic residues on the protein surface with the surrounding solvent. In other words, solubility is directly related to the physicochemical nature of the protein surface, which in turn is influenced by the folding pattern of the polypeptide chain. The degree of exposure of hydrophobic residues on the surface of a protein also influences its thermodynamic stability. Proteins that have higher amount of exposed hydrophobic surfaces are more susceptible to thermal and interfacial denaturation than those that have most of the hydrophobic residues buried in the interior.

The amino acid composition of proteins also has a bearing on several functional properties. Proteins that have high proline content tend to exist in a disordered state. For instance, about 17% of the amino residues in β-casein and about 8.5% of the residues in α_{s1}-casein are proline residues (Swaisgood, 1982). Similarly about 30% of the residues in gelatin are either proline or hydroxyproline residues. The uniform distribution of these residues in the amino acid sequence of these proteins effectively precludes formation of ordered structures, such as α-helix and β-sheet, in these proteins. Because of their high flexibility these proteins exhibit multiple functional properties such as gelation, foaming, and emulsifying properties.

In addition to the intrinsic molecular factors, several extrinsic factors such as the method of isolation, pH, ionic strength, the redox potential of the food system, and interactions with other food components also affect the functional properties of proteins (Kinsella et al., 1985). However, the effects of these extrinsic factors are simply manifestations of alterations in the conformation and other physicochemical properties of proteins.

In a phenomenological sense, the various functional properties of food proteins are manifestations of two molecular aspects of proteins (Damodaran, 1989): (1) protein surface–related properties and (2) hydrodynamic properties. The functional properties that are affected by these molecular aspects of proteins are listed in Table 1.2. The surface-related properties are governed by the hydrophobic, hydrophilic, and steric properties of the protein surface, and the properties related to hydrodynamic properties of proteins are governed by size, shape, and flexibility of proteins.