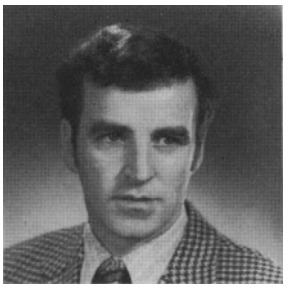

Functional Properties of Soy Proteins

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ABSTRACT

Soy protein ingredients must possess appropriate functional properties for food applications and consumer acceptability. These are the intrinsic physicochemical characteristics which afffect the behavior of protein in food systems during processing, manufacturing, storage and preparation, e.g., sorption, solubility, gelation, surfactancy, ligand-binding, and film formation. These properties reflect the composition and conformation of the proteins, their interactions with other food components, and they are affected by processing treatments and the environment. Because functional properties are influenced by the composition, structure and conformation of ingredient proteins, systematic elucidation of the physical properties of component protein is expedient for understanding the mechanism of particular functional traits. The composition and properties of the major components of soy proteins are summarized, and the functional properties of soy proteins of importance in current applications (e.g., hydration, gelation, emulsifying, foaming and flavor-binding characteristics) are briefly reviewed.

INTRODUCTION

Though most of the soy protein produced in the USA is used in animal feed, a growing volume (ca. 3-4%) is being used as a food ingredient. In 1976 ca. 320, 36 and 35 million kilograms of soy flour(s) concentrate and isolate were produced (1). These preparations are used in foods principally for their functional properties.

Both researchers and processors should have the detailed information on the methods of preparation and processing of soy products because these can affect the composition and functional properties of the component proteins. The methods of preparation of these products have been thoroughly described (2-6). In the preparation of soy flour, the desolventization-deodorization-toasting sequence can result in varying solubilities of the component proteins especially when moist heat is applied (2). A variety of soy flours possessing protein with a range of solubilities are produced commercially (2,4).

Soy concentrates (70% protein) are prepared from "low heat" undenatured, defatted soy flour by eluting soluble components (carbohydrates, ash, peptides, phytic acid) using acidic (pH 4.5); aqueous ethanol (70%), or hot water leaching agents (4). These treatments, depending upon conditions, improve flavor but may cause some denaturation of proteins then and consequently, commercial concentrates then may have variable functional properties.

Soy isolates are prepared from minimum heat-treated soy flour by dissolving the protein in dilute alkali (pH ~ 8.0), removing the insoluble materials by centrifugation (or filtration), and precipitation of the protein at pH 4.5. This isolelectric curd may be dried, or usually it is neutralized with sodium hydroxide (potassium, calcium may also be used) and spray dried (4). Commercial yields are around 35%, i.e., about 60% of the protein is recovered (5). The alkali proteinates are very soluble.

The extractability of proteins is influenced by numerous factors , e.g., particle size of flour, previous thermal history and age of meal, solvation, ratio, temperature, pH, and ionic strength of extractant (4,7). Flours subjected to moist heat, which rapidly denatures the proteins, show poor extractability (6). Generally water, dilute alkali (pH 8) or saline (0.5 M NaCl), a solvation ratio of 10:1 at temperatures of 25 to 30 C, represent normal extraction conditions for obtaining undenatured proteins from soy flour. The inclusion of thiol reagent (mercaptoethanol) in the extractant significantly increases yeild of protein. The thiols apparently cause depolymerization of disulfide-linked storage proteins rendering them more soluble in the solvent (6,7,8). An ultrafiltration system for the preparation of soy proteins with very high solubility indices was recently described (9).

Soy flours are used in a wide range of foods, particularly in bakery products and cereals. Concentrates because of their improved flavor, color and higher protein content can be used in greater quantities in many of the same foods, especially when higher levels of protein (nutrition, functionality) are required. Soy isolates are used in comminuted meats and dairy foods where emulsifying, thickening and gelling properties are of prime importance (2-6).

The typical composition of commercial soy preparations are summarized (Table I).

TABLE I

Typical Composition of Soy Protein Preparation

Component	Soy flours %	Concentrates %	Isolates %
Protein	56.0	72.0	96.0
Fat	1.0	1.0	0.1
Fiber	3.5	4.5	0.1
Ash	6.0	5.0	3.5
Carbohydrates	33.5	17.5	0.3

SOY PROTEINS

It is generally felt that the proteins are the principal functional components, though in soy flour the carbohydrates may play a role in water-binding, swelling and viscosity control. Because the functional properties are

TABLE II

Approximate Distribution of the Major Components of Soy Proteins

Fraction	Content	Principal components
2S	8	Trypsin inhibitor, Cytochrome
7S	35	Lipoxygenase, Amylase, Globulins
11S	52	Globulins
15S	5	Polymers

TABLE III

Effect of Heat on Some Physical Properties of Soy Protein

Property	Heating temperature (C)				
	80	100	120	140	160
Subunit structure	dissociation-unfolding			degradation	
Solubility	decrease - precipitation			increase in solubility	
Viscosity	increase—decrease			decrease	
Hydration	increase		decrease		
Gelation (following heating)	regular	hard-fragil		soft elastic	sol

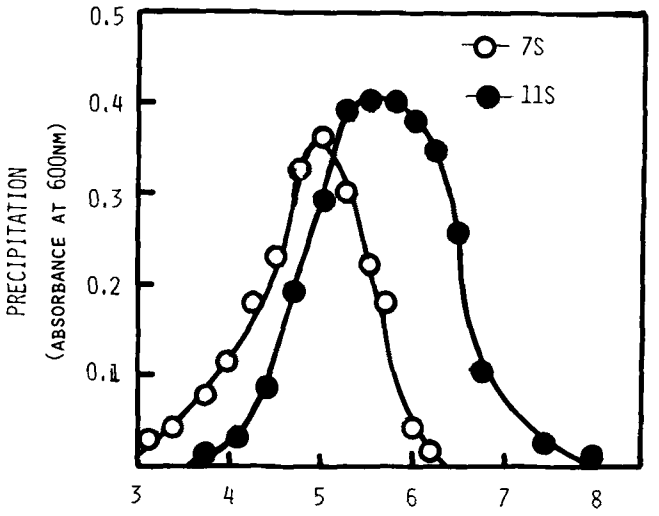

FIG. 1. The differential susceptibilities of 7S and 11S soy protein fractions to pH precipitation from solutions at low ionic strength (0.03 M). (12).

directly related to the physicochemical properties of the proteins, a detailed knowledge of the characteristics of soy proteins is essential for understanding and manipulating their properties in foods.

Approximately 90% of the proteins in soybeans, mostly globulins, exist as dehydrated storage proteins. The remaining proteins are composed of intracellular enzymes (lipoxygenase, urease, amylase), hemagglutinins, protein inhibitors and membrane lipoproteins. The protein precipitated at pH 4.5 traditionally has been called glycinin. However, numerous studies have shown that soy proteins are quite heterogeneous. The major components are classified according to their sedimentation properties (Table II).

The low molecular weight components, i.e.,2S are composed of trypsin inhibitors, cytochrome and some other globulins. The trypsin inhibitors are important in relation to the utilization of soy proteins from both a nutritional and functional standpoint. These must be thermally inactivated to facilitiate digestibility (10). Depending upon the intended application, this process may adversely affect functional properties of the proteins. The cytochromes are of potential importance because the heme components may catalyze lipid oxidation in foods, though there is no evidence of this in soy proteins.

The storage proteins, 7S (conglycinin) and 11S (glycinin), are the principal components of soy protein. The relative quantities of these proteins, according to literature data, vary widely. The discrepant data may be attributed to the association-dissociation properties of these proteins under different conditions. Some estimates indicate that glycinin accounts for 60-70% of the soybean globulins. Because of the different properties and physical behavior of these globulins, several methods have been used to prepare proteins enriched in 7S and 11S fractions which may have practical significance in food applications (11-14).

Enriched 11S fractions may be easily prepared from an aqueous extract of soy flour by cooling to 4 C. After 12 hr most of the 11S protein precipitates (11). Calcium also tends to precipitate preferentially the 11S fraction (6). A simple method based on differential solubility of 7S and 11S in calcium chloride solutions (5 - 12.5 mM) was used for the preparation of crude 7S and 11S proteins. At the higher level of calcium chloride, 7S protein was preferentially recovered (14,15). A simple method was developed for the preparation of 11S globulin by selective precipitation at pH 6.4 from a dilute Tris buffer (0.03 M, pH 8.0, low ionic strength, 0.07) extract of soy flour (12). The 7S protein was then precipitated from the pH 6.4 supernatant at pH 4.8. This method is based on the sensitivity of 11S protein to ionic strength in the isoelectric range. At ionic strengths below 0.03 M in Tris buffer, 11S shows minimum solubility around pH 6 where the 7S protein is quite soluble (Figure 1). This quite simple method can be scaled up as desired and may be used for isolation of these proteins on a commercial scale. Most of the current information on the composition and properties on these globulins is based on research preparations. The properties are briefly summarized because the behavior of these globulins determines the functional properties of soy concentrates and isolates.

The 7S fraction contains lipoxygenase, hemagglutinin and predominantly the 7S globulin (13,16). Catsimpoolas and Ekenstam (13) showed four components of which β and γ conglycinin were predominant. Thanh et al. (16) reported five fractions in 7S all of which appeared to be glycoproteins. These can undergo reversible dimerization (association-dissociation) in low and high ionic strength solutions.

The 7S fraction which dimerizes in low ionic strength solutions, i.e., ~ 85% of the total 7S protein, is globulin (conglycinin), while the nondimerizing components are hemagglutinins (12). The nondimerizing γ conclycinins (MW-104,000) represent 3% of total soy globulins, while β conglycinin (MW ~ 181,000) comprise 28% of the globulins (17). Both of these contain over 5% carbohydrate (mannose and n-acetylglucosamine) and account for over 90% of the 7S fraction.

On the basis of end-group analyses, it has been suggested that 7S had a quaternary structure of 9 subunits with an average molecular weight of 20,000 daltons (18-21). However, recently it has been shown that β conglycin exists as six isomeric molecular species each of which is composed of three discrete protein subunits (12). The 7S isomers have molecular weights ranging from 141,000 to 171,000 and carbohydrate contents from 4.0 to 5.2%. Each of the isomers is composed to different combinations of the subunits whose molecular weights ranged from 42,000 to

57,000. The separated conglycinin isomers differed in amino acid composition with the higher molecular weight species being more polar and hydrophilic. The subunits can be dissociated and denatured by urea, but reassociation and renaturation was obtained by dialysis. Thus, the 7S globulin is a quanternary trimeric protein in which the subunits are associated via hydrophobic and perhaps hydrogen bonding (12).

The 7S polypeptides are compactly folded, though considerable unstructured regions exist internally. The α helix, β-structure and random coil content of the secondary structure was 5, 35 and 60%, respectively (18). The extent of disulfide crosslinking of 7S polypeptides must be limited because there are only 2 to 3 cystine groups per mole of protein (6,19).

The true 7S globulins facilely dimerize to a 9S species upon reduction of ionic strength from 0.5 to 0.1 at pH 7.6 (20,21). At alkaline pH values (pH >10), the 7S dissociates and the polypeptides irreversibly unfold.

Glycinin, the 11S globulin located entirely in the protein bodies, is easily prepared by cryoprecipitation (22) or isoelectric precipitation from low ionic strength buffer (12). The solubility and extractability of 11S is enhanced in the presence of thiol reagents. This protein is rich in glutamine and asparagine residues and low in histidine, tryptophan, methionine and cysteine (6). Most of the basic and hydrophobic amino acids are internal (23-26). Many of the 20 disulfide groups in glycinin are buried internally and become accessible following unfolding and denaturation (27). Approximately two sulfhydryl groups are detected in glycinin; however, above pH 10.5 several thiol groups are formed by the scission of disulfide bonds by the hydroxyl anion (28,33). Simonet and Boulet (19) reported that 11S had 6 and 37 sulfhydryl and disulfide groups per mole of protein. Glycinin apparently contains no covalently bound carbohydrates (27).

The polypeptides in native glycinin are tightly folded and linked via disulfide bonds. They show a mostly disordered conformation with some β-structure (18). A range of molecular weights (from 320,000-363,000) have been reported by various 11S protein preparations (23-26). 11S is a quaternary structure composed of three acidic and three basic subunits of ca. 35,000 and 20,000 daltons, respectively (24-26). The isoelectric points of the basic subunits range between 8.0 and 8.5 and of the acidic subunits from 4.7-5.4 (29). This may account for the limited solubility of 11S globulins at low ionic strength, around pH 6.0.

Electron microscopy and x-ray light scattering studies support a model of 11S consisting of two apposed hexagonal-shaped rings each containing six alternating acidic and basic subunits (26). The two hexagonal subunits associate via electrostatic attraction and hydrogen bonds, whereas the links between the individual acid and basic subunits may also involve disulfide bonds because thiol reagents cause dissociation. Several factors, viz., ionic strength, pH, temperature, and solvents, affect the physical behavior of the 11S fractions.

At pH 7.5, 11S protein forms reversible association polymers when the ionic strength of solvent is reduced from 0.5 to 0.1. Conceivably this, like the 7S dimerization, is electrostatic in nature. However, further reduction in ionic strength (0.001) results in dissociation of 11S into 7S half molecules and ultimately causes unfolding of the polypeptides. Extremes of pH, urea, anionic detergents cause similar changes (6). Thus, variation in ionic strength of solvents may affect solubility of 11S globulin via association-dissociation phenomena; e.g., 11S shows greater solubility in 1.0 compared to 0.1 M sodium chloride. This is of practical significance since it can affect several functional properties, i.e., surface activity and emulgency. High ionic strength (0.5) significantly stabilizes 11S against heat disruption, in contrast to the 7S which is destabilized (30).

Urea-dissociated 11S globulins renature (in 70% yields) following dialysis. When mercaptoethanol is present, reassociation occurs, but the native structure is not reattained (31). Acidic conditions cause dissociation via electrostatic repulsion and subsequent unfolding. Exposure to pH 4.5 causes denaturation of portions of the 11S and 7S components to give an insoluble aggregate (6,7).

Properties of 7S and 11S

Alkali causes dissociation of glycinin and subsequent unfolding as a result of disulfide bond cleavage. This results in increased viscosity and eventual gelation (32,33). Sodium chloride (0.5 M) tends to protect the quaternary structure of the proteins against alkali denaturation. Alkali causes cleavage and unfolding of disulfide bonds of the subunits, and some disulfide bonds are changed to sulfhydryl and sulfenic acid residues. Alkali may also cause β-elimination from cysteine to form dehydroalanyl residues which in turn may interact with lysine to form lysinoalanine and result in some crosslinking. Because of their high content of disulfide groups, the 11S components are probably most affected by alkali (33).

Transparent gels can be obtained upon mixing of 2% alkaline dope of 7S and 11S with alcohols. The inclusion of sodium chloride and/or thiol reagent markedly increase viscosity, especially of the 7S. Under these conditions the 7S forms stronger gels than the 11S fraction (34).

Organic solvents, particularly aqueous mixtures of low molecular weight alcohols, rapidly denature soy globulins. Conceivably apolar moiety disrupts the internal hydrophobic region of the globulin subunits following weakening of the hydrogen-bonded segments by the polar aqueous phase (35).

Heating causes dissociation of 11S into subunits which slowly aggregate up to 70 C but rapidly thereafter, precipitate at 90 C (6). The basic subunits of 11S are most heat labile (26). Upon heating, 11S molecule is initially converted into soluble 4S fractions and insoluble aggregates (6). Heat-induced aggregation is accelerated in the presence of thiols which enhance the initial dissociation of subunits which in turn facilitate thermally induced unfolding and association of the uncoiled polypeptides. Prolonged heating above 100 C results in a subsequent increase in protein solubility due to dissociation and degradation of the polypeptides (6,14).

The 11S globulins are stabilized against thermal aggregation, up to 80 C, by high ionic strength solutions, whereas at low ionic strength aggregation occurs rapidly. On the contrary, the 7S globulins are more stable at low ionic strength, and aggregation is accelerated at high ionic strength (30).

The enthalpy of denaturation of soy proteins is maximum near pH 7.0 and minimum at extremes of pH, i.e., pH influences thermal denaturation (36). Salt stabilizes the globulins against heat denaturation. Increasing salt concentrations from 0.05 to 2.0 M increased the temperature of denaturation of 7S from 77 to 100 C and of 11S from 92 to 113 C at pH 7.0 (36). Apparently the salt stabilizes the quaternary globulins against dissociation and denaturation (37).

Changes in the physical properties of soy globulins upon heating (Table III) were summarized by Saio et al. (14). Soy proteins readily form gels following heating (38), but the 7S and 11S fractions differ in gelation behavior (15). Both fractions can form heat-induced gels or calcium-induced gels. The heat-induced gel of the 11S globulin showed higher tensile and shear strength and greater water-holding capacity than those obtained from the 7S globulin or soy isolate.

Continued studies on the physicochemical properties of

TABLE IV

Summary of Functional Properties of Soy Proteins Important in Food Applications[a]

Property	Functional criteria
Organoleptic/kinesthetic	Color, flavor, odor, texture, mouthfeel, smoothness, grittiness, turbidity
Hydration	Solubility, wettability, water absorption, swelling, thickening, gelling syneresis
Surface	Emulsification, foaming (aeration, whipping), protein-lipid, film formation, lipid-binding, flavor-binding
Structural Rheological	Elasticity, grittiness, cohesiveness, chewiness, viscosity, adhesion, network-crossbinding, aggregation, stickiness, gelation, dough formation, texturizability, fiber formation, extrudability
Other	Compatibility with additives, enzymatic antioxidant

[a]These properties vary with pH; temperature; protein concentration; protein fraction; prior treatment; ionic strength and dielectric constant of the medium. They are also affected by other treatments, interactions with other macromolecules in the medium, by processing treatments and modification, by physical, chemical, or enzymatic methods.

the 11S and 7S proteins are warranted because each displays different properties that may be exploited in food applications; e.g., the gels obtained from 11S fraction are cheese-like and are superior to that obtained from the 7S fraction. The basic subunits from the 11S proteins may be quite soluble in the pH range of acidic beverages and could represent a significant source of acid soluble proteins useful in beverages, mayonnaise and salad dressings.

Acid Sensitive Protein

Precipitation of soy proteins at pH 4.5 results in the formation of a protein complex that does not resolubilize (7,39). This acid sensitive protein is formed mostly from the 2S and 7S fractions. The quantity formed depends on duration of exposure to acidic conditions but may amount to 25-30% of soy protein (40). This protein complex is tan to brown in color and avidly binds nonprotein material, e.g., oxidizing lipids and off-flavors (41). The presence of acid sensitive protein in addition to imparting off-flavors limits the use of acid-precipitated soy proteins in beverages, coffee whiteners and beverages.

FUNCTIONAL PROPERTIES

As the world population expands, there will be a greater pressure for the direct consumption of plant products in foods possessing aesthetic and organoleptic appeal, e.g., simulated meats. This development will place great emphasis on the need for proteins with multiple functional properties. Ingredient proteins should have acceptable intrinsic properties, i.e., flavor, texture and color, good nutritional value and the requisite functional properties for the variety of intended applications (42,43). Functional properties of proteins connote those physicochemical properties which affect the behavior or proteins in food systems during preparation, processing, storage and consumption. Functional properties are not only important in determining the quality of the final product, but also in facilitating processing, e.g., improved machinability of cookie dough or slicing of processed meats.

The importance of each of these properties (Table IV) varies with the different uses, e.g., gelation in comminuted meats, emulsification in coffee creamers, and foaming in dessert toppings. In some applications a range of properties is required, e.g., solubility, clarity-turbidity, viscosity in beverages, while water-holding, emulsion stabilization and gellability are important in meats. While a single protein may not possess the desired range of functional properties, proteins are frequently heterogenous and therefore demonstrate a variety of functional properties as exemplified by soy proteins.

In current applications the functional properties of soy proteins represent the composite properties of the compo-

TABLE V

Functional Properties Performed by Soy Protein Preparations in Actual Food Systems[a]

Functional property	Mode of action	Food system	Preparation used
Solubility	Protein solvation, pH dependent	Beverages	F,C,1, H
Water absorption and binding	Hydrogen-bonding of HOH, entrapment of HOH, no drip	Meats, sausages, breads, cakes	F,C
Viscosity	Thickening, HOH binding	Soups, gravies	F,C,1
Gelation	Protein matrix formation and setting	Meats, curds, cheese	C,1
Cohesion-adhesion	Protein acts as adhesive material	Meats, sausages, baked goods, pasta products	F,C,1
Elasticity	Disulfide links in gels deformable	Meats, bakery	1
Emulsification	Formation and stabilization of fat emulsions	Sausages, bologna, soup, cakes	F,C,1
Fat adsorption	Binding of free fat	Meats, sausages, donuts	F,C,1
Flavor-binding	Adsorption, entrapment, release	Simulated meats, bakery	C,1,H
Foaming	Forms stable films to entrap gas	Whipped toppings, chiffon desserts, angel cakes	1,W,H
Color control	Bleaching of lipoxygenase	Breads	F

[a]F, C, I, H, W denote soy flour, concentrate, isolate, hydrolyzate and soy whey, respectively.

TABLE VI

Applications of Soy Flours Dependent upon Dispersibility of Protein Components (44)

Functional property	Dispersibility index
Active lipoxygenase for bleaching flour-bread. Soluble protein for maximum emulsifying, foaming, gelation.	>90
Functional ingredient in dough products (bread, donuts, macaroni, cookies) for water absorption.	60
Miscellaneous foods – waffles, gravies, soups, sausage, infant foods.	30
Crackers, beverages, cereals, extenders.	15

TABLE VII

Effects of Soy Flour in Bakery Products (44)

Absorption facilitates greater water incorporation.
Improves dough handling.
Improves machineability of cookie dough.
Improves moisture retention during baking.
Improves cake tenderness, crumb structure, texture.
Enhances rate of crust color development.
Retards fat adsorption by donuts.
Prolongs freshness and storage stability.
Reduces stickiness in macaroni.
Lipoxygenase results in whiter bread and improves flavor.
Improved nutritional quality.

nent proteins. Bakery products, comminuted processed meats and breakfast cereals are by far the most common items that are fortified with soy proteins (Table V). Occasionally in different products opposite effects may be desired; thus, in meat systems fat adsorption is desired whereas in donuts it is not (44,45).

Soy flours are widely used in bakery and cereal products (4). A range of heat-treated flours is available. The extent of heat treatment affects the solubility of the protein and also water absorption characteristics of soy flour, and this is related to their use in bakery products (Table VI). Soy flours with minimum heat treatments (PDI 80%) show high lipoxygenase activity, and are used at 0.5% to bleach flour and improve flavor of bread (4). These flours possess strong beany flavors which limit their use. Flours with PDI ~ 60% possess a milder flavor and are most commonly used (1-2% in bread, 10% in waffles, pancakes) where they markedly improve water-binding in these products (Table VII).

TABLE VIII

Functions of Soy Protein in Meat-based Products (44)

Improves uniform emulsion formation and stabilization.
Reduces cooking shrinkage and drip by entrapping-binding fats and water.
Prevents fat separation.
Enhances binding of meat particles without stickiness.
Improves moisture holding and mouthfeel.
Gelation improves firmness, pliability and texture.
Facilitates cleaner, smoother slicing.
May impart antioxidant effects.
Improves nutritional value.

In meat- and dairy-based products, solubility, water-binding, swelling, viscosity, gelation and surfactant properties are important properties of soy proteins. Comminuted meats (sausage, bologna, luncheon meats) tend to contain more fat than normal meat. Soy proteins are used to enhance and stabilize fat emulsion, improve viscosity, to impart texture upon gelation following cooking and to improve moisture retention and overall yields (Table VIII). Heat-treated soy flour is commonly used but is limited by poor flavor and mouthfeel (44,45). Various preparations of soy concentrate, i.e., toasted, alcohol and acid washed, with varying protein solubilities, may be also employed. To circumvent problems of texture, dryness and flavor associated with flours and concentrates when added above 10%, soy isolates are now being used in meat loaves, sausage-type products for their emulsion-stabilizing effects, gelation, moisture retention and improved effects on texture.

In addition to the physical functions performed by soy proteins, they may also perform biochemical and chemical actions, e.g., lipoxygenase activity and antioxidant properties. The lipoxygenase active, low heat flours are exploited for their bleaching effects in bread flours (4). Soy preparations possess antioxidant effects and stabilize lipids in formulated foods (46,47). The antioxidant properties of soy flour have been attributed to isoflavone glycosides, phospholipids, tocopherols, peptides, amino aicds, thiol compounds, and perhaps some aromatic amines. These are most concentrated in soy flour which possesses greater antioxidant properties than soy concentrate or isolate. Soy protein hydrolyzates show antioxidant activity, which is ascribed to free amino acids (46).

When developing proteins as replacements for traditional proteins in conventional foods, the functional properties and their behavior when subjected to processing must be determined, e.g., dispersibility, heat and storage stability, intrinsic organoleptic characteristics, ability to absorb-desorb desirable flavors, compatibility with other food

TABLE IX

Factors Governing the Functional Properties of Food Proteins

Intrinsic	Process treatments	Environmental factors-food system-components
	Heating	Water
	pH	Carbohydrates
Composition of protein(s)	Ionic strength	Lipids
Conformation of protein(s)	Reducing agents	Salts
Mono- or Multi-component	Storage conditions	Surfactants
Homogeneity-heterogeneity	Drying	Flavors
	Physical modification	O/R status
	Chemical modification	pH

components, etc. In addition, safety and nutritional criteria must be examined. In evaluating plant proteins, a systematic determination of functional properties is essential to assess how the protein behaves in specific food systems and if it can be used to substitute for other proteins. In this regard improved techniques for measuring functional properties are needed to determine and elucidate the functional properties of conventional proteins; to evaluate the characteristics, potential applications and limitations of new proteins; to assess methods and processes designed to improve functionality in proteins, and to monitor the effects of preparation, processing and environmental factors on functionality.

Structure and Function

Functional properties reflect the intrinsic physical attributes of the protein *per se* (composition, amino acid sequence, conformation and structure) as affected by interactions with food components (water, ions, proteins, lipids, carbohydrates, flavors) and the immediate environment, i.e., temperature, pH, and ionic strength (Table IX).

The physicochemical bases of functionality of food proteins are incompletely understood. This is the result of the traditional empirical testing approach, the lack of fundamental knowledge of the composition-structure of the proteins, the inadequacy of current methods used in testing functional properties, and the limited interest in correlating functions with protein structure. Knowledge of the fundamental properties of the proteins is essential for understanding the basis of functionality, for modifying proteins to acquire needed functionality, and for predicting potential applications.

The physical behavior of protein is determined by its amino acid composition, its molecular size, primary structure, the conformation of the protein, the charge distribution on the protein, the extent of inter- and intra- molecular bonding (quaternary structure), and the environment. Conformation affects functionality, e.g., in globular proteins the more polar-charged amino acids are oriented toward the surface. This facilitates hydration and solubility. Proteins which unfold rather easily at aqueous-lipid interfaces show good emulsifying properties; proteins composed of long, coiled polypeptides that are loosened and unfolded by heat can form gels.

The nature of the intramolecular forces responsible for molecular structure and their stability or lability under certain conditions (temperature, pH, ionic strength) as might prevail in a food system also govern observed functional properties. Hydrogen-bonding is important in the internal structure of proteins in α helix, β sheet structures. There is some controversy as to this importance in aqueous systems where water may compete with protein for available hydrogen bonds and thereby disrupt H-bonding between proteins (48).

Electrostatic interactions between charged groups probably play an important role in the structure of soy proteins, especially in aqueous systems. These are affected by salts and counterions; e.g., choride can swamp the charges on the protein and minimize electrostatic association. Hydrophobic interactions between component polypeptides are important forces stabilizing the native structure of soy proteins. These also are important in several functional properties, e.g., emulsification, foaming, and flavor-binding.

Covalent bonds, i.e., disulfide linkages, are of significance in the structure and functional behavior of soy proteins, particularly the 11S globulin subunits, e.g., in gel and fiber formation (28,32,33).

Noncovalent forces, i.e., hydrophobic interactions, hydrogen-bonding, electrostatic attractions, are involved in other protein-protein, protein ligand and protein-solvent interactions which influence the overall functional properties. The propensity to undergo conformational changes is an important attribute underlying some functional properties. Thus, for formation of stable foams, a soluble protein should facilely disassociate and unfold at an interface, or for gel formation, controlled unfolding of polypeptides and reassociation is necessary. In beverages stability against insolubilization is important.

In the following sections, some basic physical properties of soy proteins of importance to food applications are summarized.

SOLUBILITY

The commercial preparation of soy proteins causes physical and chemical changes that affect functional properties. The extent of these changes varies and consequently for food application(s) each preparation has to be evaluated for its functional properties. This is time-consuming and not always accurate; hence, most users rely on nitrogen solubility index (NSI) or protein dispersibility index (PDI) as a quick test of the functional properties of soy proteins (44). To obtain optimum functionality in uses where gelation, solubility, emulsifying activity, foaming and lipoxygenase activity are required, a highly soluble protein is required. Soluble protein preparations are also easier to incorporate into foods. Proteins with low solubility indices have limited functional properties and more limited uses. To meet solubility criteria, the sodium proteinate forms of soy proteins which have good solubility are available in isolates and some concentrate forms (4,44).

Soy flours with a range of solubilities are available depending upon their intended use (Table VI). Heat treatment, especially moist heat, rapidly insolubilizes soy proteins (4). However, heat treatment is necessary to desolventize, to inactivate antinutrient compounds and to improve the flavor of soy flours (6). Nonheated soy flours, while possessing high lipoxygenase activity, possess a bitter, beany flavor and therefore have limited applications (49). To compromise between enzyme activity, flavor quality and solubility criteria, processors now produce defatted soy flours with a range of solubilities (44). Concentrates and isolates are prepared from minimum heat-treated flours and generally possess good solubility; however, the extent and duration of treatments (i.e., isoelectric precipitation, drying) results in wide variations in functional properties of commercial preparations (4,7,44).

High solubility, while generally indicating low heat treatment and good functionality, may in some instances be misleading. Soy protein that has been heated above 120 C or exposed to alkali (pH 11) for some time may be very soluble, but functional properties may be impaired because of disaggregation and hydrolysis of the proteins (6,33). Therefore, in certain instances, confirmatory tests (e.g., digestibility, immunological properties, residual enzyme activity, enthalpy of denaturation [calorimetry]) may be informative.

Solubility data on soy proteins are plentiful, but their value is frequently limited because of incomplete descriptive data concerning samples, conditions of determination or nature (pH, ionic strength) of solvent used. Numerous factors affect apparent solubility of soy proteins, i.e., protein source, processing history, solvent composition and conditions (42,43,50).

Methods of preparation affect solubility of soy proteins, with heat treatment, especially moist heat (steam), being most significant. Heat applied to remove solvent, destroy antinutritive factors, inactivate enzymes, dry and volatilize bound off-flavors, all reduce solubility of soy protein, the extent depending upon the intensity and duration of the heat treatments.

The extractability, i.e., solubility of proteins, decreases during storage of flour (7). Acid precipitation causes the

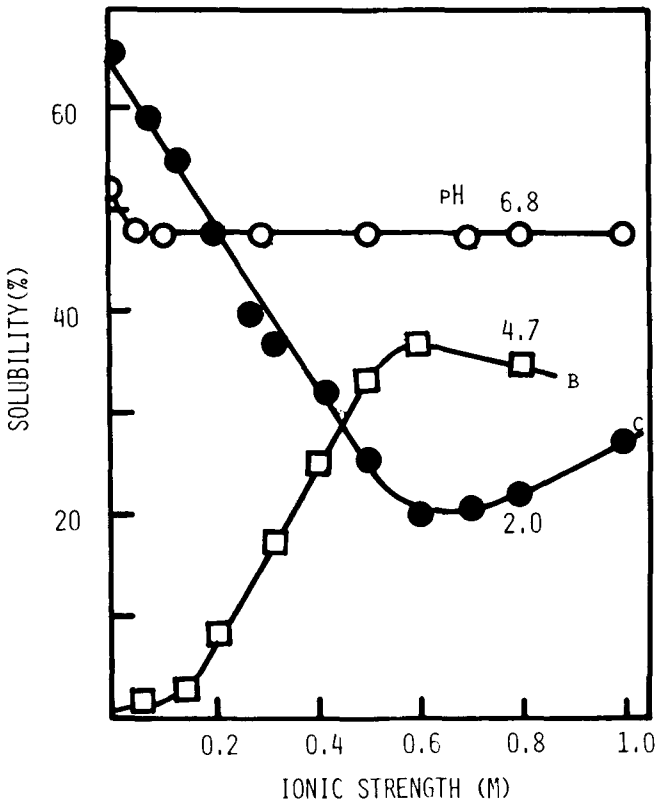

FIG. 2. The effect of changing ionic strength on solubility of soy protein isolate at different pH. (51).

insolubilization of significant quantities of soy globulins, particularly the 7S and 2S fractions (40,51). Because of differences in these treatments (heat, time, pH), commercial soy proteins demonstrate wide variations in solubilities (52). The phytates in soy flakes are water soluble. These can readily form complexes with cationic proteins, which predominate in the acidic pH range and cause insolubilization of the soy protein (53). Dialysis of alkali dispersions of soy isolate prior to precipitation improves solubility of acid-precipitated proteins (52); i.e., following dialysis the amount of acid insolubilized protein formed is significantly reduced. This may be caused by the removal of phytates during dialysis; however, dialysis may also cause dissociation of the soy proteins to yield lower molecular weight components which are very soluble (7).

Alkali treatment usually improves the solubility of soy proteins, particularly if the pH exceeds 10.5, by causing dissociation and disaggregation of the proteins (33). Disulfide bond-reducing agents, thiols (cysteine, mercaptoethanol), sodium bisulfite, by cleaving intermolecular bonds, cause disaggregation of proteins and enhance solubility (8). Hermansson (50) and Shen (51) showed that the solubilities of different soy isolates varied with source and that each was affected differently by conditions of determinations. The speed of blending or degree of agitation affected observed solubility. Equilibration times less than 45 minutes gave erroneous results because different preparations showed varying rates of hydration; usually 60 min. of hydration was adequate. There was little dependence of solubility on the initial protein concentration in the range 0.5 to 10%. Increasing temperatures in the range 25 to 60 C caused a small increase in solubility of the isolates. This increase varied with the preparation but rarely exceeded 10%. The centrifugal force used to remove particulate matter after equilibration affected observed solubility data with higher forces giving lower solubilities. Forces around 42,000 g for 20 min. at 25 C are adequate (50,51,54).

The pH and ionic strength of the aqueous solvent have the most significant effect on the solubility behavior of soy proteins. Native soy proteins show the classical aqueous pH-solubility profile at zero ionic strength with an isoelectric point around pH 4.5. The solubility of soy protein is greatly affected by ionic strength of the solvent (Fig. 2), and this effect is influenced by the prevailing pH (50,51). At pH 7 there is a slight depression in solubility at low ionic strengths but negligible effects above 0.1 M. Between pH 7 to 10, the solubility of isolates are progressively reduced with increasing ion concentration. At pH 6 there is a marked decrease in solubility at 0-0.25 NaCl, whereas above this concentration solubility is restored. In the pH range 4-5, sodium chloride (0.2 - 0.75 M) progressively increases the solubility of soy proteins (50,55,56). Calcium chloride at lower concentrations (0.1 - 0.2 M) has similar effects (56).

There is little analytical information explaining the mechanism of these ionic effects. Presumably they involve electrostatic, solvation, and salting in and salting out phenomena (50). The effect of sodium chloride may be due to the greater activity and binding capacity of the chloride ions. Chloride ions bind to the positively charged protein groups, especially in the acidic pH range, and enhance solubility by accentuating electrostatic repulsion. At low or zero ionic strength and pH values around neutrality, protein water interactions are greatest and solubility is maximum. Conceivably, dissociation of quaternary structures of 11S and 7S globulins facilitate solubility in this pH region.

Under appropriate conditions of pH and ion concentration, soy proteins form a coacervate, i.e., a protein-rich liquid phase which partitions from the protein-poor solvent phase (56). Salts at certain critical concentrations (sodium chloride ~0.55 M, calcium chloride <0.1 M) when added to soy proteins in pH range 4.0-5.0, result in the formation of two discrete liquid phases, a protein-poor, and a protein-rich phase, which may contain from 10-55% protein. The quantity of coacervate (mesophase) or partitioning protein-rich liquid phase obtained varies with pH, ion species, temperature, and initial protein concentration, but ion type and pH are major determinants of yield; e.g., sodium chloride 0.5 M, pH 4.5 gave maximum yields of coacervate (56). This peculiar behavior of soy protein has been exploited to fabricate fibers from soy protein coacervates by extruding them into hot water (57).

Beverages

While solubility is the most important criterion of soy protein intended for beverage, several other requirements must be fulfilled. Thus, the protein should form a clear or translucent solution that is bland, possess low viscosity, demonstrate stability over a range of pH, ionic strength, and temperature conditions, and be amenable to storage in liquid, concentrate, or powder form. In the latter case, facile redispersibility is essential. In the case of carbonated beverages, solubility of protein in the acidic range is necessary. Usually this is achieved by using protein hydrolyzates. However, the presence of bitter peptides is a problem with these hydrolyzates (58). The knowledge that certain salts, NaCl, $CaCl_2$, $MGCl_2$, can solubilize significant quantities of soy proteins at acidic pH might be exploited in the formulation of protein-rich carbonated beverages. Furthermore, recognition of the effects of ions on protein solubility is important, particularly if a beverage is intended to substitute for or supplement milk. Such beverages should provide calcium (3-mM) and magnesium (5 mM). At neutral pH these ions may depress solubility of the soy proteins (6).

HYDRATION PROPERTIES

The interactions of soy proteins with water are impor-

tant in relation to dispersibility, water absorption and binding, swelling, viscosity, gelation and surfactant properties. These properties directly influence the important functions of soy proteins in meat, bakery and beverage systems.

Ease of dispersibility or wettability is important in food formulations. Wettability of proteins is affected by surface polarity, topography, texture, and area, and by the size and microstructure of the protein particles, but not necessarily by the amount of native structure (59), though in the case of globular proteins it is. Temperature, ionic composition, pH and degree of agitation of the solvent are major factors affecting dispersibility (42). In some soy preparations, hydrophilic surfactants may be used to enhance aqueous dispersibility, e.g., coffee whiteners.

Water sorption and water-binding by soy proteins are extremely important in a variety of meats, bakery products and cheeses. The ability to imbibe and bind water is important during preparation of comminuted meats and baked goods. The capacity to retain moisture during cooking is important in meats, though in bakery products, (e.g., cookies) moisture release during baking is critical (44). The ability of soy protein to bind and retain meat juices enhances mouthfeel and flavor in beef patties and frankfurter type meat emulsions, while in bakery products it enhances shelf life (44,45).

When substituting for conventional proteins, soy proteins must in addition to other needed properties, have suitable water-binding capacities. The water-binding capacity of different proteins must be determined to facilitate adjustments in food formulations when interchanging protein sources. Some proteins with high water-binding capacities, when added to a formula, may imbibe a disproprotionate amount of water and dehydrate other components in food systems or vice versa. Hence, adjustments in water ratio may be necessary to obtain the required viscosity. When soy proteins are added to doughs, extra water must be added for proper development (44).

Water Sorption

In the food technology literature, the term water-binding connotes the water retained (bound and entrapped) by the protein after centrifugation, and water sorption defines water absorbed by dry protein after equilibration against water vapor of a known relative humidity (42,60). Hydrated proteins are surrounded by a "loose" hydration shell composed of several layers of water: viz., an innermost monolayer consisting of water (10 to 20 molecules H_2O per molecule of protein) tightly bound to specific sites on the protein molecule (i.e., absorbed water); another layer of water, more loosely bound, covering the immediate surface of the protein (i.e., adsorbed, hydrogen bonded, non-freezable water); and second, third, and additional layers of water with properties graduating to bulk water in physical properties (61).

Soy isolates, with solubilities of 40 and 22%, absorbed 20 and 19 g water/100 g protein when exposed to water vapor (84% relative humidity) (62). Hagenmaier (62) claimed that water-binding properties of soy protein could be accurately determined from measurement at one particular water activity. Detailed studies of water sorption by soy proteins were reported by Hermansson (60) and Hansen (63-65). Typical water sorption isotherms were obtained (Fig. 3) in which there was an initial rapid absorption up to water activity (Aw) 0.3, a slower water uptake up to Aw 0.7 and a final marked uptake up to Aw 1.0 (60). Overall soy isolates absorbed ca. 35 g water per 100 g. Prior heating of the soy isolate to 80 C and 100 C had little effect on sorption pattern, and temperatures between 5-25 C had little impact on sorption isotherms (60,63,65). The sorption isotherms for soy isolates reported by Hansen (64) were different in that between Aw 0.1 to 0.7, there was a linear

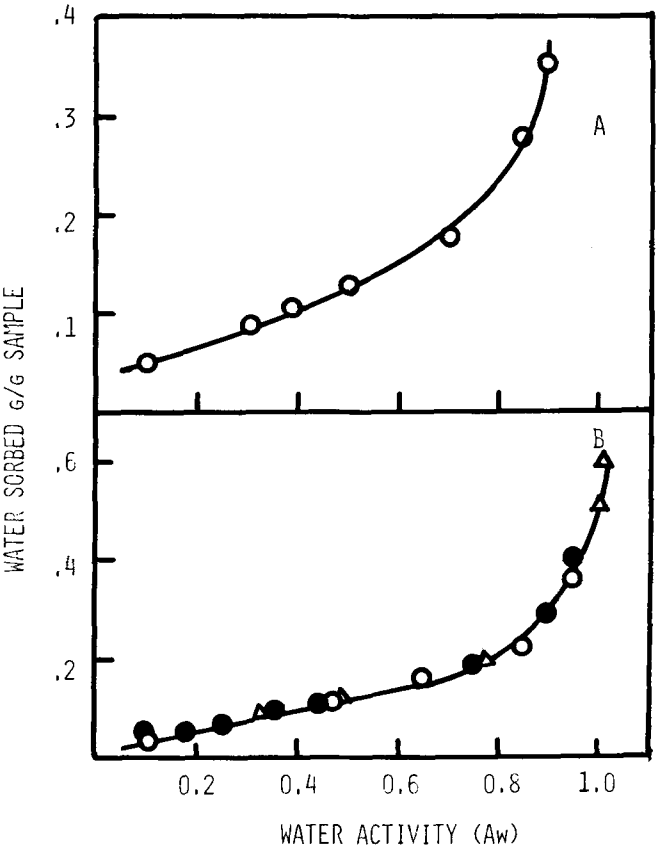

FIG. 3. Water vapor sorption isotherms for soy isolates: A-curve for soy isolate heated or unheated; B-for soy isolates (△,○) and soy concentrate (●).

uptake of water (from 0.03 to 0.12 g per g isolate). Above Aw 0.08 there was a rapid uptake of water to a final concentration of 0.4-0.6 g/g solids (Fig. 3).

Separate samples of commercial soy isolates and soy concentrate showed similar sorption isotherms, and the size of particles of soy isolate had negligible effects on the amount of water bound (64,65). The water-binding capacities of soy flours were not significantly affected by heating nor freezing treatments (66). Soy isolate bound 18.9, 19.2 and 21.6 g water per 100 g protein at pHs 4.5, 6.0 and 7.5, where protein solubilities were 5, 22 and 57%, respectively (62), indicating a slight affect of pH but the lack of a correlation between water-binding and protein solubility.

Hansen (64) observed three phases of water absorption by soy concentrate as a function of time. There was an initial, rapid linear rate of absorption for ca. 40 mins. This was directly influenced by Aw, e.g., absorption values of 0.03 and 0.07 (g water/g concentrate) were obtained at Aw of 0.79 and 0.98, respectively. The second phase of absorption, up to 100 min, was also influenced by Aw, and the final slower phase of sorption was strongly affected by water activity.

The amount of bound water, i.e., unfreezable water, increased with protein concentration of soy preparations (Figure 4), being greatest for soy isolate (65). Furthermore, the amount of truly bound water increased to 0.5 (g/g solids) as water content of soy isolate was increased to 3 g/g solids, whereas in the case of soy concentrate, the maximum content of bound water, ca. 0.25 (g/g solids) remained unaffected by water contents from 0.5 to 3.0 g/g concentrate. The amount of bound water in the soy isolate corresponded to the theoretical water-binding value of the component amino acids indicating complete occupation of binding sites (64). The reason for the greater binding by the isolate compared to the concentrate may have been due to the greater ease with which the isolate proteins swell,

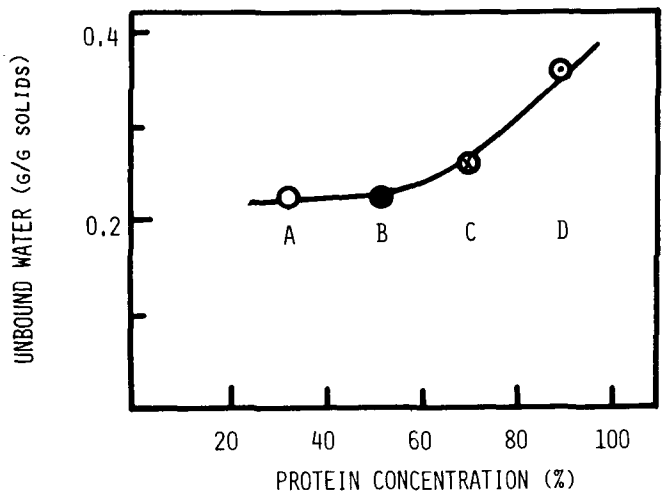

FIG. 4. Variation in water-binding capacities of different soy protein preparations as influenced by protein content. A-D denote carbohydrate enriched soy concentrate; soy flour, soy concentrate and soy isolate, respectively (64).

dissociate and unfold to expose additional binding sites, whereas the carbohydrates and other components of the concentrate may have impaired this. The alkali-acid treatment used in the preparation of the soy isolate may have some effect on this behavior.

During the initial stage of water absorption by soy proteins (up to 0.07 g water/g solids) (65) water occupies the high energy surface sites and binds to ionic sites on the polypeptides to give a highly structured monolayer. Additional absorption (up to 0.25 g water/g solids) beyond the monolayer represents water hydrogen bonded to polar groups on proteins and carbohydrates. This water displays varying degrees of mobility. This phase is accompanied by changes in strucuture-conformation of the protein and initial swelling of the protein matrix (65). The final phase involves absorption of loosely bound and free water into crevices and free spaces and is usually accompanied by swelling and partial solvation of the protein (60).

Water-Holding

In addition to water sorption, soy preparations possess water-holding capacities, i.e., the ability to physically hold water against gravity. This is related to viscosity of food systems and is influenced by pH, ionic strength and temperature. Soy flour, concentrate and isolate, 10% soy preparations after 10 min. slurrying, held 2.6, 2.75 and 6.25 g/g product, respectively (67). Sodium chloride (5%) enhanced water entrapment by soy flour but reduced it in the case of soy isolates. Lin et al. (68) showed that flour concentrates and isolates bound 1.3, 2.2 and 4.4 g water/g solids, i.e., water-holding capacity increased with protein concentration (Table III). There was no apparent correlation between solubility and water-holding capacity. Both temperature and pH affected water-binding by soy isolate (54). The maximum holding capacity, which occurred at pH 7 and between 35 and 55 C, was ca. 14 g water/g solids. Adjustment of pH from pH 5 to 7 caused a dramatic increase in water holding; e.g., at 30 C a sixfold increase occurred. Johnson (47) reported that soy flours with protein dispersibility indices (PDI) of 15, 55, 70 and 85% adsorbed 209, 307, 308 and 207 g water/g flour, respectively; i.e., heat treatment enhanced water-holding capacity.

Swelling

As soy proteins absorb water, they swell. Hermansson (69) has used swelling, the expansion of protein particles upon imbibition of water, as an index of water absorption.

TABLE X

Effect of Temperature on Some Functional Properties of Soy Isolate[a]

Temperature (C)	Solubility (%)	Swelling (ml/g)	Viscosity $15S^{-1}$
25	53	10	
70	67	17	3620
80	68	20	7490
90	71	17	5280
100	81	14	1410

[a]Measurements were made at 25 C after heat treatment.

Swelling is an important functional property in foods like processed meat, doughs and custards where the proteins should imbibe and hold water without dissolving and concurrently impart body, thickening and viscosity. Viscosity and swelling are closely related properties of real significance in processed meats (70).

Soy isolates spontaneously imbibe water and swell (Table X). A commercial soy isolate unheated and heated at 80 and 100 C for 30 min., with protein solubilities of 53, 15, and 24%, spontaneously imbibed 9.6, 20 and 15 ml of water/g of isolate, respectively, i.e., heating enhanced swelling (60). Soy isolate shows limited swelling; i.e., it can imbibe water and yield swollen particles without disintegrating at incipient solvation (69). Sodium chloride (0-0.4 M) significantly decreased (60%) the swelling ability of soy isolate. Swelling increased with increasing pH, i.e., two-fold between pH 5 and pH 9 where loosening of the protein matrix occurs. Prior gelation and drying of soy protein enhances swelling performance. This observation could be exploited in preparing soy proteins for meat systems.

A close relationship was observed between swelling ability and viscosity of soy isolate (69), and factors which affected swelling also influenced viscosity, i.e., protein concentration, pH and temperature positively affected swelling and viscosity, whereas sodium chloride depressed both.

Viscosity

Knowledge of the viscosity and flow properties of protein dispersions are of practical significance in product formulation, processing texture control and mouthfeel properties and in elucidating protein-protein interactions and conditions affecting conformational and hydrodynamic properties. Viscosity can be used to evaluate the thickening power of soy proteins which are of practical interest in fluid foods (soups, beverages, batters) and in comminuted meats. The viscosity of protein dispersions is mostly influenced by the hydrodynamic properties of the component protein(s), i.e., molecular weight, size, axial ratio, hydration and frictional ratio and shape of the molecule. These are influenced by temperature, pH, ionic strength and processing treatments insofar as they affect molecular conformation, structure, aggregation state, hydration and swellings.

The intrinsic viscosity of soluble sodium proteinate (pH 7.0, 25 C) is 4.8-5.5 cm^3/g (52) reflecting native globular state of the protein. Denaturation increases viscosity of soy isolate to 22.0 cm^2/g. Alkali treatment of soy protein causes partial denaturation and unfolding with an increase in viscosity to 14.1 cm^3/g. Dialysis of alkali-extracted soy flakes prior to acid precipitation caused extensive unfolding and viscosity increase presumably due to extensive dissociation of the 7S and 11S globulins (52).

Rheological properties of aqueous dispersions of soy globulins are influenced by several factors: shear rates, protein concentration, heat treatment, pH and ionic strength (71,72).

The apparent viscosity is affected by the size of dispersed particles (or protein aggregates), and this is in-

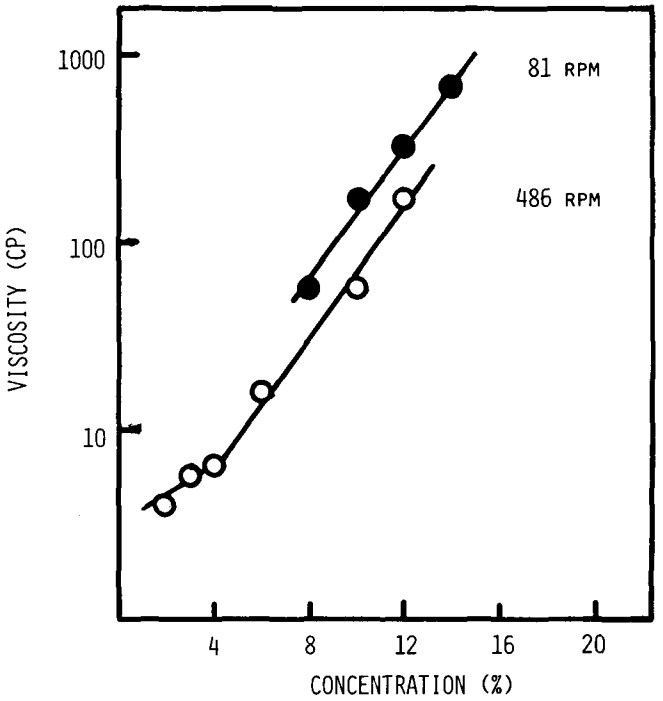

FIG. 5. Effect of protein concentration and shear rate on viscosity of soy protein isolate (69).

fluenced by shear rates (Figure 5). Increasing the shear rate of soy isolate dispersions (5%) reduced the size of the particles and shear stress (apparent viscosity). Low shear rates resulted in larger particle size or greater interactions which gave higher apparent viscosities for soy isolate (69,73,74). Dispersions of soy proteins demonstrate thixotropic behavior (38,73,74).

Generally, on an equivalent protein basis, the apparent viscosity of soy isolates are much higher than soy concentrate (Table XI) at corresponding pH and temperatures, though commercial preparations of both show wide disparities (67,68).

Apparent viscosity of soy isolates increases exponentially with protein concentration (38, 67,71, 75), and this is affected by the swelling ability of the particular protein preparation. Processing, alkaline-acid, and heat treatments enhance swelling and increase the viscosity of soy dispersions (67,73).

Temperature positively affects viscosity of soy dispersion (72). Rha (74) observed little increase in intrinsic viscosity of soy isolate upon heating up to 80 C; above this viscosity if increased rapidly to 90 C. These data were different from those of Hermansson (69) who observed a continuous graduate increase in viscosity up to 85 C but further heating above 90 C resulted in diminished viscosity (Table X). Presumably temperatures up to 80 C cause dissociation and unfolding with a concomitant increase in molecular axial ratios and hydrodynamic volume which increase viscosity. The effects of temperature and temperature of maximum apparent viscosity varied with pH of the soy isolate dispersion being maximum around pH 6-8 (71), where protein structure was most stable.

Viscosity increases with pH from 5 to 10.5; above pH 11 it dramatically drops because of disaggregation of the soy proteins (38). However, Shemer et al. (8) noted a decrease in the viscosity of soy isolate, prepared with sodium sulfite, between pH 4.5 and pH 6. Hutton and Campbell (54) showed that whereas the viscosity of soy concentrate increased, that of soy isolate decreased with increasing pH. The observed effect of pH was governed by the temperature; e.g., at 50 C the viscosity of soy isolate dispersion at pH 6 was greater than that at pH 7, whereas above 60 C this was reversed (71).

TABLE XI

Variation in Viscosity of Soy Protein Preparations with Protein Concentration (67)

	Apparent viscosity (centipoise)			
	Protein concentration			
Soy product	5	10	15	20
Flour	---	25	230	2,000
Concentrate	10	200	330	28,300
Isolate A	160	10,500	> 83,000	> 83,000
Isolate B	1,300	3,200	7,500	25,000

Sodium chloride by stabilizing the quaternary structures decreases the apparent viscosity of soy isolate dispersions (38, 67,70). This may be a practical advantage because it facilitates the mixing of ingredients in particular applications. Catsimpoolas and Meyer (70) reported anomalous effects of ionic strength on the viscosity of soy dispersions. The fact that high ionic strength tends to reduce the dissociation of 11S globulins may partly explain the observed decrease viscosity (30).

Calcium aids the formation of thickened suspensions of soy protein. At 10 mM it caused a rapid increase in viscosity of soy protein dispersions (5%), from 15 to 1500 CP; above this concentration the viscosity decreased (75). Heating of the protein dispersion to 70-80 C prior to addition of calcium enhanced the viscosity 7x further. Higher protein concentrations required higher levels of calcium for this effect and a ratio of 20-40 M Ca^{+}/mole protein was best for obtaining maximum viscosity in a fluid dispersion (75).

GELATION

Protein gels are composed of three-dimensional matrices or networks of intertwined, partially associated polypeptides, in which water is entrapped. Gels are characterized by a relatively high viscosity, plasticity, and elasticity. The ability of protein to form gels and provide a structural soy matrix for holding water, flavors, sugars, and food ingredients is useful in food applications, and in new product development, it provides an added dimension to protein functionality. This property is important in comminuted sausage products and is the basis of many Oriental textured foods, e.g., tofu.

Dispersions of soy protein form true gels upon heating and cooling (38), and upon dialysis following alkali treatment at pH >11.0 (33,34). Gel-like curds (tofu) are formed by the calcium-induced coagulation of heated soy protein dispersion, e.g., soy milk. Gelation in contrast to coagulation (random aggregation) denotes a more ordered reassociation of unfolded polypeptides. In the case of soy proteins, initial heating, above 60 C is necessary to induce dissociation of the quaternary globulins causing unfolding of polypeptides of the protein subunits, with an increase in viscosity (38,69,71). This represents the irreversible sol to progel transformation (71). Because of the high temperature coefficients of this denaturation, the viscosity of soy proteins increases exponentially as temperature is increased. Upon cooling, the unfolded polypeptides reassociate via hydrophobic associations, hydrogen bonding, ionic interactions, and possibly some disulphide linkages, to form gel (14,71).

Circle et al. (38) established the basic factors affecting soy protein gelation subsequently corroborated (8,14,34, 71,76,77). Thus the method of preparation of protein, its concentration, rate, temperature and duration of heating, cooling conditions, the presence of salts, thiols, sulfite, and/or lipids all influence the properties of the gels formed. Soy isolates form firm, tough, hard resilient gels whereas,

TABLE XII

Thermal Expansion Following Heating at 125 C of Calcium-Precipitated Gels (TOFU) Composed of 7S, 11S, and Soy Isolate (15)

	Average expansion ratio		
	7S	11S	Soy isolate
pH 6.7	2.46	2.69	3.26
pH 7.3	2.74	4.27	3.36
pH 8.0	3.14	5.70	5.11
pH 8.4	2.66	4.72	4.46

soy preparations with less than 70% protein tend to form soft fragile gels like tofu (76). A minimum protein concentration of 8% is required for gelation (71). The protein concentration increased the temperature required to attain maximum viscosity; e.g., increasing protein from 8 to 16% increased temperature for maximum gelation from 75 to 100 C (38). The firmness of the gels increased with protein concentration.

The rates of heating and cooling can be manipulated to control the physical structure and properties of the resultant gel. Catsimpoolas and Meyer (71) showed that gels could be obtained after heating at 60 C; however, at lower temperatures of heating, longer periods of heating are required and weaker gels are obtained than those obtained following high heat treatment. For 10% dispersions heating to attain a minimum viscosity of 200 poises is required for subsequent gelation (71). Excessive heating (>100 C) of soy protein preparations which causes destruction of secondary and tertiary structures impairs gelation. Soy gels can be melted by heating, and if reheating is not excessive (>100 C), depending upon protein concentration, gels reform upon cooling (71).

The pH of protein dispersions, particularly outside the range pH 6-8, affects the heating requirements by facilitating unfolding (71).

Salt affected gel formation; it reduced the viscosity of isolate dispersions at particular temperatures and increased the temperature required to induce gelation. This may be because sodium chloride stabilizes the 11S globulins (30). Circle et al. (38) reported that salt increased gel strength, whereas other studies (71,73) indicated that it decreased the viscosity of gels.

Disulfide-cleaving agents (sulfite, mercaptoethanol, cysteine) impair gelation, but this effect is concentration dependent (71); i.e., low concentrations impair, while higher concentrations apparently enhance gelation. The effect of sulfite and thiols is adduced as evidence for the involvement of disulfide bonds in gelation (77). The inclusion of lipid materials enhanced gelation of soy proteins (38,71), and this is consonant with hydrophobic interactions.

Soy protein gels show thixotropic behavior, and the extent of this increased with the pregelation heating temperature (71). The inclusion of sodium sulfite in the extraction solvent yielded soy protein isolates which formed gels with twice the strength and firmness of gels prepared from conventional isolates (8). These gels reportedly could serve as functional substitutes for egg white in applications where thermal gelation was required.

Gels formed from 11S globulins are firmer but more resilient than those formed from 7S globulins (15,30). The differential susceptibility of the 11S and 7S globulins to thermal denaturation, especially in the presence of varying salt concentrations (30), may be exploited to prepare gels with different physical characteristics. Tofu or soybean curd represents the calcium- (10-40 mM) induced coagulum obtained from heated soy milk or soy protein dispersion. This is composed of 6, 88, and 3% protein, water and lipid, respectively. When tofu is deep fried, the curd swells, coagulates, and acquires a porous elastic matrix, which as "aburage," is a food item in Japan (78). In studying individual soy proteins, Saio et al. (15) found that gels formed following autoclaving of tofu curds made from 11S globulins showed the greatest expansion and possessed a soft elastic texture, while 7S proteins did not expand to the same degree and yielded hard, inelastic gels (Table XII). Apparently disulfide bonds play a role in the formation and expansion of calcium gels, and thus the 11S fraction formed superior gels.

PROTEIN LIPID INTERACTION(S)

Many important properties of foods involve the interaction(s) of proteins and lipids, e.g., emulsions, fat entrapment in meats, flavor absorption. Natural or chemically formed lipoprotein complexes are functional components of egg yolk, meats, milk, coffee whiteners, dough, and cake batters. Therefore, the capacity of soy protein to interact with lipid materials is important in food formulation and processing.

Kamat (79) reported that native soy proteins interact to a negligible extent with lecithin; however, following dissociation of soy proteins into small subunits (possibly unfolded polypeptides), lipoprotein formation occurs upon sonication with phospholipids, and triglycerides can subsequently be involved in the formation of these complexes. Lipoproteins of denatured soy proteins with polar lipids may have use as emulsifiers in cake mixes and conceivably as substitutes for egg yolk in some applications.

The films formed upon heating soy milk, i.e., yuba, are lipid-protein complexes which, when dried and flavored, have a desirably flaky texture (80). Janes and Chou (81) devised a "semi-automated" method for making soy milk film from isoelectric precipitate proteins by heating thin films. These are probably formed by protein-protein interactions or the air-water surface and conceivably result from surface denaturation and disulfide crosslinking of these proteins.

Fat absorption by soy preparations is closely related to protein content and is little affected by pH or temperature (54,68) (Table XIII).

Emulsification

The ability of protein to aid the formation and stabilization of emulsions is critical for many applications in

TABLE XIII

Some Functional Capacities of Different Soy Protein Preparations (68)

Soy preparation	Solubility (%)	Water-holding (%)	Fat absorption (%)	Emulsification capacity (%)
Flour	21	130	84	18
Concentrate A	2.3	227	133	3
Concentrate B	6.0	196	92	19
Isolate C	17.4	447	154	25
Isolate D	71.1	416	119	22

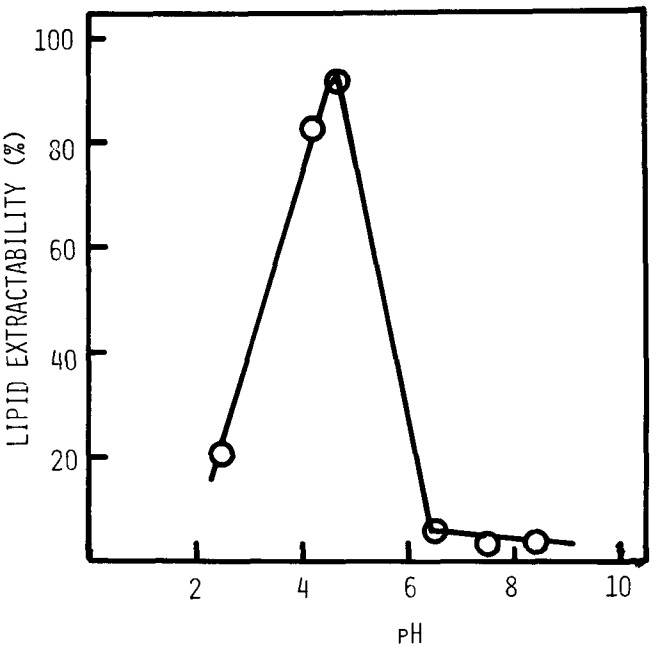

FIG. 6. Stability of a soy isolate-based emulsion as a function of pH as indicated by extractability of lipids in ether. (79).

chopped, comminuted meats, cake batters, coffee whiteners, milks, mayonnaise, salad dressings, and frozen desserts. In these products varying emulsifying and stabilizing capacities are required because of the differing composition and stresses to which these products are subjected (Table XIV).

Emulsions of fats and water are thermodynamically unstable because of the positive free energy caused by interfacial tension. Stabilization of emulsified droplets is achieved by formation of a charged layer around the fat globules causing mutual repulsion and/or by the formation of a membrane of film around the droplets by solutes, e.g., protein, which lowers interfacial energy and physically prevents droplet coalescence. This latter effect may be further enhanced by a hydration layer around the interfacial material.

The surfactancy of proteins is related to their ability to lower the interfacial tension between water and oil (emulsion) or water and air (foam). The surface activity is a function of the ease with which protein can migrate to, adsorb at, unfold, and rearrange at an interface (82). Therefore, solubility in the aqueous phase, i.e., native structure, is closely correlated with surface activity of the proteins (42,59,83).

In aqueous solution proteins are folded in a thermodynamically stable conformation in which polar segments are exposed to the aqueous phase. In oil-water systems, dispersed proteins tend to diffuse to the interface. The altered environment at the interface shifts the conformational equilibrium, and unfolding of the protein occurs, exposing hydrophobic segments of the polypeptides to the lipid interface and polar ionic segments to the aqueous phase. This sequence involves protein denaturation, the extent depending upon the flexibility of the protein, the stability of its native conformation (i.e., extensively intermolecular disulfide bonds would tend to retard unfolding), and conditions (temperature, pH, and ion effects) prevailing in the medium (84-86).

The kinetics of protein adsorption and reduction of interfacial tension sequentially involves diffusion of the protein to the interface, unfolding and spreading of absorbed molecules accompanied by intermolecular association. This may be followed by molecular rearrangements and packing of these molecules within the interfacial

TABLE XIV

Typical Stresses on Food Emulsions Containing Soy Proteins

Emulsion products	Emulsion stresses
Sausage, meats, bologna	Thermal
Cake batters	Thermal
Coffee whiteners, milks	Thermal, freezing-thawing
Mayonnaise, salad dressings	Low pH
Frozen desserts	Freezing-thawing

membrane due to the progressive accretion of additional molecules (84). The kinetics of film formation is very much influenced by the composition-conformation of the protein, viscosity of the protein, dispersion, pH, ions, temperature and inergy input, i.e., mechanical processing (84). In simple oil-aqueous protein systems, the diffusion of the protein to the interface may be rate limiting (84), whereas in very viscous systems (e.g., meat emulsion) physical factors impede mobility, and intensity of mixing is important.

In model systems the attainment of equilibrium surface tension by protein macromoles is diffusion dependent, being influenced by concentration and mobility of the molecules, surface charge (pH, salts) ease of unfolding, and facility for packing at the interface. Proteins with high molecular flexibility, i.e., ease of unfolding, show high surface activity, because facile unfolding exposes hydrophobic regions which enhance interfacial film formation (86).

Soy proteins progressively reduce interfacial tension as concentration is increased (84). Because of their molecular size, the soy globulins diffuse relatively slowly, but once at the interface, they initially spread easily, though subsequent penetration of newly arriving molecules into the film may slow further spreading (84). Soy proteins diffuse more slowly in aqueous than in saline dispersions, though in the latter, larger globulin aggregates may be present. Salt may reduce charge repulsion between the proteins and enhance hydrophilic associations at the interface.

The net charge at the interface may impede or facilitate emulsifying activity of proteins. Proteins near their isoelectric points (IpH) should perform well because protein adsorption and viscoelasticity at an oil-water interface is maximum near or at isoelectric pH (79). Also, the protein is soluble and not strongly repelled. Hence, one would expect maximum emulsifying properties near IpH. Furthermore, around neutrality the basic components of the 11S globulins have low net charges so that once dissociated they should have effective emulsion properties in pH range 6-7.5. However, Kamat et al. (79) and Frazen and Kinsella (91) reported that soy protein-stabilized emulsions upon heating were most unstable in the isoelectric pH range (Figure 6). They concluded that as net charge was near minimum in this pH range, the protein may have aggregated and destabilized the interfacial membrane.

While correlations between classical surfactant properties and emulsion behavior are positive, in food systems these fundamental properties of proteins are overridden by the mechanical processes used to make emulsions. During emulsion formation the interfacial material must be able to rapidly migrate to the newly formed lipid droplet, absorb at the interface, and form an effective barrier against lipid coalescence. Hence, mobility in aqueous phase and facility for spreading at the interface is very important. These processes are achieved by the shearing, turbulence, cavitation and mixing applied to food systems during emulsion formation, and are perhaps not so dependent on the properties of the native proteins as observed in model systems. Formation and stability of protein-based food emulsions depends very much on energy input (84,87).

Several workers have measured the emulsion capacity

TABLE XV

Factors Affecting Foaming Properties of Proteins

Stabilizing Factors
1. Surface Viscosity: denaturation and association of proteins.
2. Concentration: solubility, diffusion rate, concentration in disperse phase.
3. Electrical double layer: repulsion affected by counter ions in solution.
4. pH: theoretically maximum near isoelectric pH.
5. Complementary Surfactants: – other proteins, polysaccharides (not lipids).
6. Denaturants: limited denaturation may aid film formation.
7. Marangoni Effect: ability of surfactant solute to rapidly concentrate at a stress point in the film.

and stability of soy proteins. During the initial stages of emulsification, soy proteins rapidly adsorb as multilayers to lipid droplets, but as the droplet size and oil surface area increases with the progress of emulsification, the thickness of the protein layer diminishes (84). Soy isolates show a greater (six-fold) emulsifying capacity compared to soy protein concentrate (Table XIII) (54), though others showed that the disparity varied with preparation (8,68). Several factors effect emulsion formation and stability. While emulsion capacity (g oil emulsified/g protein) decreases with protein concentration, emulsion stability significantly increases (68, 87-89). In practical applications where there usually is an excess of protein, this latter criterion is the more important. The method of protein preparation also affects formation and stability of emulsions (8).

Many workers have shown a close relationship between emulsifying properties and solubility of soy preparations (87,90). This is more important in low viscosity emulsions (milk, salad dressing, coffee whitener) than in viscous emulsions, i.e., comminuted meats where soy proteins with 50% solubility ensure adequate emulsifying capacity and the thermal stability in preventing fat separation.

The pH and ionic strength of the aqueous dispersion affect emulsification (42). Alkaline conditions were optimum and at pH 7 emulsifying capacities of 5 and 3.5 ml oil/mg soy protein were obtained at ionic strengths of 0.05 and 0.03, respectively (89). Poor emulsions were obtained in the pH range of 5.3 -5.6 encountered in frankfurter-sausage meats. Both pH and temperature affected the emulsifying properties of soy isolate and soy concentrate, having a much greater effect on the former (54). Increasing the pH from 5 to 7 increased emulsifying capacity, but increasing temperatures above 50 C, at pH 7, decreased it. Chemical modification, i.e., succinylation, significantly enhances the emulsifying properties of soy proteins (91).

In general, the process and equipment used in making food emulsions, particularly very viscous emulsions, exert a major influence on the properties of the emulsion (84,87).

In fluid emulsions that are heated during processing and where retention of fluidity and emulsion stability are necessary without gelation, a protein of molecular size adequate for stabilizing emulsion but too small to form an extensive network for gel formation is needed. Rham et al. (92) reported that polypeptides obtained following pancreatic proteolysis of soy proteins effectively stabilized such emulsions.

In chopped meats fat absorption is important. Usually soy protein preparations with low nitrogen solubilities have highest fat absorbing capacities, whereas for emulsion formation and stabilization protein solubility is desired. However, where maximum emulsifying capacity of the protein is not needed and where thermal thickening and gelation occurs, initial solubility may not be too critical because stable emulsions can be formed with adequate energy input.

TABLE XVI

Foam Formation and Stability of Soy Protein Preparations[a] (68)

	Volume increase %	Volume (ml/6g) after time (min)				
		1	10	30	60	120
Flour	70	160	131	108	61	20
Concentrate A	170	400	28	13	8	5
Concentrate B	135	370	265	142	30	24
Isolate C	235	670	620	572	545	532
Isolate D	230	660	603	564	535	515

[a]Solubility index, Flour-D, 21, 2, 6, 17, 71, respectively.

FOAMING

Foaming, the capacity of proteins to form stable foams with gas by forming impervious protein films, is an important property in cakes (angel, sponge), souffles, whipped toppings, fudges, etc. Protein foams consist of gas droplets encapsulated by a liquid film containing soluble (initially) surfactant protein. This lowers interfacial tension between gas and water, facilitating deformation of the liquid and expansion against its surface tension. Proteins for foaming should be soluble in the aqueous phase; they should concentrate at the interface, unfold to form cohesive layers of protein around air droplets as they are formed, and possess sufficient viscosity and mechanical strength to prevent rupture and coalescence. These protein films must be stable, and the component polypeptides must exhibit a balance between their ability to engage in intermolecular cohesion required to form a membrane and the tendency to self-associate excessively which would result in foam instability. For foaming, soy protein must reduce the surface tension of the dispersed liquid, diffuse to and undergo conformational change at the interface with some unfolding and denaturation facilitating the association of the polypeptides, which then can form a continuous cohesive film around the air vacuoles. The surface denaturation facilitates protein interaction. Some common factors affecting foam stability are listed in Table XV.

Horiuchi et al. (93) related foam stability to surface hydrophobicity or hydrophobic regions in a protein molecule. This implies that the protein facilely locates at the interface and resists migration back into the water phase, hence the molecules are more concentrated at the interface, and as a consequence the foam is more stable. Partial proteolysis or heating (70-80C) improved the foaming properties of soy protein (93). These treatments may increase the tendency of the polypeptides to unfold at the interface and facilitate hydrophobic associations, thereby increasing film thickness and viscosity, reducing air leakage and enhancing stability.

Soy preparations exhibit foaming properties (Table XVI) and isolates are superior to flours or concentrates (67,68). However, the presence of lipid materials in soy preparations are very detrimental to foaming because they destabilize the protein films. Thus, hexane and aqueous alcohol treatment of soy proteins which remove neutral and bound polar lipids, respectively, markedly enhance foaming properties (90,94). Glabe et al. (95) showed that an aqueous extract of alcohol-washed defatted soy flour had good whipping properties. Treatment of commercial soy preparations with aqueous alcohol significantly improved their foaming properties (94).

The whipping properties of an aqueous alcohol-extracted soy isolate were studied by Eldridge et al. (94). Heating of soy protein dispersions was necessary to obtain maximum foam expansion (FE) and foam stability (FS), and 75 to 80 C was optimum. Both FE and FS improved with protein concentration up to 3% (Figure 7). Maximum FE and FS were obtained at pH 2 and pH 9 with minima occurring between pH 4 - 6, i.e., at the point of minimum solubility. Excessive whipping resulted in foam breakdown, and

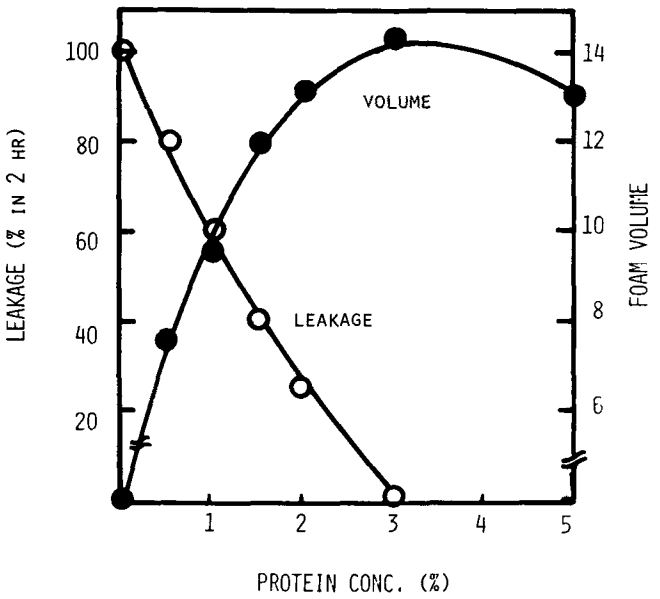

FIG. 7. Effect of soy protein concentration on foam expansion and foam stability (94).

sodium chloride depressed foaming.

Solubility of soy protein is closely correlated with foaming, and a strong relationship exists between foam expansion and foam stability. Stability was related to denaturation (90).

Modification of soy protein improves its foaming properties. Extraction of soy flour at pH 5 yielded a material composed of soluble proteins, carbohydrates and salts that had excellent whipping properties and could substitute for egg whites in meringues, divinity candy and souffles (96). Peptic hydrolyzates of soy proteins have excellent whipping properties and are commercially available for use in confections, fudges, meringues (97,98). Several whipping-foaming proteins derived from soy are commercially available for controlled aeration of semisolid food systems, e.g., frozen desserts. These improve texture, smoothness, viscosity and overrun. Succinylation markedly improved the foaming properties, volume and stability of soy proteins (91).

The use of reagents, e.g., sulfite or thiol, to allow limited rupture of intrapeptide disulfide bonds might facilitate unfolding and interfacial film formation, and Horiuchi et al. (93) have reported that mercaptoethanol improved the stability of soy protein foams.

PROTEINS AND FLAVORS

Proteins affect the sensory properties, i.e., appearance, color, flavor, taste and texture of foods. These are key attributes that determine consumer acceptance. The flavor of soy proteins and their interactions with both desirable and undesirable flavors is extremely critical and determines the acceptability of foods containing soy preparations, and thus the application of soy proteins.

The contribution of proteins to food flavors must be recognized. While proteins *per se* have no intrinsic flavor, they may modify flavor by their differing capacities to bind flavors and off-flavors, to generate flavors on cooking, and to release reactants that may produce flavors, especially following hydrolysis or proteolysis. These are important factors to be considered in fabricating foods from soy proteins.

Maga (99) evaluated the sensory and flavor attributes of several soy proteins. Quist and von Sydow (100) isolated numerous flavor compounds (carbonyls, furans, sulfides) following the heating of soy proteins to determine the role of proteins in flavors-off-flavors of food products.

TABLE XVII

Major Compounds Associated with Beany Off-flavor in Soy Proteins

Alcohols:	Isopentanol, hexanol, heptanol, octenol
Aldehydes:	Hexanol, heptenal, hexenal, decadienal
Ketones:	Hexanone, ethyl vinyl ketone
Phenols:	4-vinylguaiacol: 4-vinylphenol
Furans:	2-pentyl furan

TABLE XVIII

Amount of Flavors Bound (Nondistillable) to Soy Proteins (105)

Amount added (ppm)	Amount bound to soy protein (ppm)			
	Hexanal		Hexanol	
	Native	Denatured	Native	Denatured
50	0.6	4.8	0.5	4.2
100	1.0	7.0	0.9	6.0
200	1.2	10.2	1.1	9.0

TABLE XIX

Binding of Volatile Flavors by Soy Protein (106)

Concentration (mg/100 ml)		Amount retained or bound	
		%	mg/g Protein
Heptanal	1	70	0.1
	2	75	0.3
	5	72	0.7
	10	66	1.4
	50	69	7.0
Nonanone	2	60	0.2
	5	64	0.6
	10	58	1.2
	20	58	2.4

The most difficult problem limiting the expanded use of soy proteins is the strong "beany," grassy, and bitter flavors associated with these products. When soy meal is prepared, it has a bitter, astringent or grassy, beany flavor (101). These off-flavors may be contaminants of the protein *per se*, or they may be generated during subsequent processing and storage of the formulated food (Table XVII).

The phenolic acids (syringic, vanillic, ferulic, gentisic, chlorogenic) possess flavors that are bitter and sour. These in conjunction with the aliphatic alcohols and carbonyls may be significant components of the astringent-beany flavor.

When soy flavor is heated, a cooked off-flavor that is repulsive develops (102). Two compounds that have been identified as the main contributors to this off-flavor are 4-vinyl phenol and 4-vinyl guaiacol, which are derived from the corresponding cinnamic acids by decarboxylation. Following extraction with polar solvents, soy flour does not develop these cooked off-flavors (102).

Many off-flavor compounds in soy proteins (flour, concentrate) originate via enzymatic (lipoxygenase) or chemical oxidation of the lipid components (101). Though present at a few parts per million, these off-flavors adhere to proteins and may persist in products through processing (103). Sessa and Rackis (103) reviewed the formation and role of lipid-derived flavors in soy products and suggested that 2-pentyl furan, 3-cis-hexenal and ethyl-vinyl-ketone are the key off-flavor compounds of "beany" soy flour. These are formed from the lipohydroperoxides generated by lipoxygenase. The various aldehydes, ketones, alcohols, furans thus formed bind to soy proteins which possess a high affinity for these compounds (103-108).

These off-flavors remain bound during processing, and, in fact, processes which cause denaturation (Table XVIII)

enhance the binding capacity of soy isolate (105). Anderson and Warner (41) reported that the acid sensitive protein seemed to selectively bind the compounds responsible for beany off-flavor. It is possible however that the binding of these flavors to the soy protein may contribute to the loss in solubility, because we have observed that the binding of carbonyls to protein causes precipitation.

Several treatments have been tested for minimizing off-flavors in soybean products, i.e., heat treatment to inactivate lipoxygenase and minimize lipid oxidation; presoaking of beans in weak alkali followed by aqueous ethanol extraction, and distillation or steaming to eliminate the flavors from starting materials (4,101,109).

Moist heat rapidly inactivates lipoxygenase and volatilizes off-flavors, but this treatment may destroy functional properties. However, controlled heat treatment is the more common procedure. Wet milling or soaking of beans in aqueous ethanol reduced lipoxygenase significantly (60%) and improved flavor, but solubility was reduced 50% (109). Combinations of solvent extraction and toasting improves the flavor of soy flours and concentrates (110). Enzymatic treatment, i.e., proteolysis followed by solvent washing, is effective in removing bound flavors (111). This, however, may generate hydrophobic peptides which possess a bitter taste and cause other problems (112). Another approach involves the addition of desirable flavors which mask the impact of undesirable flavors; e.g., Haas (113) described the use of soy protein up to 30% in breakfast cereal. The problem of flavor was minimized by incorporating yeast and malt to mask the beany-bitter flavor of the soy.

The addition of flavors may not have the desired effect because of interactions between flavors and the soy proteins. The marked affinity of soy proteins for many flavor compounds influence the perceived flavor (106). When used as ingredients in foods, or when exclusively used in manufacture of simulated foods, a critical attribute of soy proteins is their capacity to be acceptably flavored. The binding of flavors by soy proteins, the uneven retention of flavors during processing treatments and storage, the preferential release (or retention) of some components of a flavor blend during mastication are problems confronting the manufacture of fabricated foods from soy proteins. The flavorist-technologist must know if there is selective absorption or entrapment of specific components, if some of the essential flavor notes are masked, and if during storage, processing or cooking a disproportionate amount of a particular flavored chemical is chemically altered or inactivated.

Soy proteins avidly bind flavor compounds (Table XIX) (104-108). Once bound, the flavors are not perceptable, though upon mastication some are probably released. Binding of flavors increases with their concentration, and it is significantly enhanced by denaturation of the soy proteins (105). Hydrophobic bonding is the major binding force (108). The binding affinity for aldehydes, particularly unsaturated species, and ketones increases with their molecular size and the reversibility, (i.e., release), varied being lowest for aldehydes (106). Because the flavor of bound aldehydes is masked, large amounts may have to be added to saturate binding sites and achieve the desired flavor in formulated foods. This is costly, and research is needed to determine more efficient methods for controlling the flavor and flavoring of soy proteins.

MODIFICATION

The functional properties of soy proteins can be manipulated by modification via enzymatic, chemical or texturization procedures (114). Proteolytic hydrolysates are commonly made to improve solubility for beverages, to enhance foaming properties in conjunction with egg white, and as aerating agents in confections (115). The acylation of the ϵ-amino groups of lysine residues, particularly with succinyl groups, markedly enhances several functional properties of soy protein (91,116). Thus wettability, solubility, emulsifying and foaming properties of succinylated proteins were superior to those of unmodified proteins.

TESTING IN MODEL SYSTEMS

The broad range of functional properties, the heterogeneous composition of proteins, their variability with refining and processing treatments, and the diversity of foods in which soy proteins can be used render the task of evaluating the functional behavior and potential of novel proteins extemely onerous and time-consuming. Therefore, many tests are made using simplified model systems that are arbitrarily devised to simulate more complex food systems. Model systems should be designed to provide general information indicative of broad functional properties, e.g., solubility, gelability, and surfactancy, and the derived information then can be used to guide further studies in food systems. Model systems are necessary and useful, and several researchers have used them with good results (87,117,118). Hermansson and Akesson (117) showed that solubility, swelling, viscosity and gelling characteristics of soy protein in model meat systems correlated quite favorably with control of moisture loss in meats; however, Lauck (119) questioned the relationship between observed viscosity and moisture loss upon cooking of comminuted meat systems. Smith (120) concluded that emulsion behavior of proteins in model systems did not correlate with their required performance in cooked frankfurters. After a comprehensive study of solubility, hydration, emulsion capacity, thickening and viscosity of soy protein in model systems and in a food item requiring these properties, Hutton and Campbell (54) concluded that it could be misleading to extrapolate findings from model systems to actual food systems. Model systems generally do not reproduce the conditions, i.e., pH, ionic strength, temperature treatments, processing, mixing, multiple components, chemical and physical interactions, concentration effects, mechanical storage treatment, etc., as may occur in the actual food system. Despite these limitations, simple, rapid diagnostic if not predictive tests, are necessary for the screening of the functional properties of the various protein components and their derivatives.

In addition to testing, the intrinsic functional properties model and/or food systems should provide information on the compatability of soy proteins with other components, e.g., lipids, starch, proteins, flavors. Soy protein should not impair the functional qualities of the other proteins in the system nor reduce the organoleptic (or nutritional) quality of the food. In breads addition of soy protein is limited by its dilution of the gluten proteins in addition to its associated flavor problems; in meat systems it is limited by its effects on texture, mouthfeel and flavor. Soy-wheat flour blends develop off-flavors, and following storage, yield bread showing reduced loaf volume (121). However, spaghetti up to 15% soy isolate was added without adverse effects on physical and/or organoleptic qualities (122).

GENERAL OBSERVATION

Soy proteins have made an impact in the food industry; however, commercial success has not been commensurate with the volume of literature on the properties and potential of soy proteins. This may be attributable to the conservative tastes of the consumer and reflect the fact that the functional attributes of soy protein preparations are quite variable, and the organoleptic properties have been less than desirable. To achieve its potential as a food ingredient, the organoleptic and functional properties of soy protein

preparations must be determined in detail, and protein preparations with reliable, standard, specific functional properties must be prepared for particular applications. It is desirable to understand the composition and properties of soy protein components and have a detailed understanding of the physicochemical basis of particular functional properties in order to facilitate the simulation of traditional food items and provide the range and variety of foods that would be acceptable to consumers in different parts of the world.

A basic knowledge of the physicochemical properties of food proteins, i.e., interactions that affect texture or color, and an understanding of the multiple factors affecting the ultimate quality of foods are phenomena that the food scientist must master to fabricate an acceptable food product. While soy proteins are considered as substitutes for existing protein ingredients, they should also be viewed as the vital functional components that will enable the food technologist to simulate exotic foods and fabricate new foods.

In the context of the world protein situation, when attempting to provide acceptable protein-rich foods to the malnourished, technological problems are often overshadowed by sociological, psychological and economic factors. However, extensive fundamental knowledge, which can provide the solution to technological problems, should go a long way toward overcoming the sociological, psychological, and economic challenges facing the successful introduction of soy protein foods.

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