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Functional Properties of a Soy Isolate and a Soy Concentrate in Simple Systems as Related to Performance in a Food System

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I am submitting herewith a dissertation written by Cheryl Whetstone Hutton entitled "Functional Properties of a Soy Isolate and a Soy Concentrate in Simple Systems as Related to Performance in a Food System." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Food Science and Technology.

Ada Marie Campbell, Major Professor

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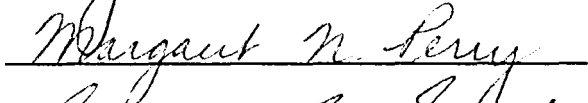

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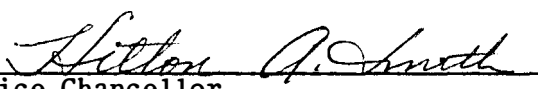
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Ada Marie Campbell, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:


Vice Chancellor
Graduate Studies and Research

FUNCTIONAL PROPERTIES OF A SOY ISOLATE AND A SOY
CONCENTRATE IN SIMPLE SYSTEMS AS RELATED TO
PERFORMANCE IN A FOOD SYSTEM

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee

Cheryl Whetstone Hutton

August 1975

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C.W.H.

ABSTRACT

Two commercial soy protein products, Promine-D (a soy isolate) and Promosoy-100 (a soy concentrate), with protein contents on a moisture-free basis of approximately 97 and 72% respectively, were studied. Part A of the study was an investigation of protein solubility, hydration capacity, emulsion properties, fat absorptivity, and thickening function of the soy products in simple systems at pH levels of 5.0, 6.0, and 7.0 and at temperatures of 4°, ambient (22-25°), and 90°C. The soy products were compared on both equal sample weight and equal protein bases. Part B involved evaluation of the functional performance of the soy products, compared on an equal protein basis, in food system base products and dips formulated from the base products. Base products prepared at pH 5.0 and 6.0 and held at 4 and 90°C were evaluated for emulsion stability and apparent viscosity. Dips were held and evaluated at 4° by a consumer panel for viscosity, mouthfeel, oiliness, flavor, and general acceptability. The findings of Part A were related to those of B to evaluate the degree to which the simple system measurements could predict functional performance of the soy protein products in the food system selected.

The isolate (P-D) was more soluble than the concentrate (P-100) at all pH-temperature combinations. Solubility of both soys generally increased as the pH of the dispersion increased. Solubility of P-D increased as temperature increased from 4°C to ambient, whereas the

response of P-100 depended on the basis of comparison, sample weight or protein. Solubility increased for both P-D and P-100 as the temperature was increased from ambient to 90°C. Hydration capacity, expressed as percent water absorption, generally paralleled solubility.

P-D, the isolate, was a more effective emulsifier than P-100. The soy products differed in their overall response to pH and temperature. Generalization is complicated further by a strong interdependence of pH and temperature effects and by the dependence of P-100's emulsifying performance on its use on the equal sample weight or equal protein basis relative to P-D.

Percent fat absorption of P-D was greater than that of P-100 at pH 7.0 at all temperatures studied. Maximum fat absorption of P-D occurred at ambient temperature, whereas that of P-100 occurred at 4°C. The fat absorption response of P-100 to temperature depended on its use on the equal sample weight or equal protein basis relative to P-D.

P-D and P-100 were compared as to dispersion viscosity only on the equal protein basis. P-D dispersions exhibited greater apparent viscosity than did P-100 dispersions at all pH-temperature combinations. P-D dispersions decreased and P-100 dispersions increased in apparent viscosity as the pH increased from 5.0 to 7.0. For both soys the apparent viscosity was minimal at ambient temperature and increased slightly at 4° and dramatically at 90°C.

Of the measurements made on simple systems, emulsion stability and viscosity were applicable to the base products used for dips. In addition, the consumer panel evaluated the dips from the standpoint of

oiliness and viscosity, as well as smoothness, which is closely related to solubility.

All base product emulsions were stable when held at 4°C. P-D products were unstable at 90°C, particularly at pH 5.0, whereas P-100 products were stable. The consumer panel rated dips made with P-100 as more oily than those made with P-D, but the dips presented to the panel had been held only at 4°C.

Contrary to the results with simple systems, P-D base products were less viscous than corresponding P-100 products. Similarly to the results with simple systems, apparent viscosity of P-D base products decreased with increased pH; on the other hand, apparent viscosity of P-100 base products increased with increased pH. Apparent viscosity of base products made with both soys was higher at 90° than at 4°C; this response paralleled the temperature response of both soys in simple systems. The consumer panel rated both P-D and P-100 dips as more viscous at pH 5.0 than at 6.0.

Mouthfeel, representing smoothness of the dispersion, was rated higher at pH 6.0 than at 5.0. This response paralleled the solubility results for simple systems. The panel preferred the flavor of dips prepared at pH 5.0. They also gave these dips higher overall acceptability ratings than those prepared at pH 6.0.

Many interactions were observed throughout the study. In addition, simple and complex systems sometimes differed in their response to variations in pH and temperature. Therefore, extreme caution is needed in extrapolation of results from simple systems to food systems.

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CHAPTER I

INTRODUCTION

Animal proteins derived from the meat, poultry and egg, dairy and fishing industries are the most common sources of high protein foods for man (Circle and Smith, 1972; Gutcho, 1973). Unfortunately, animal proteins are most expensive and most scarce (Goldsmith, 1973). The steadily increasing cost of animal proteins has compelled the consumer and the food industry to look for new, more economical sources of additional protein. The most promising sources of additional protein for food consumption are nuts and edible oilseeds, including soybeans, cottonseed, groundnut (peanut), sesame, and chickpea (Bressani and Elias, 1968; Martinez et al., 1971).

At present in the United States, the least expensive and most readily available high quality vegetable proteins are the soybean and its derivatives (Circle and Smith, 1972). Whole soybeans are used only in small quantities in the United States. However, soy protein derivatives such as soy grits, flours, concentrates, and isolates are used frequently as food ingredients (Wolf and Cowan, 1971). Except for some consumer-ready textured foods (meat analogs), soy protein products have little appeal in themselves but for the most part are sold in the form of unflavored dry powders, grits, granules, or chunks (Circle and Smith, 1972). Processed soy protein products can be grouped into three categories based on their protein

contents—soy flours and grits, soy concentrates, and soy isolates. Soy flours and grits contain approximately 50-55% protein (De, 1965). With extended processing to remove the soluble carbohydrates, the soy concentrates with protein contents of not less than 70% on a dry weight basis become available. Soy isolates with protein contents of 90+% are the most refined forms of soy protein (Wolf and Cowan, 1971).

With the recent interest in the food uses of edible soy protein products, the desirability of quantitative information on the functional properties of these products has become apparent (Circle et al., 1964). Findings concerning functional properties provide information as to how the protein will perform in a food system (Hermansson, 1973). The desirability of having simple physical or chemical tests that could be used to predict how soy proteins will perform in food systems has occurred to several workers (Catsimpoolas and Meyer, 1970, 1971a,b; Circle et al., 1964; Hermansson, 1972; Inklaar and Fortuin, 1969; Lin, et al., 1974). Mattil (1971) reported solubility profiles for various plant and animal proteins in a variety of pH and ionic environments. Emulsifying and emulsion stabilization performance of two isolates, a soy concentrate, and sodium caseinate were compared in model systems by Inklaar and Fortuin (1969). They reported that the findings of the simple system test agreed with observations in the sausage industry. Thickening and gelation phenomena of soy proteins were studied by Catsimpoolas and Meyer (1970, 1971a,b) and Circle et al. (1964). Lin et al. (1974) compared protein solubility, water absorption, fat absorption, emulsification, and whippability of soy

and sunflower products. All of the functional properties described by Lin et al. were evaluated on an as-is pH basis and without measuring the effects of manipulation, heating, or the presence of added ingredients. Further research is needed to define the functional properties of soy proteins and to assess the effects of various processing and formulation variables.

Some empirical functionality tests have been devised for use in simple systems. However, these tests could yield misleading information as to how the soy proteins would perform in food systems; functional properties in simple systems and performance in food systems have not been studied in relation to each other and under varying pH and temperature conditions. Therefore, it seemed feasible to undertake a systematic investigation of selected physical and chemical properties in simple systems and to relate these findings to function and performance in a food system. The objectives of this study were:

- (1) to evaluate protein solubility, hydration capacity, emulsion properties, fat absorptivity, and thickening function of a soy isolate and a soy concentrate in simple systems at specified pH and temperature levels;
- (2) to evaluate the functional performance of the soy isolate and the soy concentrate in a food system.

CHAPTER II

REVIEW OF LITERATURE

I. SOY PROTEIN FORMS USED IN FOODS

Soy protein forms used in foods consist of two groups—whole soybeans and processed soybean products. Whole soybeans are used only in small quantities in the United States. The largest use of whole soybeans in the preparation of foods is in the Orient (Wolf and Cowan, 1971). Processed protein products used as food ingredients in the United States can be classified by protein content as soy flours and grits, protein concentrates, and protein isolates (Alden, 1975; Wolf and Cowan, 1971).

The soybean on a fresh weight basis contains 30-46% protein. When the oil and crude fibers are removed to produce flours and grits, the protein content is increased to 50-55% (De, 1965). The major difference among flours and grits is particle size. However, they also vary in fat content and extent of heat treatment. Grits are obtained by coarse grinding and screening while flours are prepared by fine grinding (Wolf and Cowan, 1971). Soy flours and grits are available as ingredients in a variety of particle sizes and forms, including the defatted, low-fat, high-fat, and lecithinated products (Lockmiller, 1973; Meyer, 1971). The extended processing that results in soy concentrates makes possible minimum protein concentrations of 70% on a moisture-free basis; in addition, most of the unwanted flavors are

removed. Soy concentrates are produced commercially by three processes that differ in the means used to immobilize the major protein fraction of the defatted flakes or flours. The three processes are (1) aqueous alcohol leach, (2) dilute acid leach (pH 4.5), and (3) moist heat denaturation and water leach (Meyer, 1971). The end-products of all three processes are similar in gross compositional characteristics but vary in physical properties. The comparative characteristics of the soy concentrates derived from the three processes are listed in Table 1 (Rakosky, 1974).

Table 1—Comparative characteristics of various soy protein concentrate products (Rakosky, 1974)

Characteristic	Ethanol extracted	Isoelectric wash	Heat denaturation and water extracted
Moisture-free protein (%)	70 ^a	70 ^a	70 ^a
Water-soluble protein (%)	5-10	25-35	5
Sodium content	Low	Moderate	Low
Flatus factor	Low	Low	Low
Color	Light tan	Tan	Dark tan
Flavor	Very bland	Bland	Nutty

^aMinimum

The most refined forms of soy protein are the isolates. They are processed one step further than the concentrates by removal of the water-insoluble polysaccharides as well as the water-soluble sugars, ash, and other minor constituents (Wolf and Cowan, 1971). Isolated soy

protein has been defined as a product containing not less than 90% protein ($N \times 6.25$) on a moisture-free basis (Meyer, 1971). Edible soy protein isolates are produced by extracting defatted flakes or flour with water or dilute alkali (pH 7.0-9.0). The extract then is separated from the insoluble residue and the protein in the extract is precipitated with food grade acid. The resulting curd is washed and spray dried in the isoelectric form, or the curd is neutralized before spray drying to produce the proteinate form (Rakosky, 1974). The proteinates usually are preferred because they are water dispersible and therefore easier to incorporate into food products. Sodium proteinates are the major form of soy isolates sold, but potassium and calcium proteinates also are available (Wolf and Cowan, 1971). Figure 1 is a diagram showing the general steps in commercial isolation of soy proteins, as presented by Wolf (1969).

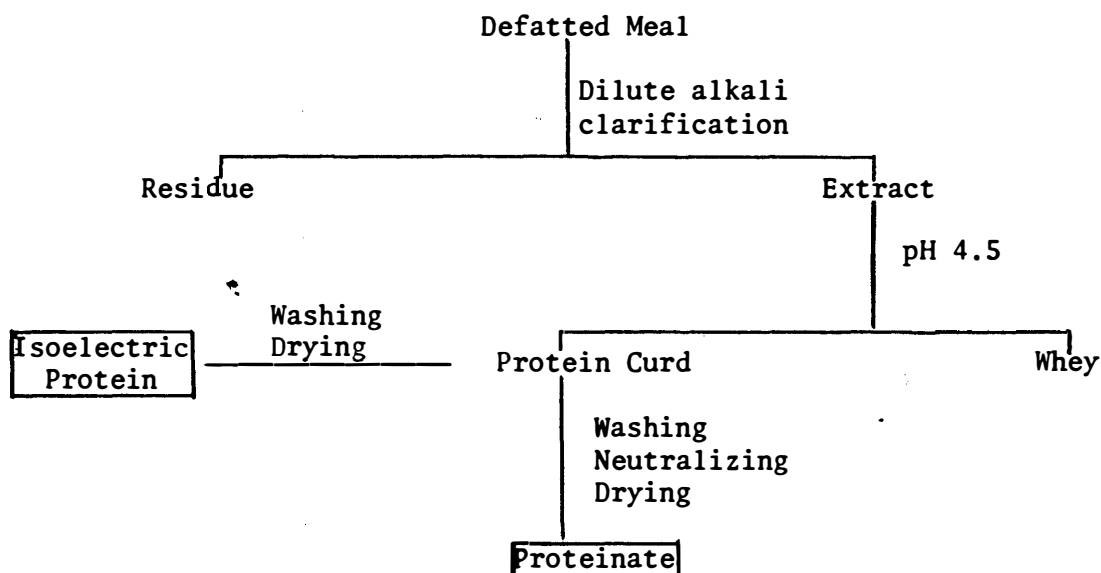


Fig. 1—Diagram for commercial production of soybean protein isolates (Wolf, 1969)

Soy protein concentrates and isolates are concentrated sources of protein for incorporation into existing foods or for design of new foods. It is, therefore, important to evaluate these protein forms in terms of their potential contribution to or alteration of the final food system.

II. FUNCTIONAL PROPERTIES

Proteins have two important roles to play in foods. The traditional role of protein is to provide nutrition, and intensive research has been focused on the development of new protein sources (Hermansson, 1973). Protein is utilized in many foods, however, for the particular characteristics that it contributes to the final product (Hammonds and Call, 1970). In order for protein products to maintain or enhance the quality and acceptability of a food, the protein ingredient should possess certain functional properties that are compatible with the other ingredients of the food system (Hermansson, 1973). Therefore, an important aspect of the development of new protein products is to establish their functional physico-chemical properties.

Functional properties are defined as physico-chemical properties that provide information as to how the ingredient will perform in a food system (Hermansson, 1973; Hermansson and Åkesson, 1975; Johnson, 1970). A nonfunctional ingredient should not alter the characteristics of the food system. There are a number of functional characteristics or physico-chemical properties desired in protein-containing products. Proteins as a group are denaturable and coagulable; they imbibe water

and enter into carbonyl-amine reactions. These properties singly or in combination contribute to structural, binding, foaming, emulsifying, thickening, and gelling qualities in food as well as contributing to color, odor, and flavor (Circle and Smith, 1972).

With the recent increase in food uses of edible soy products, the desirability of quantitative information on the functional properties of these products has become apparent (Circle et al., 1964). The availability of commercial soy protein concentrates and isolates provides the food processor, and ultimately the consumer, concentrated sources of protein with varied functional properties (Mattil, 1974). Soy protein concentrates and isolates with their relatively high protein concentrations seem particularly applicable to assessment of functional characteristics of soy proteins. The functional properties of interest in this review and subsequently reported investigations are protein solubility, hydration capacity, emulsion properties, fat absorptivity, and thickening function.

Protein Solubility

The majority of soy proteins are globulins. Globulins are generally thought to be insoluble in water and soluble only in salt solutions (Wolf, 1969). Soy proteins are insoluble in water at their isoelectric point but will dissolve in the isoelectric state when salts, such as sodium or calcium chloride, are added. As the pH diverges from the isoelectric region (4.2-4.6), the solubility of the soy globulins increases without the addition of salts (van Megen, 1974;

Wolf, 1969; Wolf and Cowan, 1971). This effect of pH on solubility of the soy proteins explains the variation in the ability of water to extract soy proteins and their classification as globulins.

Many researchers (Hermansson, 1973; Mattil, 1971; Wu and Inglett, 1974) support the idea that the solubility or dispersibility of soy protein is a physico-chemical property that is associated with the other functional properties of the protein and is, therefore, the first property to be studied in a systematic investigation of proteins. Various methods and terms have been proposed in the literature to evaluate and describe protein solubility. Currently, the methods have been narrowed down to two—the "solubility" and "dispersibility" methods. Both methods involve extracting the protein with water and analyzing the extract by standard Kjeldahl procedure (Johnson, 1970; Wolf and Cowan, 1971). The "solubility" method, also referred to as "slow-stir" method, requires a 2-hr extraction period. In contrast, the "dispersibility" or "fast-stir" method requires only a 10-min extraction period with a high-speed mixer equipped with cutting blades. The literature contains a variety of terms to describe or define the results of these two extraction methods. The terms are often misleading and confusing in interpretation of results of solubility measurements. The terms most frequently used in the recent literature are nitrogen solubility index (NSI) and protein dispersibility index (PDI). NSI was defined by Wolf and Cowan (1971) as the percent of total nitrogen in a sample that is water extractable by the "solubility" method of extraction.

PDI was defined as the percent of total protein ($N \times$ conversion factor) in a sample that is water extractable by the "dispersibility" method of extraction. Occasionally results are expressed as protein solubility index (PSI) or as nitrogen dispersibility index (NDI). Extraction method and terminology should be considered in comparing solubility data.

Ultracentrifugation studies of soy proteins have resulted in separation of soybean proteins into four fractions primarily on the basis of their molecular size. The fractions have been designated 2, 7, 11, and 15S based on their approximate sedimentation rates. Approximate amounts of the four fractions as compiled by Wolf and Cowan (1971) are recorded in Table 2. Fractionation studies revealed that the proteins were more complex mixtures than were first indicated by the sedimentation rate. The 7S and 11S fractions have been reported to account for approximately two-thirds of the soybean protein. Wolf (1969) has reported the response of 7S and 11S globulins to varying ionic environments at pH 7.6. However, solubility data on soy proteins in the literature for the most part have not included the effects of treatments on the specific fractions of the soybean globulins.

A number of factors, such as temperature, product processing, pH, ionic strength, method of nitrogen extraction, and particle size have been reported to exhibit an effect on the solubility characteristics of the soy protein under investigation (Anderson et al., 1973; Hermansson, 1973; Hermansson and Åkesson, 1975; Johnson, 1970; Lin et al., 1974; van Megen, 1974; Wolf, 1969).

Table 2—Approximate amounts and components of ultracentrifuge fractions of water-extractable soybean proteins (Wolf and Cowan, 1971)

Fraction	Percent of total	Components	MW
2S	22	Trypsin inhibitors Cytochrome c	8,000-21,500 12,000
7S	37	Hemagglutinins Lipoxygenases β -Amylases 7S Globulin	110,000 102,000 61,700 180,000-210,000
11S	31	11S Globulin	350,000
15S	11	---	600,000

Effect of heat. Soybean proteins are readily insolubilized by moist heat. This insolubilization with heat is exhibited in both water and salt solutions (Wolf and Cowan, 1971). Belter and Smith (1952) reported that the water dispersibility of nitrogenous constituents of soybean flakes decreased from an initial value of 80% to 20-25% after steaming at atmospheric pressure for only 10 min. Because of the dramatic effect of heat denaturation on soy protein solubility, protein solubility measurements are used to determine the extent of heat treatment given to soy products during processing. Since most foods are heated during one or more stages of processing, this form of denaturation is commonly encountered (Wolf and Cowan, 1971).

Effect of processing method. Variations in solubility measurements as reported earlier are supported by the work of Mattil (1974). Samples of eight different commercial concentrates and 11 isolates were obtained for investigation. Protein solubility values of selected soy

concentrates and isolates were obtained under mild extraction procedures. One part of the protein product under investigation was dispersed in 80 parts of water; the pH of the dispersion was adjusted to 2, 6, or 7, and more water was added to be equivalent to 100 parts water. The mixture was held at 37.5°C for 40 min and dispersed on a laboratory shaker for 30 min at room temperature. Agitation of the mixture was increased by the addition of three glass beads to each flask. The mixture was centrifuged for 20 min at 2000 rpm and the supernatant fluid was filtered; aliquots of the filtrate were analyzed for dissolved nitrogen. NSI and PDI also were determined on selected soy samples. Mattil (1974) compared data obtained in his laboratory with data published in product specifications and performance brochures. With one exception, the PDI values differed from those claimed by the manufacturer. There were wide differences in the solubility patterns among the concentrates and isolates. Solubility values for the soy concentrates ranged from 27 to 52, 1 to 39, and 2 to 54% respectively for pH levels of 2, 6, and 7. Similar variations were reported for soy isolates. Again, there were wide differences among products with the solubility ranging from 7 to 96% at pH 6 and from 17 to 100% at pH 7.

Lin et al. (1974) compared the PSI of five commercial soy protein products with that of sunflower products. The PSI's were determined following the "slow-stir" method of extraction. Both concentrates studied, Isopro and Promosoy, had low PSI values of 2.3 and 6.0%

respectively. The isolates exhibited greater variation in PSI. The isolates studied, Supro 610 and Promine-D, had PSI values of 17.4 and 71.1% respectively.

Wolf and Cowan (1971) reported that commercial isolates vary more than laboratory samples. Isolates from different manufacturers are similar in chemical composition but dissimilar in physical properties. The differences in physical properties of the soy isolates are attributable to processing variations.

Effect of pH. The data of Smith and Circle (1938), as reported by Wolf (1969), demonstrated the extractability of proteins in defatted soybean meal as a function of pH (Figure 2). The only salts present were those occurring in the meal or those resulting from the adjustment of pH with acid or base. The minimum solubility of the soy meal proteins was pronounced in the isoelectric region of the proteins. As the pH diverged from the isoelectric region of the protein, solubility increased. Protein solubility approached 85% at both pH 2.5 and 6.5. The pH-solubility relationship has been used in the production of soy concentrates and isolates (Central Soya, 1974a,b; Wolf and Cowan, 1971).

Effect of ionic strength. The addition of salt may influence properties of solvated proteins in several ways: by binding specific ions, by influencing the ionic strength, and by altering the properties of the solvent (Hermansson and Akesson, 1975).

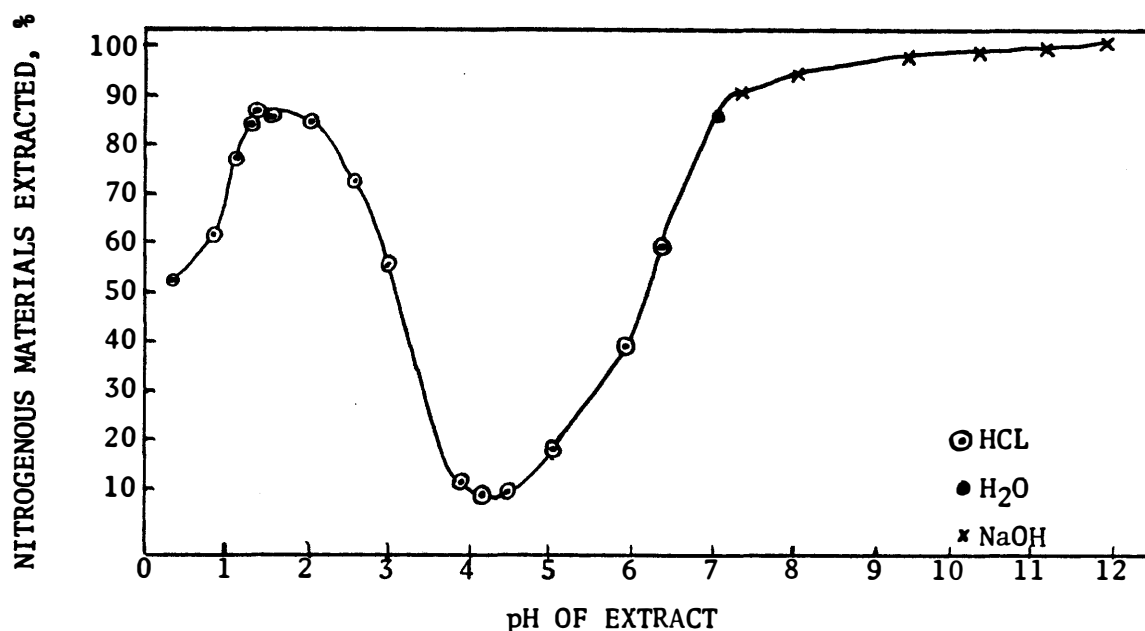


Fig. 2—Extractability of proteins in defatted soybean meal as a function of pH (Wolf, 1969)

The solubility response of the soybean globulins extracted from soybean meal as a function of sodium and calcium chloride concentrations at pH 4.5 was investigated by Anderson et al. (1973). At pH 4.5, in the absence of added salt, only 2S and 7S fractions were extracted. The amount of 2S and 7S fractions extracted increased with increasing NaCl concentration. Extractability of the 2S fraction leveled off at 0.3N NaCl whereas the extractability of the 7S fraction continued to increase up to 0.8N NaCl. Solubilization of the 11S fraction did not begin until the salt concentration exceeded 0.2N but the solubility curve of the 11S fraction rose more rapidly than those of the 2S and 7S fractions. The 15S fraction required 0.4N NaCl before solubilization occurred. Ultracentrifugal analyses of the CaCl_2 extracts gave results that were similar to those of NaCl, except that less CaCl_2 was required

to obtain extracts with given protein concentration. The 2S and 7S fractions required no salt for extraction. The 11S fraction required approximately 0.08N CaCl_2 before extraction occurred, whereas the 15S fraction required a CaCl_2 normality of 0.1. These researchers concluded that the bulk of soybean proteins consisted of globulins that were insoluble at their isoelectric points (pH 4.2-5.0) in the absence of salts but were solubilized at their isoelectric points by the addition of salts. The solubilities of the respective fractions appeared to be dependent in part upon molecular size. The smallest molecules dissolved at the lowest salt concentration and the largest molecules (15S fraction) were solubilized at the highest salt concentrations. The maximum solubility of the mixture of fractions occurred with 0.3N CaCl_2 or 0.7N NaCl. These data are similar to those reported by van Megen (1974) and reviewed below.

Effect of pH and ionic strength. The solubility of partially purified soybean globulins as a function of pH and ionic strength was investigated by van Megen (1974). The soybean globulins were partially purified by removing the irreversibly denatured insoluble protein which resulted from isoelectric precipitation of the protein isolates. Mixtures with final concentrations of 10, 20, and 30% protein were prepared by dispersing the purified protein in water. The mixtures were adjusted in pH with 0.25N NaOH or HCL and solid NaCl or CaCl_2 was dissolved until the desired concentration was reached. Portions of about 15g of each mixture were allowed to

equilibrate in stoppered bottles by moderate shaking for 16 hr at 20°C. The pH was readjusted if needed and samples were centrifuged for 45 min at $40,000 \times G$. Following centrifugation, the mixtures were either homogeneous or separated into a protein-poor upper layer and a protein-rich lower layer. The separate phases and homogeneous mixtures were analyzed for protein and salt content. The solubility behavior of the soy proteins was characterized by the occurrence of liquid-liquid phase separations. Below a certain salt content, termed the "critical salt concentration," a protein-rich lower layer and protein-poor upper layer were formed. The extent of a center layer was dependent on the type of salt present and the pH. Even at the isoelectric point the soy protein was dissolved to very high concentrations, provided the ionic strength of the solution exceeded a critical value. At pH 4.5 the critical value was approximately 0.7M for NaCl and 0.25M for CaCl_2 . At pH 7.0 no phase separation occurred except at low ionic strengths.

Hermansson (1973) evaluated the solubility behavior of Promine-D, caseinate, whey protein concentrate, and fish protein concentrate. The solubility of these proteins was studied as a function of pH at 0.2M NaCl and of ionic strength at pH 7.0. At 0.2M NaCl approximately 35% Promine-D was soluble at pH 2.0 but less than 10% was soluble in the pH 4-4.6 range. Between pH 4.6 and 5.0 the protein solubility of Promine-D increased dramatically to about 90%. At pH 7.0 and NaCl concentrations of 0-2.0M, protein solubility of Promine-D was approximately 92% and was affected only slightly by ionic strength. However, with increasing NaCl concentration from 2.0 to 4.0M the

protein solubility decreased steadily until only about 5% protein was soluble. These findings support the ultracentrifugation studies of Wolf (1969), which showed that the quaternary structure of the protein is unstable and dissociation occurs at very low ionic strengths. The dissociation of the quaternary structure of the soy proteins probably is attributable to prevailing intramolecular repulsion forces (Hermansson and Akesson, 1975).

Hydration Capacity

Water absorption, hydration capacity, and swelling all have been used to describe the uptake of water by food systems. Hermansson (1972) reported that most protein foods of interest as ingredients are neither completely soluble nor completely insoluble in water. Therefore, the concept of water uptake or swelling must be considered in evaluating a protein as a food ingredient. Most semisolid foods are water-swollen systems. Swelling was defined by Hermansson (1973) as

. . . the spontaneous uptake of a solvent by a solid. It is a phenomenon frequently observed as the first step in the solvation of polymers, in which case swelling continues until the molecules are randomized within the system. In other cases solvation may be prevented by various intermolecular forces in the swollen sample, resulting in limited swelling and a definite volume increase.

This concept could explain the variations reported between protein solubility and water absorption characteristics of proteins, and also could shed light on possible relationships of water retention with other functional characteristics, such as viscosity and gelling functions.

Protein was reported to be responsible primarily for water binding but other constituents in the soy products must be considered. Soy proteins contain numerous polar side chains along their peptide backbone, thereby making the proteins hydrophilic. Water retention of proteins is related to the polar groups. Consequently, soy proteins absorb water and tend to retain it in the finished product (Huffman et al., 1975; Wolf and Cowan, 1971). Some of the sites, such as carboxyl and amino groups are ionizable.

Relationship to solubility. Dippold (1961) as reported by Johnson (1970) compared the NSI of a soy flour with its water absorption characteristics. These data indicated that as the NSI of the soy flour decreased, water absorption of the sample increased to a point and then decreased with decreasing NSI. Within the group of soy isolates or soy concentrates studied by Lin et al. (1974), the water absorption capacity of the samples increased as the PSI of these products decreased.

Effect of pH. The polarity of the protein was reported to change with varying pH. Changing the pH, therefore, changes the water absorption characteristics of the protein. Wolf and Cowan (1971) reported the pH-water retention curve of soy proteins to follow the pH-solubility curve. Both solubility and water retention were minimal at the isoelectric point (4.5) and increased as the pH diverged from this point.

Effect of concentration. Water absorption characteristics of a soy flour, two soy concentrates, and two soy isolates were determined by

Lin et al. (1974). The percent water absorption of the soy products increased as the total protein content of the samples increased from flour to isolate. The soy flour absorbed 130.0% water, the soy concentrates absorbed an average of 211.7% water, and the soy isolates absorbed an average of 432.2%. No calculations were made, however, which related the percent water absorbed to the grams of nitrogen or protein contained in the samples.

Use in food systems. Although few data have been reported on water absorption or hydration capacity of soy proteins, this functional property has been used as a criterion for selection of soy proteins as ingredients in food systems. Soy flour was incorporated into bread to increase storage stability by retaining moisture (Wolf and Cowan, 1971). Soy protein was used to reduce cooking losses of comminuted meat products (Rakosky, 1970). The delayed absorption of water by soy proteins was used advantageously in canned products by Johnson (1970). Soy proteins often are added to prepared foods but presently the relation of hydration capacity to functional characterization of soy protein products is lacking.

Emulsion Properties

Emulsification capacity of soy proteins is of utmost importance in their use as food ingredients, particularly in salad dressing, creamed products, and comminuted meat systems. Soy proteins probably play two roles in emulsification. They aid in the formation of oil-in-water emulsions and stabilize the emulsions once formed. Since proteins are

surface active, they lower surface tension and collect at oil-water interfaces. Proteins stabilize emulsions by forming a protective barrier around the fat droplets to prevent their coalescence (Lin et al., 1974; Wolf and Cowan, 1971).

The methods for measuring emulsification and emulsion stability have been numerous and subject to lack of precision. Several researchers (Crenwelge et al., 1974; Huffman et al., 1975; Pearson et al., 1965; Swift et al., 1961) observed the sudden decrease in viscosity associated with exceeding of emulsion capacity as the criterion of emulsion collapse. Electrical conductivity or electrical resistance was used by Webb et al. (1970) to determine emulsification endpoints. This method was found to be useful for dilute protein dispersions only. Inklaar and Fortuin (1969) and Lin et al. (1974) used a simple system test in which the protein and water were dispersed under controlled conditions, after which a given amount of oil was added to the dispersion. The mixture was centrifuged and the volume of free oil read. Emulsified oil was defined as total minus the free oil. Inklaar and Fortuin (1969) reported that the findings of the simple system test agreed with observations in the sausage industry. Tsai et al. (1972) utilized a microemulsifier in their evaluation of emulsion stability. Evaluation of emulsion stability necessitated stopping the addition of oil just prior to the point at which collapse of the emulsion was known to occur.

In addition to the methods of evaluation, many factors have been reported to have significant influence on the emulsification capacity of oilseed proteins. Some of these factors include protein solubility, pH, ionic strength, and protein concentration.

Relationship to solubility. It was reported that only the fraction of protein which is soluble can function as an effective emulsifying agent (Huffman et al., 1975; Pearson et al., 1965). The data of Inklaar and Fortuin (1969) indicated that as the NSI values of the soy proteins decreased, the percent oil separation increased. Crenwelge et al. (1974) reported a general positive correlation between emulsification capacity and solubility of a soy protein concentrate.

Effect of pH. The pH influences the emulsifying capacity of protein ingredients in an indirect manner by affecting the solubility of the proteins. As the pH of an emulsion made with a soy protein isolate increased from 7.0 to 7.8, the percent oil separation of the emulsion decreased from 42.8 to 37.6 (Inklaar and Fortuin, 1969). The decreased oil separation was interpreted as increased emulsifying capacity of the soy isolate. Similar results were reported by Crenwelge et al. (1974). These researchers evaluated the emulsification capacity of glandless cottonseed flour, a soy protein isolate, and two proteins of animal origin over a pH range of 3.0 to 10.0. At pH 3.0 the emulsification capacity of the soy concentrate was evident. With increased pH (4.0-5.0), a minimum emulsification capacity was observed. As the pH of the emulsion increased from 5.0 to 10.0 there was increased emulsification capacity.

Effect of pH and ionic strength. Emulsions made with soy sodium proteinates were evaluated for emulsifying capacity and stability at ionic strengths of 0.05 and 0.3 at pH values of approximately 5.4,

6.8, and 10.5 (Pearson et al., 1965). At low pH (5.4), the emulsifying capacity of the soy isolate was low. This decreased emulsifying capacity of the soy isolate was attributed to a decreased solubility of the protein as the isoelectric point was approached. The greatest emulsifying capacity for the soy protein occurred at pH 10.7 and an ionic strength of 0.05 (0.017M Na_2CO_3). At constant ionic strength, the emulsifying capacity of the soy decreased as the pH of the emulsion decreased. Ionic strength of the emulsions was not shown to have a major effect on emulsifying capacity of the soy products in emulsions at pH values of 6.9, 7.5, and 10.7. However, at an emulsion pH of 5.1, the grams of oil emulsified per gram of nitrogen increased as the ionic strength increased from 0.05 to 0.3.

Effect of concentration. In emulsions made with a given amount of water and oil, Inklaar and Fortuin (1969) demonstrated that as the amount of soy isolate increased from 1 to 9g there was a corresponding increase in emulsion stability. The increased emulsion stability with increased protein concentration was exemplified by a decrease in percent oil separation from 80 to less than 10%. The same effect of increased emulsion stability with increased protein was exhibited in emulsions made with sodium caseinate (Inklaar and Fortuin, 1969). Emulsification capacities of a soy protein concentrate were determined for soy concentrations between 0.20 and 1.70g/100ml of aqueous phase. Increased protein concentration resulted in increased emulsification. The soy concentrate attained an optimum emulsification capacity (28.7% oil phase volume) at a concentration of 0.986g/100ml (Crenwelge et al., 1974).

Fat Absorptivity

Fat absorption data for soy protein products are meager and the mechanism of fat absorption or binding has not been elucidated. However, soy proteins have been used for contrasting purposes in regard to fat absorption in foods. Soy proteins have been added to comminuted meats to promote fat absorption or fat binding and therefore decrease losses and maintain dimensional stability during processing. Some researchers reported that in ground meat products, fat binding appeared to involve formation and stabilization of an emulsion (Wolf and Cowan, 1971) and the formation of a gel (Hermansson and Åkesson, 1975) that interferes with fat coalescence. Therefore, fat absorption or fat binding may be another factor in emulsification of soy products.

In other foods such as doughnuts and pancakes, soy flour has been added to prevent excessive fat absorption (Johnson, 1970; Wolf and Cowan, 1971). The protective effect of soy flour in controlling fat absorption during frying has not been explained. It was postulated that this effect may be related to heat denaturation of the proteins to form a protective layer at the oil-food surface.

The fat absorption characteristics of a soy flour, two soy concentrates, and two soy isolates were evaluated by Lin et al. (1974). Fat absorption of the samples was determined by combining the soy products with corn oil, dispersing, centrifuging, and reading the volume of free oil. Percentage of oil bound was used as the measure of fat absorption of the soy products. Fat absorption characteristics of the soy products ranged from 84.4 to 154.4% of their weight on a

14% moisture basis. Within the group of soy isolates or concentrates studied, the percent fat absorption decreased as the PSI of the product increased. This relationship was not discussed (Lin et al., 1974).

Thickening Function

Previous research has shown that the rheological properties of aqueous dispersions of soybean globulins are dependent on protein concentration, pH, ionic strength, heating time, and temperature (Catsimpoolas and Meyer, 1970; Circle et al., 1964). According to Hermansson (1972), the viscosity of soy dispersions is related to the degree of protein hydration. Hydration capacity, as discussed earlier, was found to be influenced by protein solubility, pH, ionic strength and protein concentration. It is not known, however, to what extent water absorption can be a measure of swelling (Fleming et al., 1974).

Effect of temperature. Gelation of soybean globulins was accomplished at concentrations between 8 and 14% by heating and subsequent cooling. On heating, the sol was irreversibly converted to a progel which was characterized by high viscosity. The progel set to a gel upon cooling and was reconverted to the progel state by reheating. These gelation phenomena of soybean globulins were summarized by Catsimpoolas and Meyer (1970) as follows:



During conversion of the sol to a progel, viscosity of the dispersion increased until a maximum was reached. With excessive heat (125°C) the progel was converted to a metasol of lower viscosity which did not form a gel on cooling (Circle et al., 1964). Irreversibility of the protein sol to progel state was attributed to irreversible disruption of the quaternary structure of soybean globulins with heat (Catsimpoolas and Meyer, 1970, 1971a). These researchers theorized that the bonds involved in the change from progel to gel state were noncovalent bonds. They suggested that stabilization of the network with cooling was dependent upon hydrogen and ionic bonds.

Effect of concentration. The apparent viscosity of soy dispersions was reported to increase exponentially with increasing concentration (Circle et al., 1964; Ehninger and Pratt, 1974; and Fleming et al., 1974). Circle et al. evaluated the apparent viscosity of fluid and gelled dispersions of 8, 9, 10, 11, and 12% concentrations unheated and heated at 100°C for 30 min. Apparent viscosity increased as protein concentration increased for both unheated and heated dispersions. The heated dispersions exhibited greater viscosity than the unheated dispersions at a given concentration. The effects of pH and concentration on the gel viscosity and stability of soy isolate dispersions were investigated by Ehninger and Pratt (1974). Concentration of the soy isolates ranged from 6 to 14% of the weight of a 200-ml volume. The dispersions were blended for 2 min with an Osterizer and then placed in an agitating water bath kept at 92-96°C. After 60 min, the dispersions

were cooled (approximately 3 hr) in a 25°C water bath. The apparent viscosity of the isolates increased as the protein concentration increased from 6 to 14%. The change in apparent viscosity of the dispersions with concentration appeared to be pH dependent.

Effect of temperature and concentration. The interaction effects of various temperatures and protein concentrations on apparent viscosity of soy isolate dispersions were evaluated by Circle et al. (1964). At concentrations of 6% and lower, gelation did not occur with or without heating and cooling was primarily concentration-dependent. Eight, 10, and 12% dispersions were heated for 30 min at various temperatures. The 8% dispersion displayed maximum viscosity at about 80°C, and the 12% at 110°C. At all three concentrations, apparent viscosity of the soy dispersions dropped sharply with heating at 125°C. However at 16, 18 and 20% soy concentrations, heating at 125°C for 30 min formed rigid gels, all with viscosities greater than 33,000 poises (the upper limit of the Brookfield Helipath with T-F spindle at 0.3 rpm). Therefore, the gel stability under stress conditions of heat was dependent primarily on the soy concentration; the higher the concentration, the firmer and the more heat-stable was the gel.

Effect of pH and concentration. pH of the soy dispersion of Ehninger and Pratt (1974) was adjusted to 4.5, 5.0, 5.5, 6.0, and 6.5 with citrate-phosphate buffer. As previously reported, the change in apparent viscosity of soy isolate dispersions with increased

concentration was pH dependent. At pH 4.5, there was a decreased apparent viscosity with increased soy concentration between 7 and 9%. This decrease was followed by an increased apparent viscosity as the protein content increased from 9 to 14%. As the pH of the dispersions as a group increased, the apparent viscosities also increased. This was attributed to increased protein solubility at the higher pH values.

Five, 10, 15, and 20% dispersions of untreated and pH-activated slurries of soy flours, concentrates, and isolates were prepared either by adding water to the soy product with stirring for 1 min (short mix) or by grinding the protein product for 10 min in enough water to form a thick paste (long mix) then adding the remaining water to make 5, 10, 15, and 20% slurries ($\text{g dry matter/g total} \times 100$). For "pH activation," 1.25N NaOH was added in 1 min with continuous stirring to reach pH 12.2, and 6.0N HCl was added to return the pH to 6.0 in 10 min. The apparent viscosity of the soy products increased with increased soy concentration for both the untreated and pH-activated samples. The slurries of the soy flour and the soy concentrates cycled through the pH activation process exhibited higher apparent viscosities than the corresponding untreated slurries.

Circle et al. (1964) evaluated the effect of heating a 10% dispersion over a 6.0-9.0 pH range. The apparent viscosity of the unheated soy isolate dispersion was considerably lower at pH 6.0 than at pH 7.0 or above. This was attributed to lowered solubility or aggregation of the protein at pH 6.0. The lowered solubility presumably was overcome by heat since the apparent viscosity of the heated dispersion at pH 6.0 equalled that at pH 7.0 and 8.0.

Effect of ionic strength. Ten percent dispersions of soy globulins in 0.2-2.0M NaCl were heated at 70, 80, 85, 90, and 95°C and apparent viscosity was measured (Catsimpoolas and Meyer, 1970). At temperatures above 70°C, the apparent viscosity of the dispersions decreased with increased NaCl concentration. Below 70°C, higher viscosities were favored by higher salt concentrations.

Apparent viscosity of 15% slurries of soy flour, two soy concentrates, and a soy isolate was evaluated in water and in 5% NaCl solutions (Fleming et al., 1974). The apparent viscosity of the soy flour and one soy isolate (Isopro) was greater in the NaCl solution than in water.

Low concentrations (0.05 and 0.1%) of salts exhibited minor effects on apparent viscosity of unheated and heated 10% soy dispersions (Circle et al., 1964). As the concentration of salt increased from 0.5 to 1%, the apparent viscosity of the unheated dispersion decreased while the apparent viscosity of the heated dispersions increased.

CHAPTER III

PROCEDURES

I. SOURCE OF SOY PRODUCTS

Two commercial soy products, Promine-D (a general purpose, functional sodium soy isolate) and Promosoy-100 (a fine-grind soy protein concentrate), with protein contents on a moisture-free basis of not less than 90 and 70% respectively were obtained from Central Soya, Chemurgy Division, Chicago. The products were reported in the Technical manuals to have the proximate analyses shown in Table 3 (Central Soya, 1974a,b).

Table 3—Proximate analyses of Promine-D and Promosoy-100 (Central Soya, 1974a,b)

	Promine-D	Promosoy-100
	(%)	(%)
Moisture	4.8	5.3
Protein, N \times 6.25 (as-is basis)	92.0	67.8
Protein, N \times 6.25 (moisture-free basis)	96.6	71.6
Crude fiber	0.25	3.6
Ash	4.0	4.8

The soy products were obtained in 50 lb bags and transferred to large plastic bags contained in plastic storage bins with lids. Both

the bags and bins were closed tightly between samplings. Frequent moisture determinations (AOAC, 1970) revealed that the moisture contents of Promine-D and Promosoy-100, under the described storage conditions, leveled off to 6.73 and 6.55% respectively.

II. PLAN OF STUDY

The study consisted of two parts. Part A involved a systematic investigation of selected functional properties in simple systems and Part B related the findings of Part A to functional performance of the soy products in a food system.

Part A: Simple Systems

The objectives of Part A were to examine the following functional properties in simple systems:

- (1) protein solubility, water absorption, and emulsion properties of a soy protein isolate, Promine-D, and two levels of a soy concentrate, Promosoy-100, at selected conditions of pH and temperature;
- (2) fat absorption of the soy samples at selected temperature levels and the "as-is" pH;
- (3) thickening function of the soy isolate and the soy concentrate at selected pH and temperature levels.

Sampling. A sample concentration has been specified in the literature for each functionality test. These concentrations of the soy isolate and of the soy concentrate were used for all treatment

combinations of pH and temperature except for the measurement of apparent viscosity. The exception will be explained later. Using equal weights of the isolate and the concentrate resulted in different protein levels. Consequently, additional measurements were made with the concentrate used on an equal protein basis. Thus, three sample series were used throughout the study for the measurement of protein solubility, water absorption, emulsion properties, and fat absorption: (1) isolate (P-D), weight specified for each functionality test, (2) concentrate (P-100₁), weight equal to weight of isolate (as-is basis), (3) concentrate (P-100₂), weight required for protein quantity equal to that of isolate. Viscosity measurements were made on the soy isolate and only the equal-protein level of the soy concentrate because dispersibility of the concentrate (P-100) and range of the Brookfield viscometer did not permit use of the lower concentration of Promosoy-100. Sample size for providing the desired protein quantity was based on moisture determinations (AOAC, 1970) and nitrogen content on a moisture-free basis.

pH variations. The pH values of the soy dispersions for all functionality tests except fat absorption were 5.0, 6.0, and as-is (7.0 ± 0.1 pH unit, Corning Model 10 pH Meter). The pH values of the soy dispersions for the measurements of protein solubility, water absorption, and emulsion properties were adjusted with 0.096N HCl. Adjustments in pH for thickening function of the soy dispersions were made with 2.8N HCl. Fat absorption measurements were made only at the as-is pH of the

soy and oil dispersion. The amounts of acid required for the pH adjustments were determined on ambient temperature samples during preliminary investigations. To obtain the desired pH values for all soy levels for functionality measurements, varying levels of the acid were substituted for part of the distilled water in the dispersing medium. Proportions of HCl to water for each functionality test as determined in preliminary investigations and used throughout the study are listed in Table 26, Appendix A.

Temperature variations. The temperatures selected for evaluation were 4°C, ambient (22-25°C), and 90°C. Four degree samples were held in a cold room. Temperature of the 90° samples was maintained by use of a water bath.

Statistical arrangement. Sufficient quantities of the soy isolate and the soy concentrate were secured from the manufacturer so that all samples of each soy product were from the same lot. The various functionality tests, however, required different dispersions with regard to concentration and additives. For this reason, each functionality test or measurement was set up as an independent experiment which required a separate statistical arrangement and analysis.

For the measurements of protein solubility, water absorption, and emulsion properties, the basis for the individual statistical analyses was a 3^3 factorial arrangement in which the soy sample, pH, and temperature were the factors represented at three levels each. Data were collected in a 9×9 quasi-latin square arrangement (Cochran and

Cox, 1962). This design was chosen to remove the effect of day and order presentation. The Statistical Analysis System (SAS) Package was used to calculate the analyses of variance commensurate with the 9×9 quasi-latin square arrangement. The effects of soy, pH, temperature, soy \times pH, soy \times temperature, pH \times temperature, and soy \times pH \times temperature independent of day and order effects were estimated for NSI, water absorption, and emulsified oil. Differences in the main effects and interactions were partitioned by the use of polynomials. From these polynomials, the estimated response surfaces of NSI, water absorption, and emulsified oil for the soys were drawn with a Hewlett-Packard flat-bed plotter. The thickening function of the soy products was evaluated in a $2 \times 3 \times 3$ factorial arrangement in which soy sample was represented at two levels and pH and temperature were represented at three levels each. Fat absorption of the soy samples was examined at all temperature levels but only at the as-is pH. Thickening function and fat absorption data were collected in randomized complete block designs for three replications. Analyses of variance were performed to test the significance of observed differences in viscosity and fat absorption attributable to the main and interaction effects.

Part B: Food System

A product that could be prepared at more than one pH and served hot or cold was developed during preliminary investigations as the carrier system for the soy protein isolate and concentrate. The soy, pH, and temperature variations were selected from those treatments

evaluated in soy simple systems in Part A. The product was presented as a ham and onion flavored dip. The objectives of Part B were to evaluate:

- (1) by objective measurements the emulsion stability and apparent viscosity of the base product at two pH and two temperature levels for both Promine-D and Promosoy-100, and
- (2) by sensory panel the viscosity, mouthfeel, oiliness, flavor, and overall acceptability of the formulated dip at two pH levels and one temperature for both soy products.

Sampling. Promine-D and Promosoy-100 were compared only on an equal protein basis because the lower level of Promosoy-100 was eliminated for measurements of apparent viscosity in Part A.

pH variations. The pH levels for all evaluations in Part B were 5.0 and 6.0. During preliminary investigations, the amount of acid required for the pH adjustments was determined on ambient temperature base products. The pH values of the base products were adjusted with 0.568N HCl. A table of substitutions of HCl for part of the distilled water is provided as Appendix A (Table 26).

Temperature variations. Emulsion stability and apparent viscosity measurements on the base products were made on samples held at 4 and 90°C. Consumer panel evaluations of the dips were made on 4°C samples only. All samples, base and dip products, were held until the time of evaluation in a cold room (4°C). Temperature of the 90°C samples was maintained during the holding period by use of a water bath.

Statistical arrangement. Emulsion stability and apparent viscosity data were collected for two replications in a balanced 2^3 factorial arrangement with soy, pH, and temperature represented at two levels each. Emulsion stability data were not subjected to analysis of variance because only one treatment had a measurable response. Variance among treatment effects for apparent viscosity was partitioned through analysis of variance. Sensory panel scores were collected in a randomized complete block design. Analysis of variance was used to partition the variation among the four dips for each quality attribute, i.e., viscosity, mouthfeel, oiliness, flavor, and overall acceptability.

III. MEASUREMENTS

Functionality Measurements in Simple Systems

Protein solubility and water absorption. Nitrogen solubility indices (NSI) of the soy products were determined by water extraction (Inkelaar and Fortuin, 1969) and micro-Kjeldahl analysis (AOAC, 1970) of the extract. Percent water absorption was determined for the same samples by a modification of the procedure of Sosulski (1962).

Procedure:

Numbered 90-ml centrifuge tubes were labeled then dried for 25 min at 50°C in an air oven. Following drying, the tubes were cooled in a desiccator for 30 min and weighed. A 1.25g sample of Promine-D or Promosoy-100, or 1.684g of Promosoy-100 was weighed to the nearest 0.1mg and transferred to a labeled centrifuge tube. Fifty ml of dispersion medium at the predetermined pH were added to

disperse the soy sample. A teflon stirring bar (length = 37.2mm) was placed in each centrifuge tube and the sample was dispersed for 30 sec with a magnetic stirrer. Following dispersion with the magnetic stirrer, the tubes were placed in a shaker water bath [Precision Model, speed setting = 4.5 (125 cycles/min), water depth = 10cm] at the predetermined temperature of 4°C, ambient (22-25°C) or 90°C. The contents of the tubes were stirred for 1 hr by plastic "policemen" suspended from a line stretched between two ringstands. During the 1-hr extraction period, the samples were stirred for 30 sec every 15 min with a magnetic stirrer. After extraction, the samples were removed from the water bath and centrifuged for 30 min at $1500 \times G$ (International Model U Centrifuge). The supernatant liquids were decanted into labeled 200-ml volumetric flasks and the residues were reextracted for 1 hr with 50 ml of distilled water. Before the second centrifugation, the magnetic stirring bars were removed from the centrifuge tubes and rinsed with distilled water into the tubes. Following centrifugation, supernatant liquids were combined with the respective extracts in the 200-ml flasks and made to volume. Extracts were filtered through Whatman No. 1 filter paper, labeled, and saved for nitrogen determination. The centrifuge tubes with residues were placed mouth down on paper toweling at an angle of 15-20° in an air oven at 50°C and allowed to drain and dry for 25 min. The samples were cooled in a desiccator for 30 min and weighed to the nearest 0.1mg. The water absorption or hydration capacity was calculated as the difference between hydrated weight and

original weight and expressed as a percentage of the original (as-is and dry) weight of the sample.

Total nitrogen contents of the extracts and of the dry unextracted samples, Promine-D and Promosoy-100, were determined by the standard micro-Kjeldahl method (AOAC, 1970). The nitrogen solubility index, NSI, of the samples following the previously described extraction procedure was calculated by the following equation:

$$NSI = \frac{N \text{ in } H_2O\text{-soluble protein}}{N \text{ in dry sample}} \times 100.$$

Emulsion properties. Emulsifying and emulsion stabilizing activity of the soy protein additives were determined according to the procedure of Inklaar and Fortuin (1969).

Procedure:

Thirty ml of dispersing medium of predetermined pH were added to a 400-ml beaker (height = 86.7mm, internal diameter = 62.9mm) containing a teflon stirring bar (length 37.2mm). Approximately 1.66g of Promine-D or Promosoy-100, or 2.314g Promosoy-100 were weighed to the nearest 0.1mg on an Ainsworth analytical balance and slowly transferred to the beaker while dispersing with the magnetic stirrer. The sample and water were dispersed for a total of 15 min after which 1g NaCl was added and stirring resumed for 1 min. While the sample was being dispersed with a magnetic stirrer, 8.3g of corn oil (density = 0.92g/cc at 25°C) were added in 5 min after which the mixture was further dispersed for 1 min. The samples were transferred quantitatively to 50-ml graduated centrifuge tubes, stoppered, and placed in a Precision

shaker water bath (water depth = 14cm) of the predetermined temperature of 4°C, ambient (22-25°C), or 90°C with the speed control positioned at setting 4 (89 cycles/min). After shaking for 15 min, the samples were equilibrated to ambient temperature with running tap water for 15 min. The samples were centrifuged twice at $873 \times G$ (International Model U Centrifuge) for 15 min. The volume of separated oil was read directly from the graduated centrifuge tube. The amount of emulsified oil (total minus free) was converted from milliliters to grams by multiplying by the density of the oil.

Fat absorption. The effect of temperature on the fat absorption characteristics of soy samples was measured according to a modified procedure of Lin et al. (1974).

Procedure:

Corn oil (2.76g) was weighed into each of 18, 15-ml conical graduated centrifuge tubes. Approximately 0.5g of Promine-D or Promosoy-100, or 0.674g Promosoy-100 was transferred into each centrifuge tube containing the oil. The contents of each tube were stirred with a thin brass wire for 1 min to disperse the soy product in the oil. The samples were dispersed 30 sec with a Vortex shaker prior to incubation of the samples at 4°C, ambient temperature (22-25°C), or 90°C for 30 min. Following incubation at the predetermined temperature, the samples were held at ambient temperature for 40 min to permit temperature equilibration. The samples then were centrifuged at $1030 \times G$ (International Model U Centrifuge) for 25 min after which the volume of free oil was read. The milliliters of absorbed oil (total

minus free) was converted to grams by multiplying the density of the oil (0.92g/cc at 25°C). The percent fat absorbed was expressed on both the as-is and dry weight bases.

Thickening function. Thickening function of the soy products was determined by a modified procedure of Circle et al. (1964).

Procedure:

Three hundred ml of dispersing medium of predetermined pH were added to a blender jar. During blending at rheostat setting 45, 45.0g of Promine-D or 60.6g of Promosoy-100 were added to the blender jar and the contents were blended for a total of 5 min. The dispersion was transferred from the blender jar into three 100-ml Griffin low-form beakers to an inside depth of 5cm (etched on beakers). One of the dispersion subsamples was held in a water bath at each of the three predetermined temperatures of 4°C, ambient (22-25°C), or 90°C for 30 min. The apparent viscosities of the subsamples were measured at each temperature with a Brookfield LVF model viscometer on the Helipath stand and with the T-spindles. The gear speed on the viscometer was adjusted as needed. The Helipath was allowed to descend until the crossbar of the T-spindle contacted the surface of the subsample. The viscometer was turned on and spindle allowed to travel through the subsample for 60 sec. At this point, the viscometer and Helipath were stopped and the reading was recorded. The readings were adjusted to centipoise units by the conversion factors for spindle size and gear speed.

Food System Preparation and Evaluation

Preparation. Thin boiling starch¹ (16.9g) was weighed into a tared 400-ml Griffin low-form beaker. One hundred thirty ml of distilled water were added to the beaker and the beaker was placed on a preheated electric unit set on "high." The contents of the beaker were heated for 5 min with constant stirring with a glass rod. While the starch dispersion was heated, 8.0g of dried whey,² 26.8g of sodium caseinate,³ and either 9.9g of Promine-D or 14.8g of Promosoy-100 were combined in a blender jar. After the dry ingredients were combined in a blender jar, 90.4g of Mazola margarine warmed to room temperature and the hot paste were added to the blender jar. The contents were blended at rheostat setting 40 for a total of 10 min, during which 120ml of dispersing medium of predetermined pH were added to the dispersion. Part of the dispersion from the blender jar was transferred into two, 50-ml graduated centrifuge tubes to a volume of 50 ml for emulsion stability measurements and part into two, 100-ml Griffin low-form beakers to an inside depth of 5cm (etched on beakers) for apparent viscosity measurements. The remaining product was transferred to preweighed labeled containers. All of the product samples were covered tightly with aluminum foil and stored in a 4°C cold room until the testing period. The product was prepared in two replications; for

¹Amaizo Quick-Set 68, American Maize-Products Co., 113th St and Indianapolis Blvd., Hammond, Indiana 46326

²Land O'Lakes, Inc., Minneapolis, Minnesota 55413

³Land O'Lakes, Inc., Minneapolis, Minnesota 55413

each replication the blender capacity necessitated preparation of four lots, which were pooled for panel evaluation.

Emulsion stability. The subsamples in the 50-ml centrifuge tubes were stored overnight at 4°C. One of the tubes was held in a water bath at 90°C for 1 hr. The second tube was held at 4°C. Both the 4 and 90°C subsamples were equilibrated to ambient temperature in a water bath (30 min). The subsamples were centrifuged at $873 \times G$ (International Model U Centrifuge) for 30 min. Volume of the separated liquid was read directly from the graduated centrifuge tube. The separated liquid was expressed as a percentage of the total volume after centrifugation.

Apparent viscosity. Following overnight storage at 4°C, one of the 100-ml subsamples for each treatment combination of soy and pH was held in a water bath at 90°C for 1 hr. The second subsample was kept in 4°C storage. The apparent viscosity of the subsamples was measured at both temperatures with a Brookfield LVF model viscometer on the Helipath stand and with a T-spindle. Gear speed was maintained at 6 rpm but spindle size was adjusted as needed. As the Helipath descended, timing was begun when the crossbar of the T-spindle contacted the surface of the subsample. The Helipath was allowed to descend into the subsample for 30 sec. The viscometer then was turned on and the spindle was allowed to travel through the subsample for an additional 30 sec. At this point, the viscometer and Helipath were stopped and

the reading was recorded. The readings were adjusted to centipoise units by the conversion factors for spindle size and gear speed.

Consumer sensory evaluations. The products in the containers were weighed and the product weights obtained by difference. Ten percent ham flavored Bontrae⁴ and 10% rehydrated minced onion⁵ were added to the base product. Each dip was mixed thoroughly and transferred into coded 3/4-oz cups. The cups were covered with plastic wrap and held at 4°C until the time of sensory evaluation.

An untrained consumer panel of 115 judges, mostly students, evaluated the dips on descriptive scales for viscosity, mouthfeel, oiliness, flavor, and overall acceptability. Each judge evaluated the four dips only once, some judging during the first replication and others during the second. Order of presentation of the dips was randomized among judges. The judges were instructed to evaluate one dip for all quality attributes before evaluating the next dip. A sample scorecard is included as Appendix B.

⁴Bontrae, General Mills, Inc., Minneapolis, Minnesota 55426

⁵Instant Minced Onions, Spice Islands, Inc., South San Francisco, California 94080

CHAPTER IV

RESULTS AND DISCUSSION

I. PART A: SIMPLE SYSTEMS

Results for Simple Systems

Protein solubility. Nitrogen solubility index, NSI, for soy proteins was evaluated with variations in pH and temperature. The response surfaces of NSI for P-D, P-100₁, and P-100₂ are shown in Figures 3, 4, and 5 respectively.

The NSI for P-D (Figure 3) increased dramatically as the pH of the extracting medium increased from 5.0 to 7.0 (as-is pH). The increase was evident at all temperatures studied and was greater between pH 6.0 and 7.0 than between 5.0 and 6.0. The curvilinear effect of pH on NSI is evident in Figure 3 and Tables 4 and 5. The magnitude of change in NSI values for P-D samples with pH change from 6.0 to 7.0 was lower at ambient temperature than at either 4 or 90°C.

NSI for P-D increased as temperature was increased from 4 to 90°C (Figure 3, Table 4). The increase was evident at all pH levels studied; however, temperature generally exhibited less effect than pH on NSI. At pH 5.0, the response of NSI to increased temperature appears nearly linear. At pH 6.0, the curvilinear response of NSI to increased temperature becomes obvious. At this pH, the greatest increase in NSI occurred as temperature increased from 4°C to ambient. At pH 7.0,

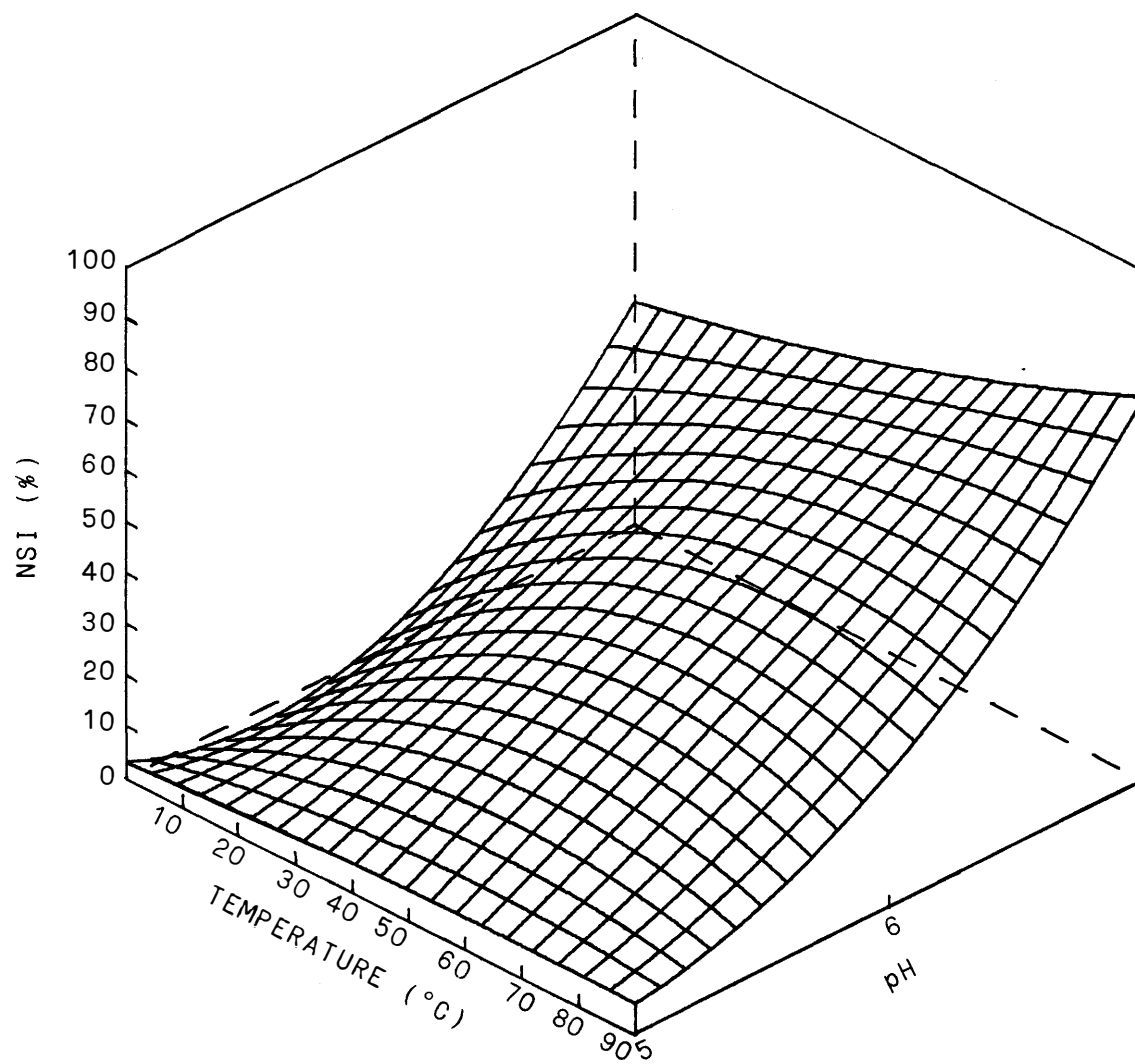


Fig. 3.—NSI response surface for Promine-D with variations in pH and temperature

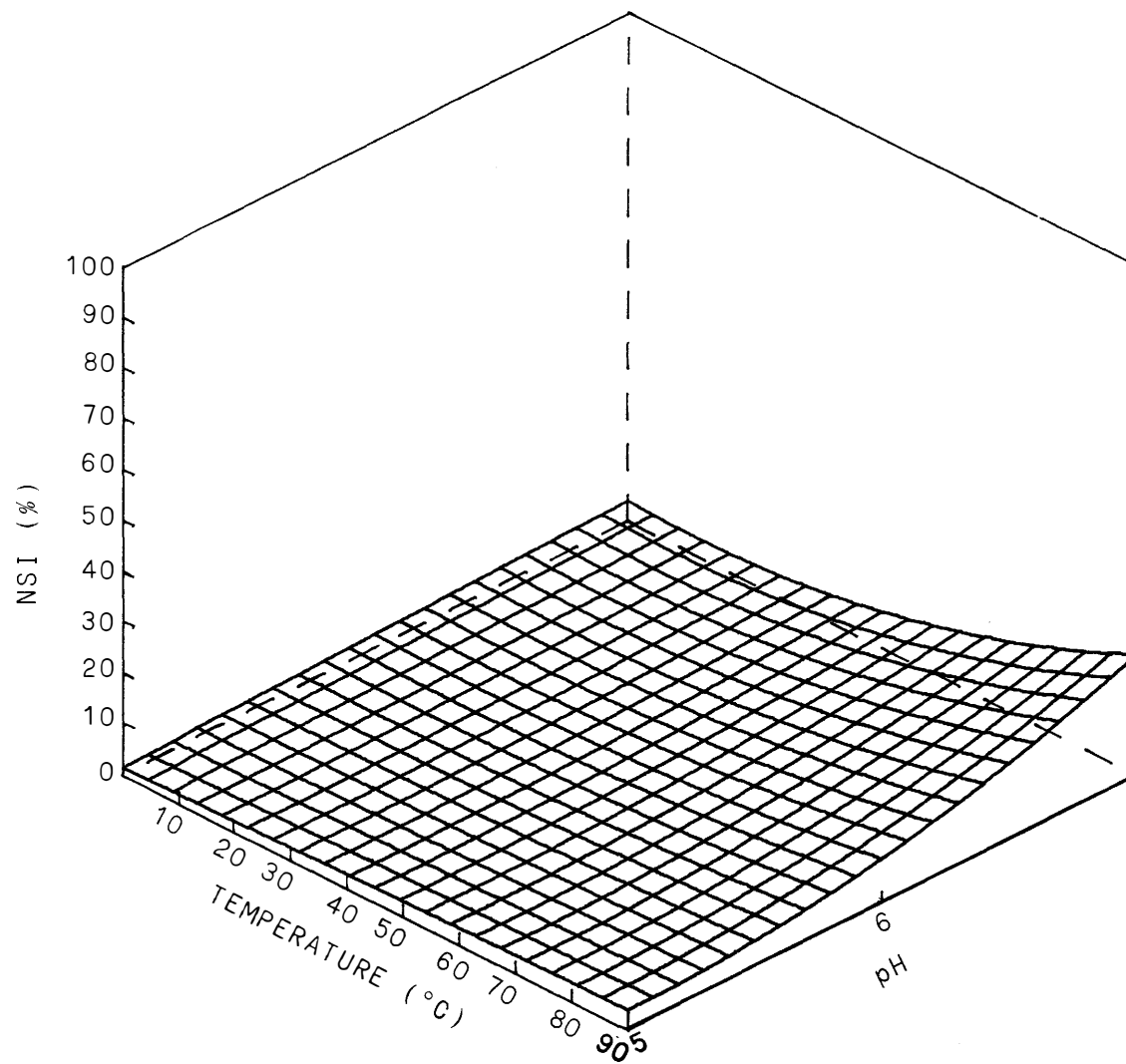


Fig. 4—NSI response surface for Promosoy-100₁ with variations in pH and temperature

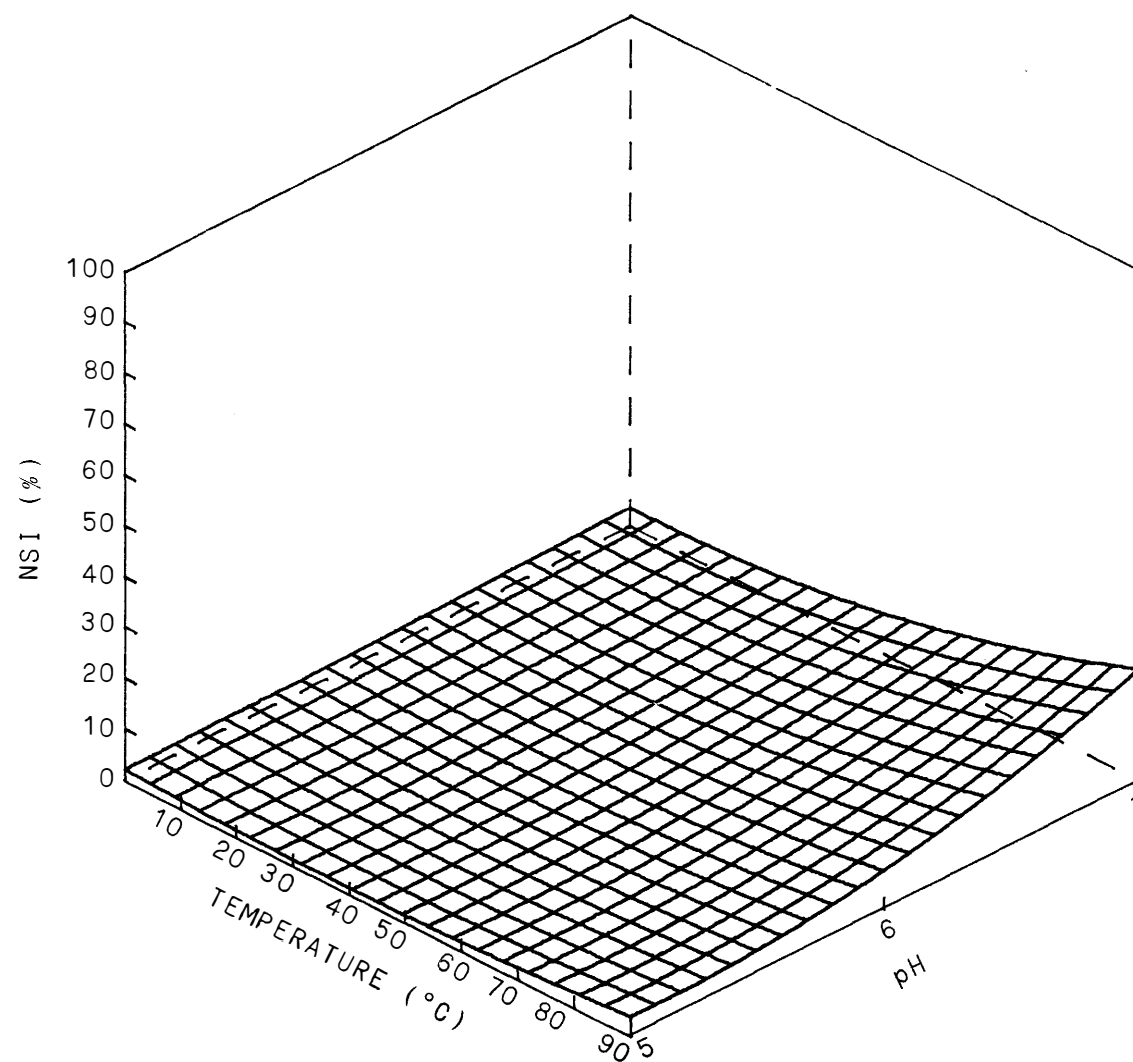


Fig. 5—NSI response surface for Promosoy-100₂ with variations in pH and temperature

Table 4—NSI mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ at all combinations of pH and temperature

Soy	NSI (%)								
	P-D			P-100 ₁			P-100 ₂		
pH	5.0	6.0	7.0	5.0	6.0	7.0	5.0	6.0	7.0
Temp (°C)									
4	2.91	5.95	44.75	1.30	2.71	3.38	1.99	1.85	3.48
Ambient ^b	4.72	21.73	49.27	2.09	2.09	4.03	0.81	1.74	4.57
90	5.92	26.18	75.10	3.70	8.43	23.63	3.62	7.32	21.69

^aAdjusted for day and order effects

^b22-25°C

Table 5—NSI mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ as a function of pH

Soy	P-D			P-100 ₁			P-100 ₂		
	5.0	6.0	7.0	5.0	6.0	7.0	5.0	6.0	7.0
NSI (%)	4.52	17.95	56.38	2.36	4.41	10.35	2.14	3.63	9.91

^aAdjusted for temperature, soy × temperature, pH × temperature, day, and order effects

a slight increase in NSI was observed as temperature increased from 4°C to ambient. The most dramatic effect of temperature on NSI of P-D samples at pH 7.0 occurred as the temperature increased from ambient to 90°C. The pH-temperature relationship is evident in Figure 3, page 44, and Table 4, page 47.

The NSI response surfaces for P-100₁ and P-100₂ samples (Figure 4, page 45, and Figure 5, page 46) are similar to each other. The response surfaces and the corresponding data (Table 4) demonstrate that NSI for Promosoy samples increased, with two exceptions, as pH increased from 5.0 to 7.0. The exceptions were between pH 5.0 and 6.0 at ambient temperature for P-100₁ and at 4°C for P-100₂. For both P-100₁ and P-100₂, the greatest effect of pH was the increase in NSI that occurred as pH increased at 90°C.

The effect of temperature on NSI of Promosoy samples was a consistent increase in NSI between 4 and 90°C (Figures 4 and 5, Table 4). This overall effect of temperature reflects the NSI response of P-100₁ and P-100₂ to the temperature increase from ambient to 90°C; response was not consistent to the increase from 4°C to ambient temperature. The increased NSI with the temperature increase from ambient to 90°C became greater as pH increased and this curvilinearity is apparent in Figures 4 and 5 and Table 4.

The independent effects of pH and temperature on NSI for all soy samples are presented in Table 5, page 47, and Table 6 respectively. The general trend of increased NSI, for all soys, with increased pH

and increased temperature was significant at the level $P < 0.0001$ (Table 7). Differences attributable to soy and to second and third order effects, also were significant at the level $P < 0.0001$.

Table 6—NSI mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ as a function of temperature

Soy	P-D			P-100 ₁			P-100 ₂		
Temp (°C)	4	ambient ^b 90		4	ambient ^b 90		4	ambient ^b 90	
NSI (%)	17.87	25.24	35.74	2.46	2.74	11.92	2.45	2.37	10.87

^aAdjusted for pH, soy \times pH, pH \times temperature, day and order effects

^b22-25°C

Water absorption. Water absorption or hydration capacity of the soy samples was computed as a percentage of the original sample weight on both the as-is and dry weight bases. Since protein content of soy samples has been reported to be primarily responsible for water binding, water absorption of the soy samples also was computed as a percentage of the protein weight of the samples. Similar response surfaces were obtained for a given soy whether water absorption was expressed on the as-is, dry, or protein weight basis. Therefore, only the response surfaces for water absorption as a percentage of the sample dry weight are presented in Figures 6, 7, and 8.

Water absorption of P-D samples (Figure 6) increased as the pH increased from 5.0 to 7.0. The increase was evident at all temperatures

Table 7—NSI mean square values and significance of F-ratios

Source	df	Mean square
Total	80	
Soy	2	3999.6***
pH	2	3712.4***
Temperature	2	1065.4***
Soy × pH	4	1557.4***
Soy × Temperature	4	68.2***
pH × Temperature	4	321.8***
Soy × pH × Temperature	4	21.2***
Day	8	1.5 ^{NS}
Order	8	12.7*** ^a
Residual	42	0.7

*** $P < 0.0001$

^{NS} $P > 0.05$

^aSignificance may be attributable to confounding of 4 df of the soy × pH × temperature effect with the day and order effects.

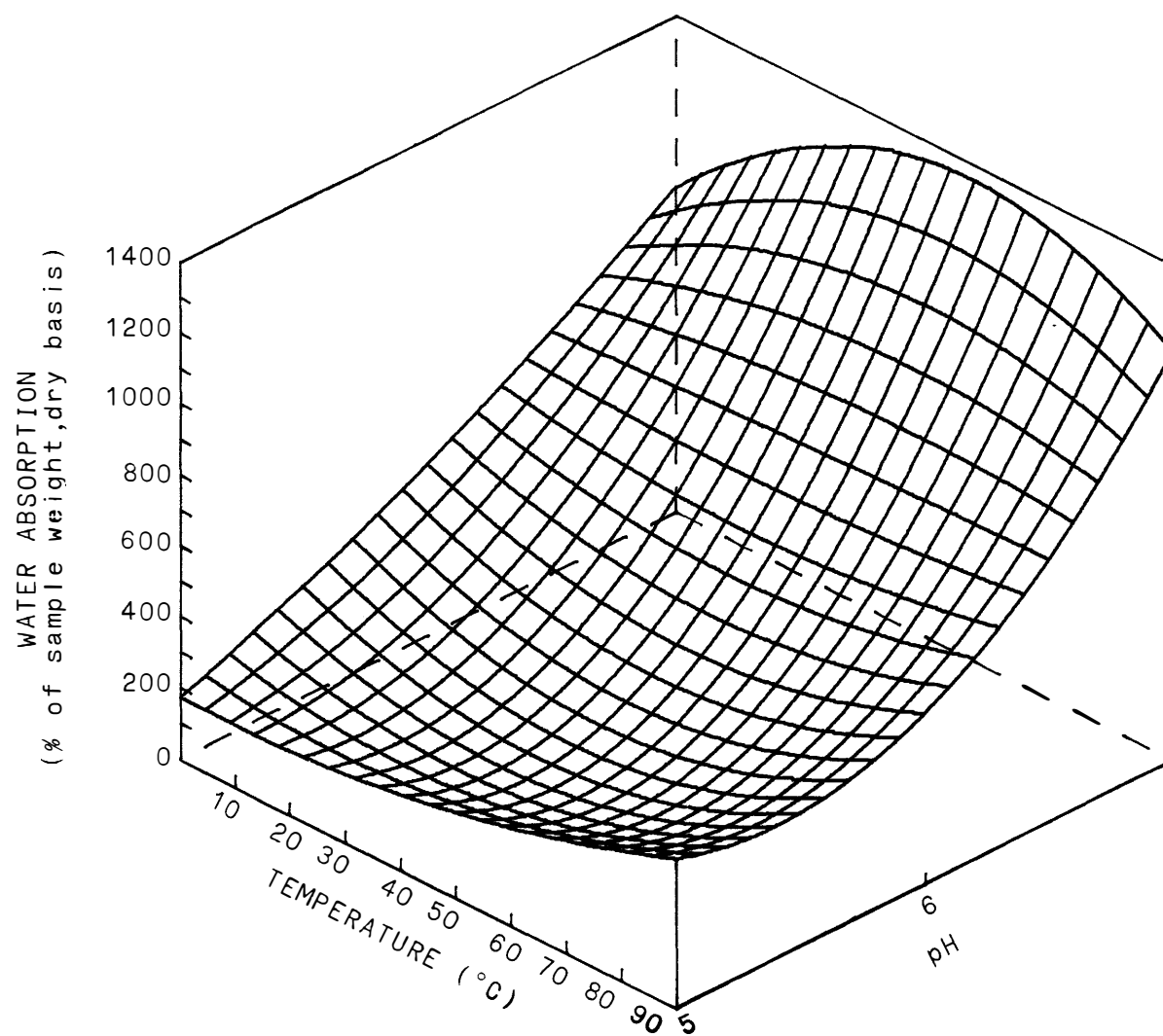


Fig. 6—Water absorption response surface for Promine-D with variations in pH and temperature

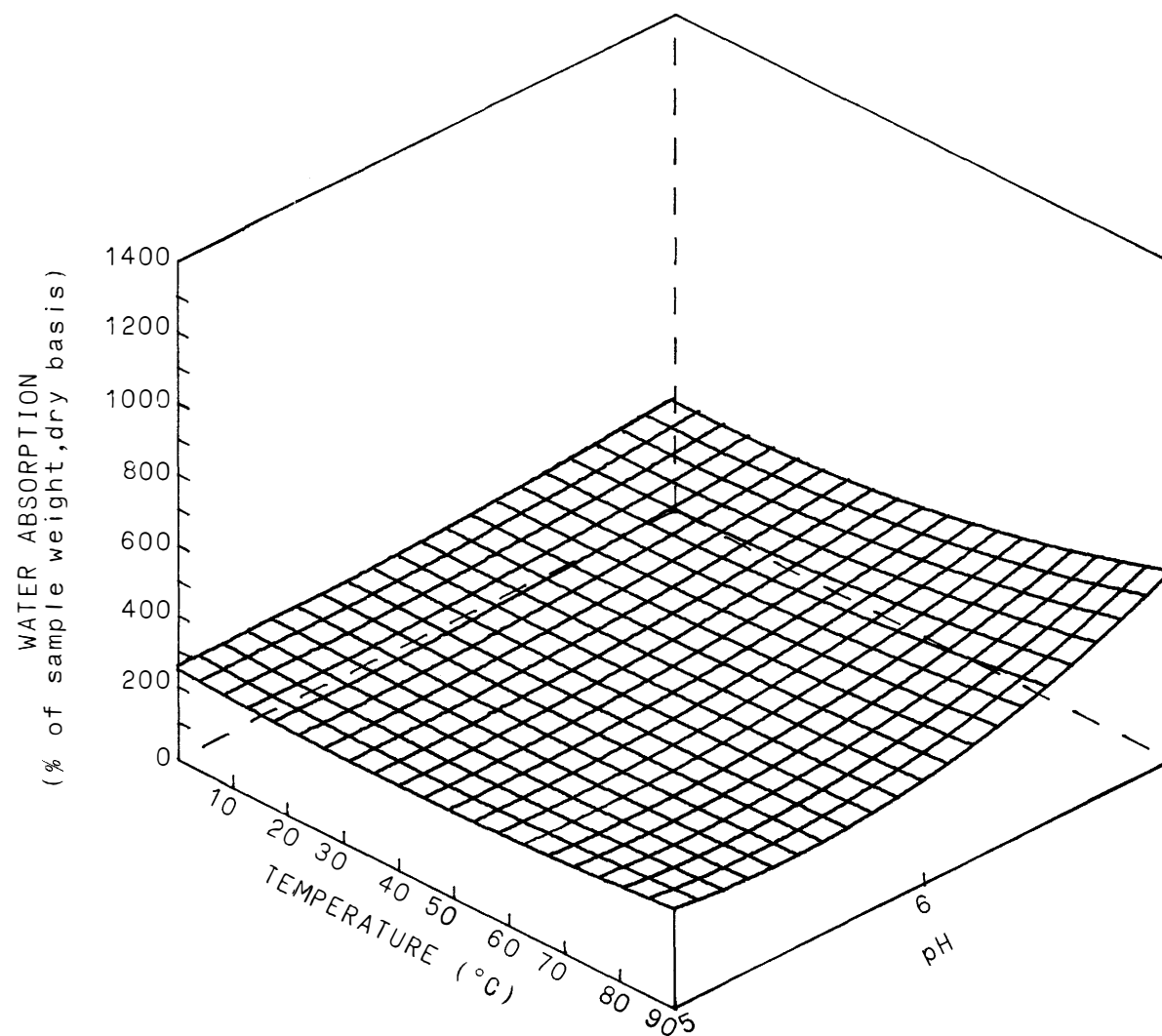


Fig. 7—Water absorption response surface for Promosoy-100₁ with variations in pH and temperature

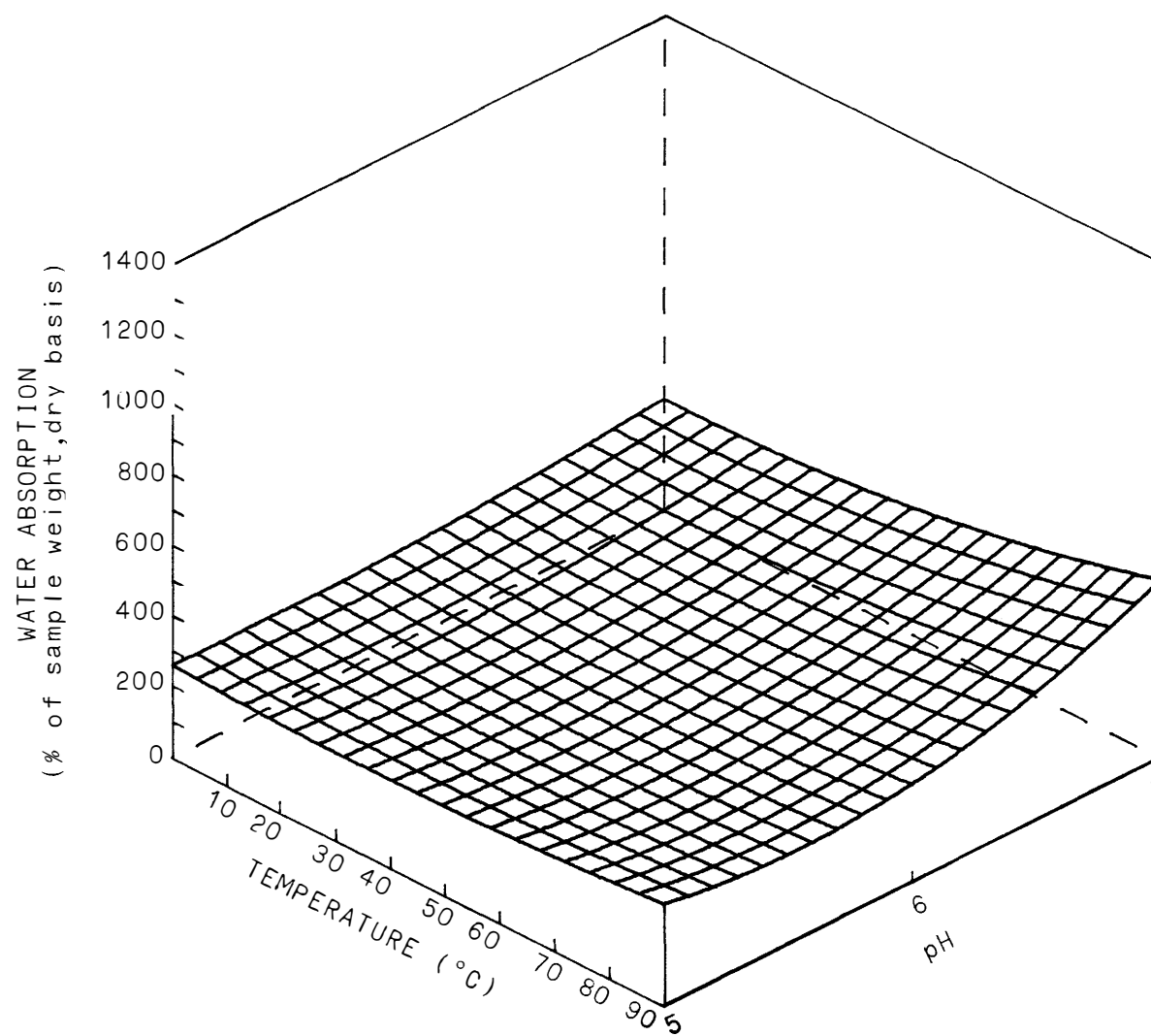


Fig. 8—Water absorption response surface for Promosoy-100₂ with variations in pH and temperature

studied. At the lowest temperature, the increase in percent water absorption with increased pH appears linear on the response surface. However, with increased temperature, the curvilinear effect of pH becomes obvious. The increased curvilinearity is shown also by the data in Table 8, in which the effect of pH change from 6.0 to 7.0 relative to that from 5.0 to 6.0 is seen to have become greater with increasing temperature.

Table 8—Percent water absorption mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ at all combinations of pH and temperature

Water absorption (% of sample weight, dry basis)									
Soy	P-D			P-100 ₁			P-100 ₂		
pH	5.0	6.0	7.0	5.0	6.0	7.0	5.0	6.0	7.0
Temp (°C)									
4	174.9	456.5	975.3	246.5	267.6	325.5	253.4	259.5	315.1
Ambient ^b	189.6	349.6	1218.3	241.0	273.2	340.1	250.3	250.6	312.2
90	407.6	492.6	1158.3	304.7	305.5	536.7	286.7	262.8	513.9

^aAdjusted for day and order effects

^b22-25°C

As shown in Figure 6, page 51, and Table 8, the effect of temperature on percent water absorption of P-D was less than that of pH and was pH dependent. At pH 5.0, percent water absorption increased curvilinearly as temperature was increased. At pH 6.0, percent water absorption first

decreased then increased with increasing temperature. At pH 7.0, percent water absorption first increased then decreased with increasing temperature.

The response surfaces for percent water absorption of P-100₁ and P-100₂ are similar to each other and somewhat different from that for P-D. The response surfaces and the corresponding data (Table 8, page 54, and Table 9) show that the effect of pH on water absorption of Promosoy samples was similar in direction to that for P-D samples but of smaller magnitude. Percent water absorption of P-100₂ was less than that of P-100₁ at all pH levels.

Table 9—Percent water absorption mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ as a function of pH

Soy	P-D			P-100 ₁			P-100 ₂		
pH	5.0	6.0	7.0	5.0	6.0	7.0	5.0	6.0	7.0
Water absorption (%)	257.4	432.9	1117.3	270.1	282.1	401.7	263.5	257.6	380.4

^aAdjusted for temperature, soy × temperature, pH × temperature, day, and order effects

Temperature exhibited less effect than pH on water absorption of Promosoy samples (Figures 7 and 8, pages 52 and 53, Tables 9 and 10). For both P-100₁ and P-100₂ the effect of increasing temperature was a small increase in percent water absorption beyond ambient.

The overall effects of pH and temperature on water absorption are shown in Tables 9 and 10 respectively. The effect of increased pH

overall, disregarding temperature (Table 9, page 55), was increased water absorption for P-D and P-100₁ and a trend in that direction for P-100₂. The effect of increased temperature overall, disregarding pH (Table 10), also was increased water absorption for P-D and a trend in that direction for the Promosoys.

Table 10—Percent water absorption mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ as a function of temperature

Soy	P-D			P-100 ₁			P-100 ₂		
Temp (°C)	4	ambient ^b	90	4	ambient ^b	90	4	ambient ^b	90
Water absorption (% of sample weight, dry basis)	535.6	585.8	684.1	285.9	285.8	382.3	276.0	271.0	354.5
(% of protein weight)	558.0	610.0	713.9	439.0	438.8	573.6	425.2	418.2	534.8

^aAdjusted for pH, soy × pH, pH × temperature, day, and order effects

^b22-25°C

The mean values of percent water absorption expressed on a protein weight basis also are recorded in Table 10. Although this method of expressing the percent water absorption does not affect the direction of the response of any sample to temperature variation, it does bring the response of P-100₁ and P-100₂ closer to that of P-D.

The pH-temperature interaction that is apparent both in the response surfaces and in the two-way table of water absorption values (Table 8, page 54) was significant at the level $P < 0.0001$, as were the other

two-factor interactions, the single effects of soy sample, pH, temperature, and the three-way interaction of soy sample, pH, and temperature (Table 11).

Emulsion properties. The method employed (Inklaar and Fortuin, 1969) for measurement of emulsion properties of soy protein additives did not assess the emulsifying capacity of the soy products. Instead, the method involved measurement of the emulsion stabilizing activity of the soy products as a function of pH and temperature. The oil that was still emulsified after centrifugation was expressed as a weight fraction of the soy sample weight on the as-is, dry, and protein weight bases. The response surfaces for a given soy product were similar whether expressed on the as-is, dry or protein basis and only those for the dry weight are included (Figures 9, 10, and 11).

The response surface of P-D (Figure 9) and the data in Table 12 for P-D on the dry weight basis show the two largest amounts of emulsified oil to have occurred at quite different pH-temperature combinations, pH 7.0 at 4°C and pH 5.0 at 90°C. At 4°C, the amount of emulsified oil increased with increasing pH. At ambient temperature, pH appeared to exhibit little effect on emulsified oil. At 90°C, the effect of pH was reversed over that at 4°C. Temperature effects similarly were pH-dependent.

The emulsified oil response surfaces for P-100₁ and P-100₂ differ from each other as well as from that for P-D. The surfaces are lower for the Promosoy samples than for the P-D and are different in shape for all three samples. P-100₁ emulsified maximum amounts of

Table 11—Percent water absorption mean square values and significance of F-ratios

Source	df	Mean square
Total	80	
Soy	2	776,169.5***
pH	2	1,060,464.7***
Temperature	2	93,257.5***
Soy × pH	4	444,250.8***
Soy × temperature	4	3,635.6***
pH × Temperature	4	18,263.4***
Soy × pH × Temperature	4	15,639.6***
Day	8	1,386.8*** ^a
Order	8	8,024.3*** ^a
Residual	42	345.2***

***P < 0.0001

^aSignificance may be attributable to confounding of 4 df of the soy × pH × temperature effect with the day and order effects.

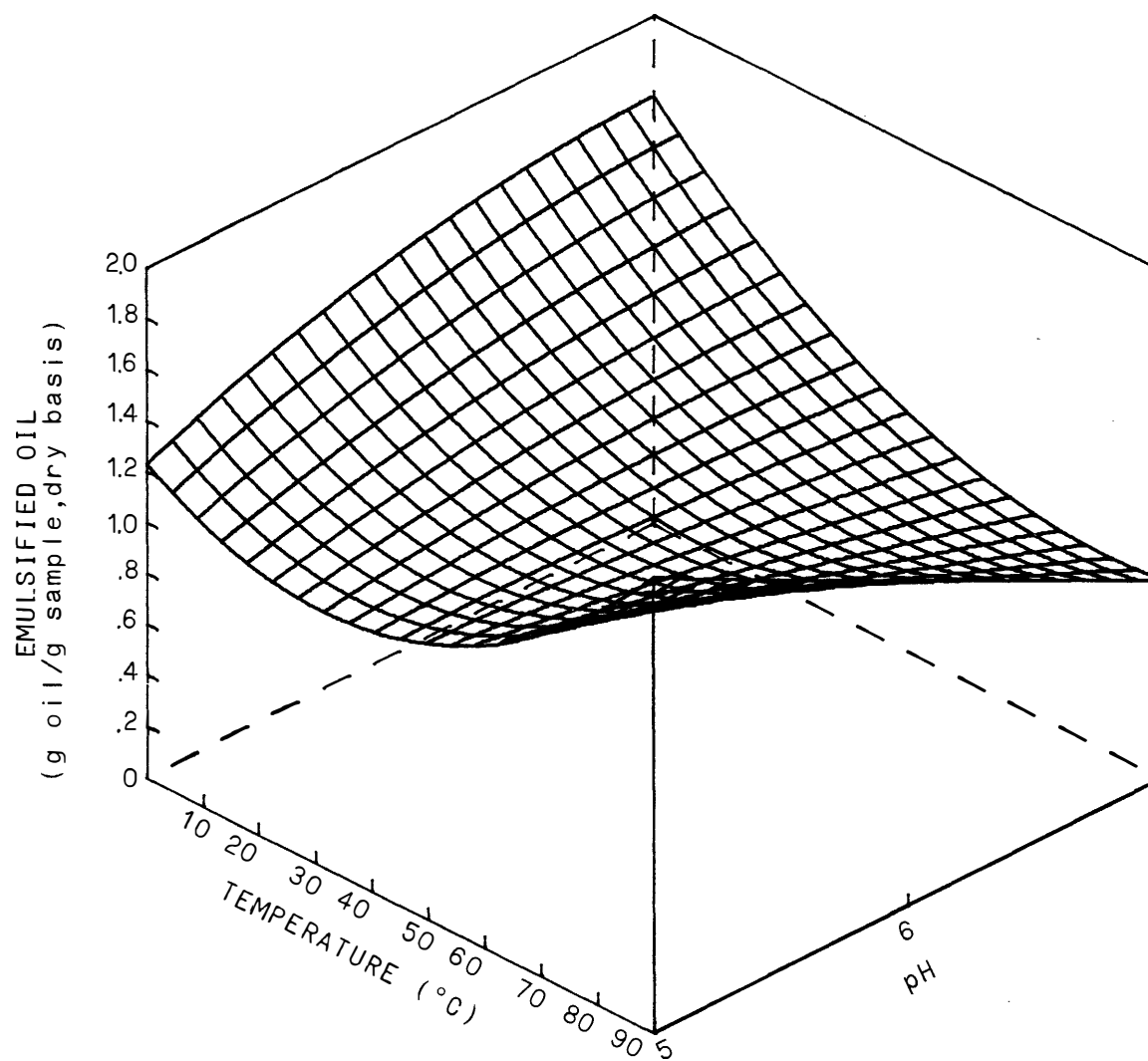


Fig. 9—Emulsified oil response surface for Promine-D with variations in pH and temperature

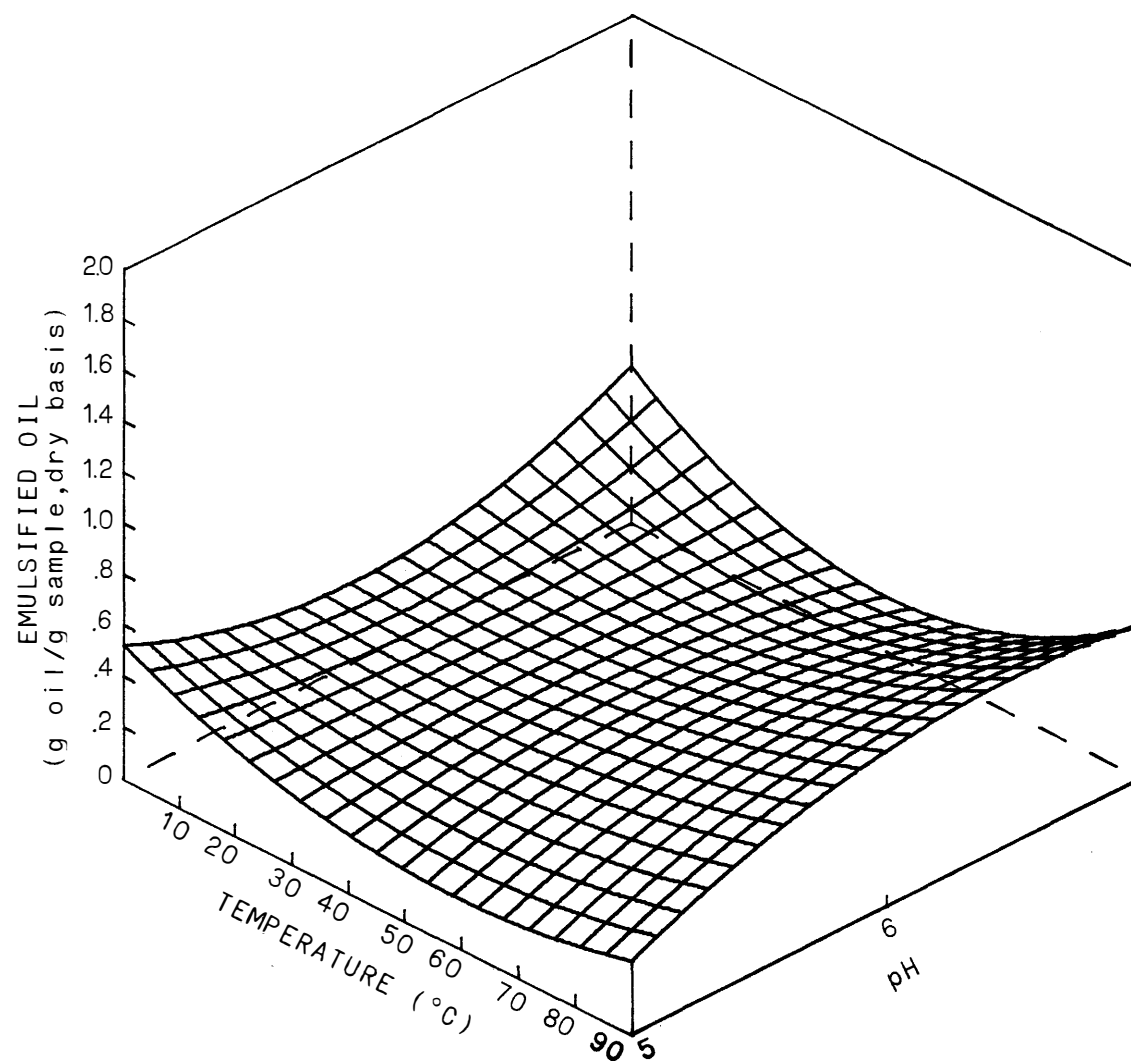


Fig. 10—Emulsified oil response surface for Promosoy-100₁ with variations in pH and temperature

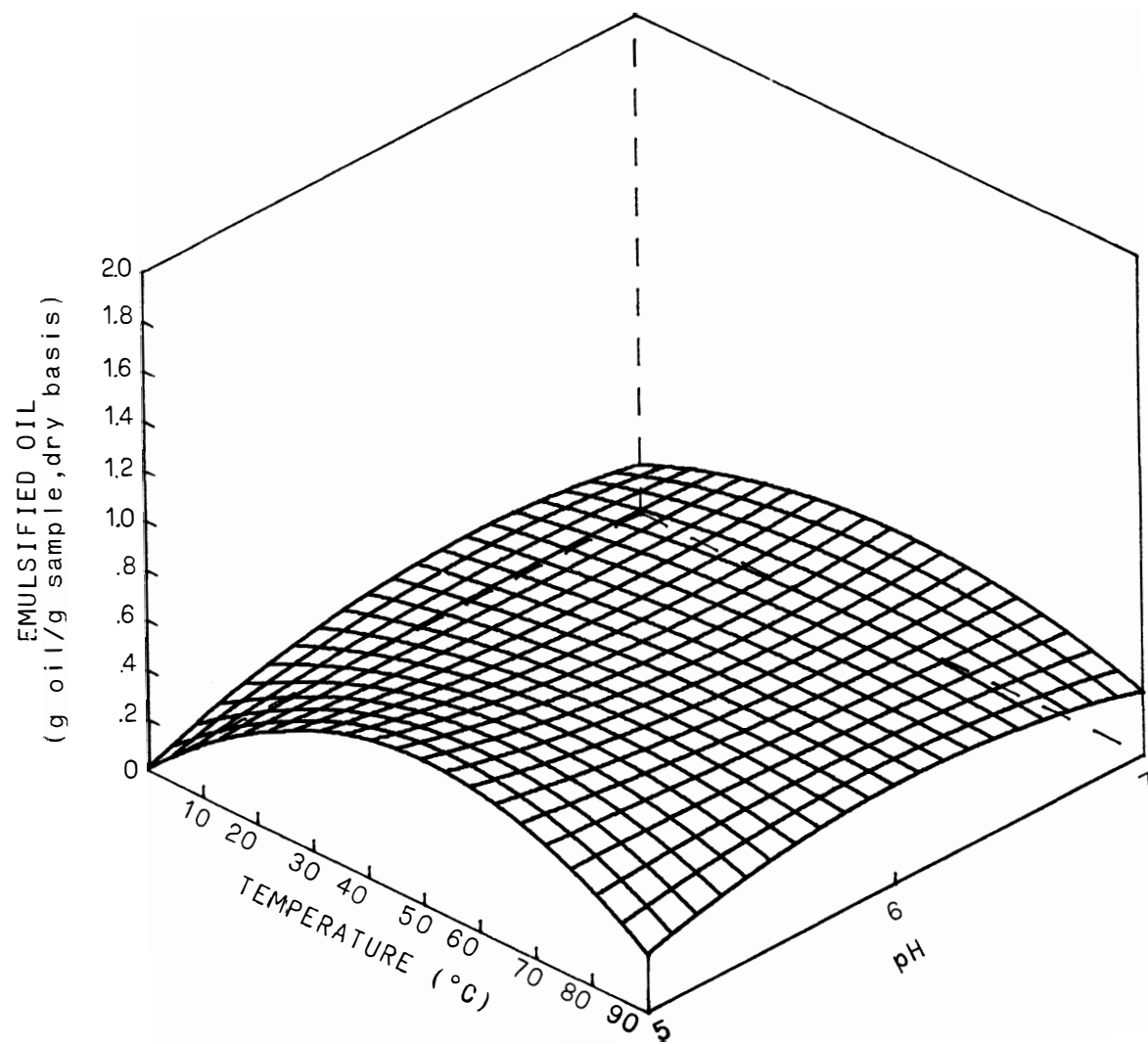


Fig. 11—Emulsified oil response surface for Promosoy-100₂ with variations in pH and temperature

oil at pH 7.0 and the temperature extremes, 4 and 90°C (Figure 10, page 60, Table 12), as well as at 90°C in combination with pH 6.0. P-100₂, on the other hand, emulsified maximum amounts of oil at ambient temperature with the highest and lowest pH values as well as at 90°C in combination with pH 6.0 (Figure 11, page 61, Table 12). The differing responses of the soy samples are seen also in Tables 13 and 14, in which the overall effects of pH and temperature on amount of oil emulsified are shown.

Table 12—Emulsified oil mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ at all combinations of pH and temperature

Soy	Emulsified oil (g oil/g sample, dry basis)								
	P-D			P-100 ₁			P-100 ₂		
pH	5.0	6.0	7.0	5.0	6.0	7.0	5.0	6.0	7.0
Temp (°C)									
4	1.19	1.47	1.59	0.48	0.32	0.54	0.09	0.27	0.24
Ambient ^b	1.06	1.17	1.20	0.28	0.34	0.29	0.40	0.32	0.40
90	1.74	1.31	0.81	0.31	0.55	0.63	0.26	0.42	0.20

^aAdjusted for day and order effects

^b22-25°C

Although the soy samples differed in their overall response to pH and to temperature, Promine-D was a more effective emulsifier than the Promosoy, even when the Promosoy was used on an equal-protein basis or when the values were expressed as g oil/g protein.

Table 13—Emulsified oil mean values^a for Promine-D, Promosoy-100₁, and Promosoy 100₂ as a function of pH

Soy	P-D			P-100 ₁			P-100 ₂		
pH	5.0	6.0	7.0	5.0	6.0	7.0	5.0	6.0	7.0
Emulsified oil									
(g oil/g sample, dry basis)	1.33	1.31	1.20	0.36	0.41	0.49	0.25	0.34	0.25
(g oil/g protein)	1.38	1.36	1.24	0.50	0.57	0.68	0.34	0.47	0.39

^aAdjusted for temperature, soy × temperature, pH × temperature, day, and order effects

Table 14—Emulsified oil mean values^a for Promine-D, Promosoy-100₁, and Promosoy-100₂ as a function of temperature

Soy	P-D			P-100 ₁			P-100 ₂		
Temp (°C)	4	ambient ^b	90	4	ambient ^b	90	4	ambient ^b	90
Emulsified oil									
(g oil/g sample, dry basis)	1.41	1.14	1.29	0.45	0.31	0.50	0.20	0.38	0.29
(g oil/g protein)	1.46	1.18	1.33	0.62	0.43	0.70	0.28	0.52	0.41

^aAdjusted for pH, soy × pH, pH × temperature, day, and order effects

^b22-25°C

Mean squares and significance levels are reported in Table 15 for emulsified oil expressed on as-is, dry weight and protein weight bases.

Table 15—Emulsified oil mean square values and significance of F-ratios

Source	df	Mean square		
		sample weight, as-is	sample weight, dry	protein weight
Total	80			
Soy	2	6.619***	7.847***	6.448***
pH	2	0.011 ^{NS}	0.012 ^{NS}	0.024**
Temperature	2	0.054***	0.062***	0.077***
Soy × pH	4	0.047***	0.046***	0.069***
Soy × Temperature	4	0.116***	0.133***	0.207***
pH × Temperature	4	0.102***	0.117***	0.126***
Soy × pH × Temperature	4	0.153***	0.176***	0.218***
Day	8	0.050*** ^a	0.057*** ^a	0.068*** ^a
Order	8	0.054*** ^a	0.062*** ^a	0.077*** ^a
Residual	42	0.004	0.004	0.005

***p < 0.0001

^{NS}p > 0.05

**p < 0.05

^aSignificance may be attributable to confounding of 4 df of the soy × pH × temperature effect with the day and order effects.

Regardless of the basis of expression, the effects of soy product, temperature, and all two-factor interactions were significant at the level $P < 0.0001$. The three-factor interaction was significant at the level $P < 0.0001$ or $P < 0.05$, depending on the basis of expression. The effect of pH as an individual factor was significant ($P < 0.05$) only for the analysis of values based on protein weight.

Fat absorption. Fat absorption data were collected for all soy samples at all temperature levels but only at the as-is pH. Fat absorbed by the soy samples was expressed as a percentage of the original sample weight on the as-is, dry, and protein bases. Fat absorption data, expressed on each basis, for soy samples held at 4°C, ambient temperature, and 90°C are presented in Figures 12, 13, and 14. The general response of each soy product was not altered as the basis of expressing the absorbed oil was changed. However, expression of fat absorption on the basis of protein weight (Figure 14) brings the curves for the different soy products quite close together and changes their relationship at 4 and 90°C.

Fat absorption for P-D was significantly higher than that for the Promosoy with fat absorption expressed on either the as-is or dry weight basis ($P < 0.0001$, Tables 16 and 17). The fat absorption data for the as-is basis are not included in Table 17 because of their similarity to the dry weight data. Fat absorption values are expressed on all three bases, but with temperature disregarded, in Table 18. The much higher fat absorption values for Promine-D than for the Promosoy-100 are changed when the values are expressed on the basis

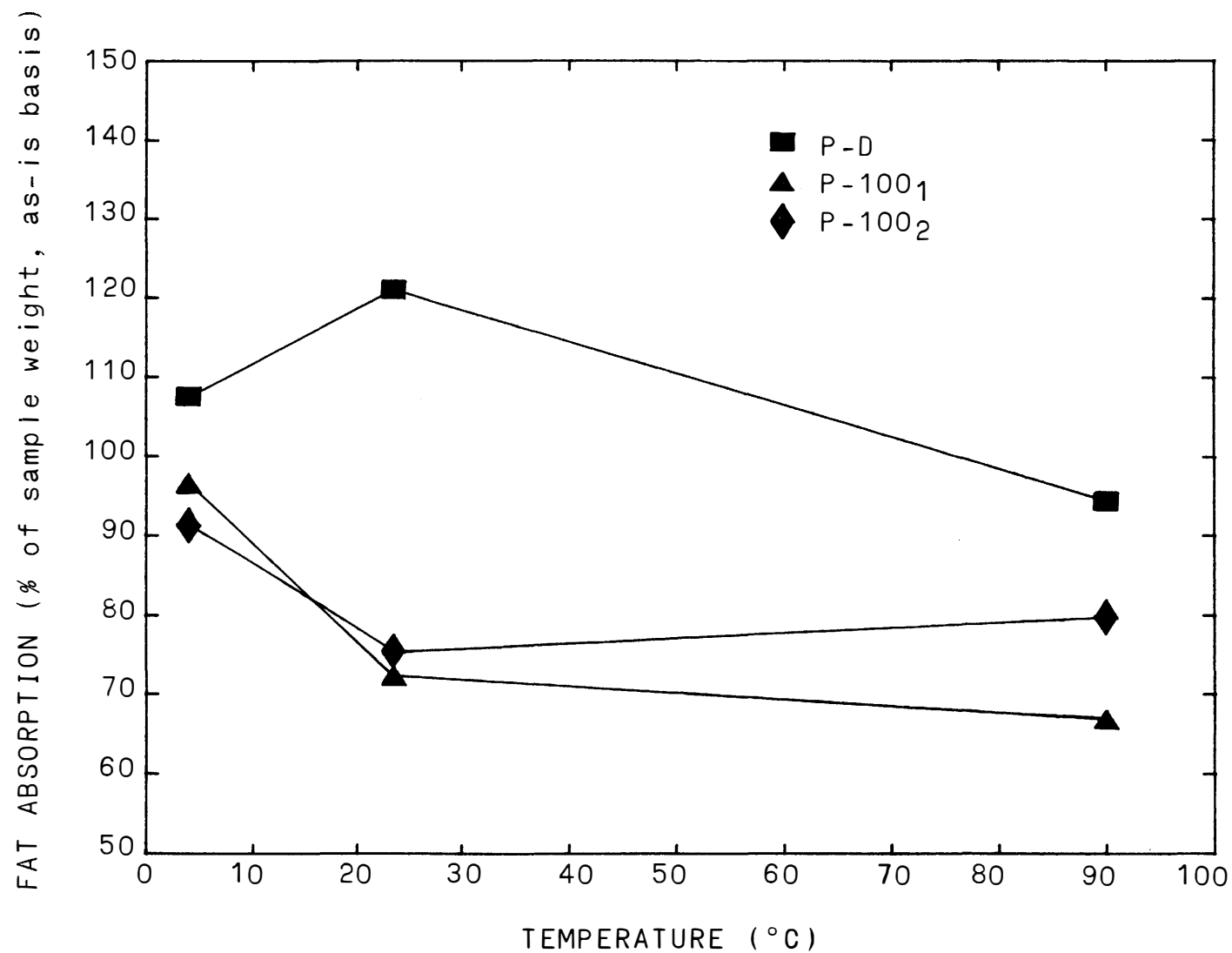


Fig. 12—Fat absorption (% of sample weight, as-is basis) of Promine-D, Promosoy-100₁, and Promosoy-100₂ held at 4°C, ambient temperature (22-25°C), and 90°C

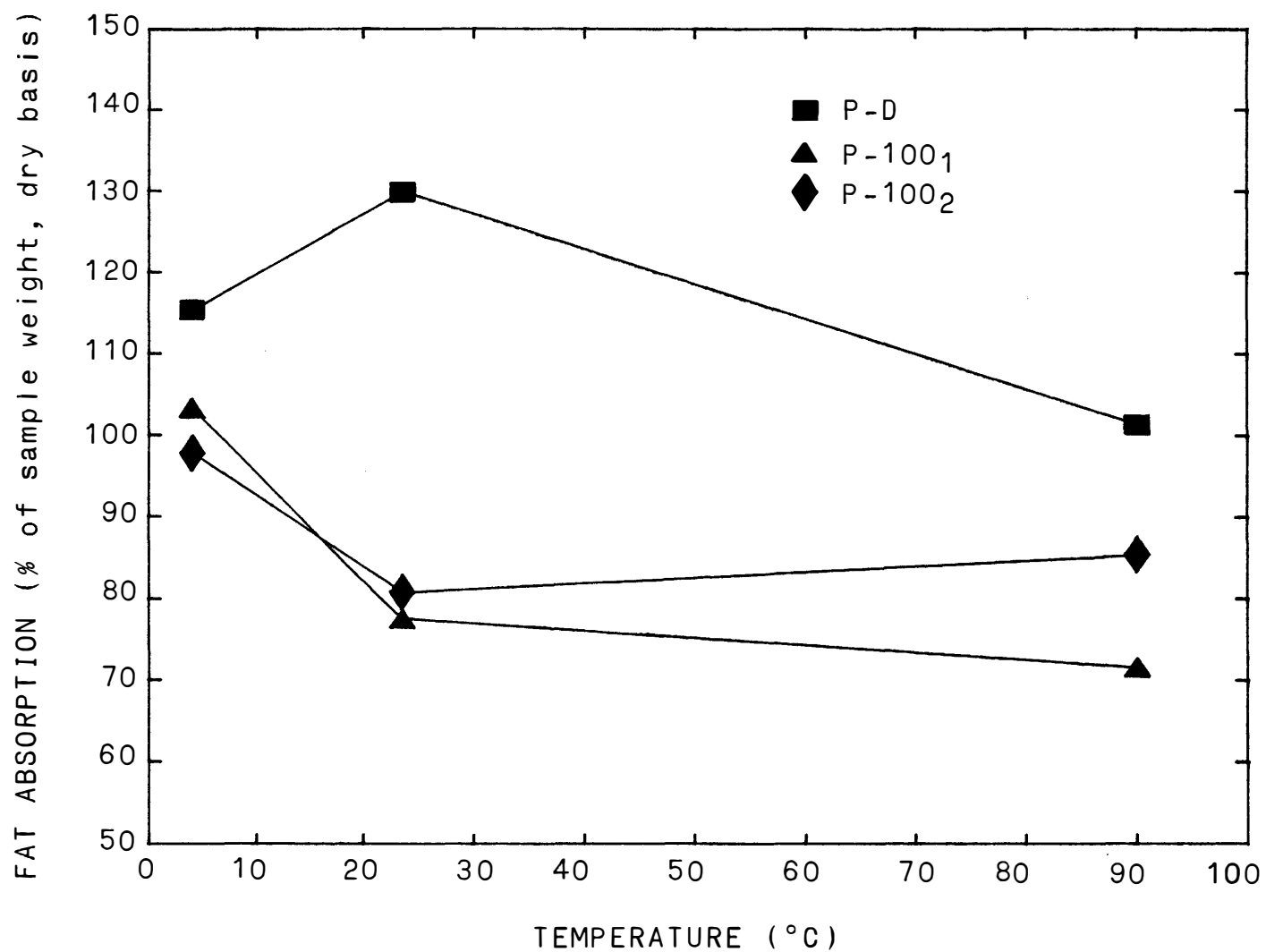


Fig. 13—Fat absorption (% of sample weight, dry basis) of Promine-D, Promosoy-100₁, and Promosoy-100₂ held at 4°C, ambient temperature (22-25°C), and 90°C 2

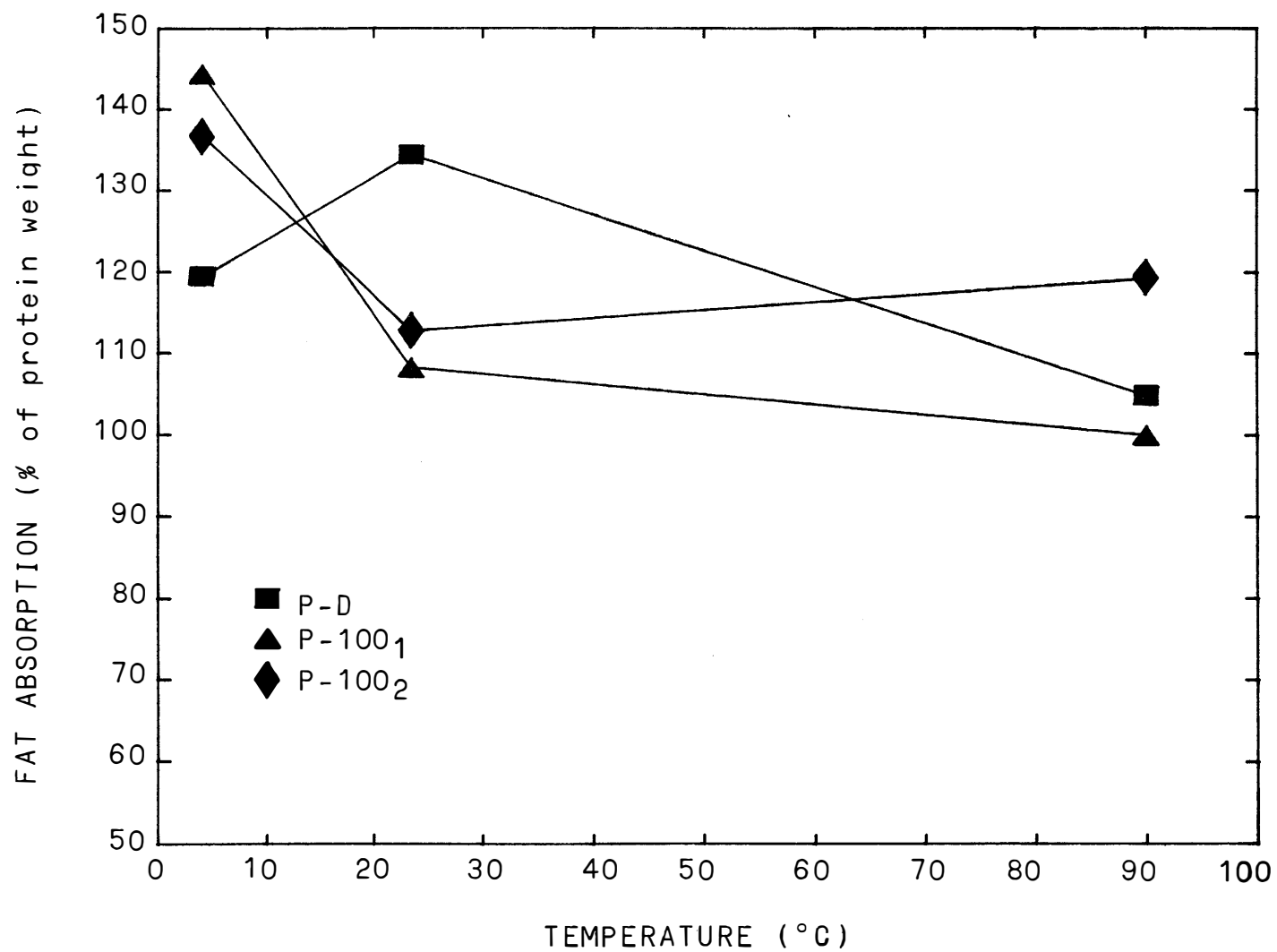


Fig. 14—Fat absorption (% of protein weight) of Promine-D, Promosoy-100₁, and Promosoy-100₂ held at 4°C, ambient temperature (22-25°C), and 90°C

Table 16—Fat absorption mean square values and significance of F-ratios

Source	df	Mean square		
		sample weight, as-is	sample weight, dry	protein weight
Total	26			
Soy	2	2264.7***	2630.5***	68.42 ^{NS}
Temperature	2	742.6***	850.8***	1473.0***
Soy × Temperature	4	372.4***	426.1***	655.3***
Replication	2	7.6 ^{NS}	8.8 ^{NS}	15.65 ^{NS}
Residual	16	14.1	16.2	20.7

^{NS}_P > 0.05

***p < 0.0001

Table 17—Fat absorption mean values for Promine-D, Promosoy-100₁, and Promosoy-100₂ with variations in temperature

Soy	P-D			P-100 ₁			P-100 ₂		
Temp (°C)	4	ambient ^a	90	4	ambient ^a	90	4	ambient ^a	90
Fat absorption (%)									
Sample weight, as-is	107.6	121.1	94.4	96.6	72.4	66.8	91.4	75.5	79.8
Sample weight, dry	115.4	129.8	101.3	103.4	77.5	71.5	97.8	80.8	86.5
Protein weight	119.5	134.4	104.8	144.4	108.3	99.9	136.7	112.9	119.5

^a22-25°C

Table 18—Fat absorption mean values for Promine-D, Promosoy-100₁, and Promosoy-100₂

Soy	Fat absorption (%)		
	P-D	P-100 ₁	P-100 ₂
Sample weight, as-is	107.7	78.6	82.3
Sample weight, dry	115.5	84.1	88.0
Protein weight	119.6	117.5	123.0

of protein weight. Differences attributable to temperature and the soy-temperature interaction effects were significant at the level $P < 0.0001$ for all bases of expression (Table 16, page 69).

Maximum fat absorption of P-D samples occurred at ambient temperature and minimum fat absorption occurred at 90°C. Fat absorption of P-100₁ decreased dramatically as temperature increased from 4°C to ambient. The decrease, though more gradual, continued as the temperature increased to 90°C (Figure 13, page 67, Table 17, page 69). The fat absorption response of P-100₂ samples was a decrease similar to that of P-100₁ samples as the temperature was increased from 4°C to ambient, but a slight decrease as the temperature was increased further to 90°C (Figure 12, page 66, Figure 13, page 67, Figure 14, page 68, and Table 17, page 69). When the values for all soy samples are averaged (Table 19), the overall effect of increasing temperature is seen to be decreased fat absorption. Such an effect could be attributable to increased viscosity of oil at decreased temperature.

Table 19—Fat absorption mean values as a function of temperature

Temperature (°C)	Fat absorption (%)		
	4	Ambient ^a	90
Sample weight, as-is	98.6	89.7	80.4
Sample weight, dry	105.5	96.1	86.1
Protein weight	133.5	118.5	108.0

^a22-25°C

Thickening function. The soy products used and the varied pH and temperature conditions under which they were studied presented problems in the measurement of apparent viscosity. One problem involved dispersion stability; some dispersions tended to separate, especially at low pH and high temperature combinations. Another problem was the wide overall range in viscosity of the dispersions relative to the capacity of the Brookfield Helipath with T-spindles. Apparent viscosity of dispersed Promine-D and that of dispersed Promosoy-100 on the equal weight basis represented the upper and lower extremes of viscosity, far exceeding the capacity of the viscometer. The only way that it was possible to compare the isolate and the concentrate was to narrow the viscosity range by using the soy products only on the equal protein basis. Therefore, apparent viscosity values are reported only for P-D and P-100₂.

As the pH of P-D dispersions increased (Table 20), the dispersions decreased in apparent viscosity but were observed to increase in stability. The effect of pH occurred primarily between pH 6.0 and 7.0 and the decreased viscosity with increased pH was evident at all temperature levels studied.

Table 20—Apparent viscosity mean values of soy dispersions with variation in pH and temperature^a

Apparent viscosity (cps)						
Soy	P-D			P-100 ₂		
pH	5.0	6.0	7.0	5.0	6.0	7.0
Temp (°C)						
4	62,693	50,519	2,153	84 ^c	166 ^c	765 ^c
Ambient ^b	55,278	43,326	1,268	86 ^c	151 ^c	451 ^c
90	166,000 ^{d,e}	166,000 ^{d,e}	64,463	233 ^{c,f}	456 ^{c,f}	19,992

^aAll P-D samples were tested at 6 rpm and all P-100₂ samples at 12 rpm.

^b22-25°C

^cMeasurements were made with T-B spindle; others were made with T-F spindle.

^dUpper limit of Brookfield with Helipath stand

^eA clear aqueous layer separated downward from the soy-rich dispersion, which became a grainy semisolid.

^fA thin cloudy aqueous layer separated upward from the soy-rich dispersion which had the same appearance as the original dispersion.

Temperature effects on apparent viscosity of P-D dispersions also are recorded in Table 20, page 72. P-D dispersions exhibited minimum viscosity at ambient temperature. Apparent viscosity increased slightly as the temperature was lowered to 4°C and dramatically as the temperature was increased to 90°C.

P-100₂ dispersions, like P-D dispersions, were more stable at pH 7.0 than at the lower pH values. Stability also was greater at the lower temperatures than at 90°C.

P-100₂ differed from P-D in the effect of pH on dispersion viscosity. Apparent viscosity of P-100₂ dispersions, as shown in Table 20, page 72, increased as pH increased from 5.0 to 7.0. The increase occurred primarily between pH 6.0 and 7.0 and was evident at all temperatures studied. At pH 7.0 and 90°C, the apparent viscosity values of P-100₂ dispersions were of a far greater magnitude than those of the other P-100₂ dispersions.

The effect of temperature on apparent viscosity of P-100₂ dispersions was similar to that for P-D dispersions (Table 20). The apparent viscosity values were consistently lower for P-100₂ dispersions than for P-D dispersions. Differences in apparent viscosity attributable to soy, pH, temperature, and all interactions were significant at the level $P < 0.0001$ (Table 21).

Discussion of Results for Simple Systems

The Promosoy samples, P-100₁ and P-100₂, had much lower NSI values than did the P-D samples (Table 4, page 47). Lin et al. (1974) compared PSI of Promine-D and Promosoy-100 at as-is pH and ambient temperature

Table 21—Apparent viscosity mean square values and significance of F-ratios

Source	df	Mean square
Total	53	
Soy	1	57,882,066,182***
pH	2	5,676,668,795***
Temperature	2	15,911,258,845***
Soy × pH	2	8,485,821,335***
Soy × Temperature	2	12,090,294,789***
pH × Temperature	4	184,848,810***
Soy × pH × Temperature	4	827,379,497***
Replication	2	419,470 ^{NS}
Residual	34	1,006,784

***P < 0.0001

^{NS}P > 0.05

and reported PSI values of 71.1 and 6.0% for P-D and P-100 respectively. Mattil (1974) reported variations in solubility measurements among soy isolates and soy concentrates studied. The maximum solubility reported by Mattil for the isolates as a group was considerably higher than that for the concentrates. Mattil did not identify the isolates and concentrates studied; therefore, no direct comparisons can be made with data of the present investigation.

Since NSI is computed from the ratio of soluble nitrogen to total nitrogen of the sample, the differences in NSI cannot be attributed to the differences in total nitrogen content between isolates and concentrates. Also, P-100₂ was compared on an equal protein ($N \times 6.25$) basis with P-D but the NSI values for P-100₂ samples were similar to those of P-100₁ samples. Therefore, the dramatic differences in NSI between isolate and concentrate samples would seem to be attributable to one or more other factors. One possibility is variation in processing methods. Another possibility is the effect of the non-protein portion of the soy product. This component is primarily polysaccharide in soy isolates and concentrates. Polysaccharides could compete with other system components, protein in this case, for the available water. The carbohydrate content of the soy used in the NSI measurement was only about 3% for the Promine-D and approximately 28% for Promosoy-100. Because of the larger amount of Promosoy-100 used for the equal protein comparison, P-100₁ and P-100₂ samples also differed in carbohydrate content but not as much as they both differed from Promine-D.

With nearly every soy-temperature combination, the lowest degree of solubility was at pH 5.0; and in every case solubility increased considerably between pH 6.0 and 7.0 (Table 4, page 47). This obviously reflects the well-known low solubility of protein in the vicinity of the isoelectric point. The isoelectric range of soy protein has been reported by Wolf (1969) to be 4.6-4.9.

With every soy-pH combination, the lowest degree of solubility was at 4°C and the highest was at 90°C (Table 4, page 47). Solvent effectiveness normally does increase with increasing temperature, and apparently protein denaturation at 90°C was not a factor. Probably the processing conditions had brought about as much denaturation as would heating to 90°C.

Effects of pH on water absorption paralleled those on solubility, as is to be expected. Effects of temperature on water absorption, for the most part, also paralleled those on solubility. Water absorption results did differ markedly from those for solubility (NSI) for P-D at pH 7.0. At pH 7.0, NSI values for P-D samples increased as temperature increased from 4 to 90°C (Table 4, page 47). On the other hand, percent water absorption for P-D samples at this pH (Table 8, page 54) increased from 4°C to ambient temperature and then decreased gradually from ambient to 90°C. This indicated that water absorption and solubility may be related until a point, perhaps maximum hydration, at which solubility continues to increase and hydration decreases. Several factors and combinations of factors could influence the point at which absorption and solubility trends take different directions.

The emulsion stability data showed few similarities for the soys. P-D consistently emulsified more oil than did P-100₁ or P-100₂ samples (Table 12, page 62). Although the difference between P-D and P-100₁ could be explained at least partially by a difference in the amount of protein to serve as emulsifying agent, the difference between P-D and P-100₂ cannot. Possibly the additional carbohydrate in the P-100₂ successfully competed for water and thus reduced the water available as a dispersion medium.

The pH effect on emulsion stability (Table 12, page 62) not only varied with the soys but also was somewhat temperature-dependent. For the most part, however, the trend was toward increased emulsion stability with increased pH. This general effect probably is related to protein solubility. As the pH increases beyond the isoelectric point, the amount of protein available as an emulsifying agent should increase.

The temperature effect on emulsions (Table 12, page 62) varied so much with the soys that interpretation is extremely difficult. The P-D data indicate an increased emulsion stability when emulsions made at ambient temperature were stored at 4°C. If pH is disregarded (Table 14, page 63), the overall effect of increased temperature from ambient to 90°C also was increased emulsion stability. The effects of both temperature changes from ambient probably can be related to the effect of temperature on viscosity, yet to be discussed. With increased viscosity at storage temperatures of 4 and 90°C relative to ambient, the opportunity for dispersed fat globules to rise toward the top and coalesce was lessened.

The emulsions are the least simple systems studied because of the addition of oil superimposed on differing quantities of carbohydrate present in the different soys. Therefore, no attempt will be made to discuss further the effects of temperature on stability of emulsions made with different soys.

The greater absorption of oil by P-D than by P-100₁ on the basis of sample weight (Table 18, page 70) suggests that the protein was largely responsible for fat absorption. (P-D and P-100₁ were alike as to sample size but P-D contained more protein.) Fat absorption values for P-D also were higher than those for P-100₂ on the basis of sample weight, even though the amount of protein was the same; this indicates that the additional carbohydrate present in P-100₂ with the use of Promine-D and Promosoy on the equal-protein basis certainly did not absorb as much oil as the protein. Finally, expression of the oil absorption results as percent protein weight, also in Table 18, page 70, brings the values for all soy samples into a relatively narrow range, further indicating that most of the fat absorption by the soy products was attributable to the protein.

The apparent viscosity of P-D dispersions was of far greater magnitude than that of P-100 dispersions (Table 20, page 72). This difference in response may be attributable to the greater solubility and water absorption of the P-D samples. The soy dispersions also responded differently with respect to pH. P-D dispersions decreased in apparent viscosity as pH increased from 5.0 to 7.0, whereas P-100₂ dispersions increased in viscosity. At pH 7.0 and 90°C, the apparent

viscosity of P-100₂ dispersions was at a maximum and was similar to that for P-D dispersions. The particularly high viscosity at this pH-temperature combination may be related to the maximum solubility and water absorption of the Promosoy at pH 7.0 and 90°C. The greatest increase in viscosity with increased pH for P-100₂ dispersions was observed as the pH increased from 6.0 to 7.0 (Table 20, page 72). This sudden increase in viscosity from pH 6.0 to 7.0 was evident at all temperatures. Circle et al. (1964) evaluated the apparent viscosity of 10% soy dispersions over a 6.0-9.0 pH range. The viscosity of the unheated dispersions was lower at pH 6.0 than at 7.0 or above. This was attributed to lowered protein solubility at pH 6.0. The decreased viscosity of the soy dispersions as pH was lowered to 6.0 are in agreement with the findings of the present study with regard to Promosoy samples. However, the response of the Promine-D dispersions to pH variations in the present study was not in agreement with any data reviewed.

P-D and P-100₂ responded similarly to variations in temperature, with minimum viscosity exhibited at ambient temperature (Table 20, page 72). Apparent viscosity of the soy dispersions increased slightly as the temperature decreased to 4°C but maximum viscosity was observed at 90°C. Catsimpoolas and Meyer (1970) reported that when 8 and 14% soy dispersions were heated, the sol was irreversibly converted to a progel, which was characterized by high viscosity. This would account for the increased viscosity of the soy dispersions at 90°C.

II. PART B: FOOD SYSTEM

Part B was divided into two phases. The first involved measurement of emulsion stability and apparent viscosity of base products prepared from Promine-D and from Promosoy-100 at two pH levels and held at two temperatures. The second phase involved consumer panel evaluation of a dip formulated from the base products with variations only of soy and pH.

Properties of Base Products

Emulsion stability. All base products were stable when held at 4°C. The P-D base products were unstable at 90°C. An average of 4% (volume basis) liquid separated out of the P-D base products at pH 5.0 and held at 90°C. The P-D base products prepared at pH 6.0 and 90°C appeared "crumbly" throughout; however, no liquid was separated during centrifugation. The P-100₂ base products were stable at 90°C, as well as at 4°C.

Apparent viscosity. Apparent viscosity of the base products prepared at pH 5.0 and 6.0 and held at 4 and 90°C is recorded in Table 22. Maximum viscosity was observed for both P-D and P-100₂ base products at pH 5.0 and a holding temperature of 4°C. These products were too viscous to measure with the Brookfield Helipath. Therefore, if a difference between the P-D and P-100₂ base products existed at pH 5.0, it was not measurable under the conditions of the study. For all other pH-temperature combinations, the P-D prepared

products were similar in viscosity or less viscous than the corresponding P-100₂ products. For both soy products, apparent viscosity was higher at pH 5.0 than at 6.0, and higher at 4°C than at 90°C. Differences attributable to soy, pH, temperature, and all interactions were significant at the level $P < 0.0001$ (Table 23).

Table 22—Apparent viscosity mean values for Promine-D and Promosoy-100 base products prepared at pH 5.0 and 6.0 and held at 4 and 90°C^a

Soy	Apparent viscosity (cps)			
	P-D		P-100 ₂	
pH	5.0	6.0	5.0	6.0
Temp (°C)				
4	166,000 ^b	85,674	166,000 ^b	150,977
90	3,537	2,980	3,320	3,184

^aAll measured at 6 rpm, with spindle T-F for 4°C samples and T-B for 90°C samples

^bUpper limit of Brookfield viscometer with Helipath stand

Consumer Panel Evaluation

Dips prepared from the base products were evaluated by means of descriptive scales for viscosity, mouthfeel, oiliness, flavor, and overall acceptability. The mean scores for these attributes are recorded in Table 24. With both P-D and P-100₂, dips prepared at pH 5.0 were more viscous and scored higher on flavor and overall acceptability than soy dips prepared at pH 6.0. On the other

hand, dips prepared at pH 6.0 were smoother and less oily than dips prepared at pH 5.0. The lower scores for mouthfeel at pH 5.0 were attributable to decreased solubility or increased aggregation of the soy proteins as the pH approached the isoelectric region of the proteins. Levels of significance of F-ratios in the separate analyses of variance are combined into Table 25 for the quality attributes rated. Differences attributable to pH were highly significant (at least $P < 0.0012$) for all quality attributes.

Table 23—Apparent viscosity mean square values and significance of F-ratios for base products

Source	df	Mean square
Total	15	
Soy	1	986,176,672***
pH	1	2,428,538,113***
Temperature	1	76,483,193,480***
Soy × pH	1	1,164,211,932***
Soy × Temperature	1	1,150,400,199***
pH × Temperature	1	2,133,993,135***
Soy × pH × Temperature	1	963,468,686***
Replication	1	779,072 ^{NS}
Residual	7	3,829,766

***p < 0.0001

^{NS}p > 0.05

Table 24—Mean sensory scores for soy dips prepared from Promine-D and Promosoy-100 base products at pH 5.0 and 6.0 and held at 4°C

Soy	P-D		P-100 ₂	
	5.0	6.0	5.0	6.0
pH				
Quality attribute				
Viscosity ^a	5.7	3.2	5.5	3.5
Mouthfeel ^b	4.0	4.5	4.3	4.5
Oiliness ^c	3.0	2.7	3.1	2.8
Flavor ^d	4.1	3.3	4.1	3.6
Overall acceptability ^e	3.3	2.7	3.2	2.9

^aEvaluated on scale 1-6, 6 = "very thick"

^bEvaluated on scale 1-6, 6 = "very smooth"

^cEvaluated on scale 1-4, 1 = "not very oily"

^dEvaluated on scale 1-6, 6 = "very desirable"

^eEvaluated on scale 1-5, 5 = "very good"

Table 25—Significance of main effects and soy-pH interactions for sensory scores

Attribute	Soy	pH	Soy-pH Interaction
Viscosity	NS	P < 0.0001	P < 0.0007
Mouthfeel	NS	P < 0.0012	NS
Oiliness	NS	P < 0.0005	NS
Flavor	NS	P < 0.0001	NS
Overall acceptability	NS	P < 0.0001	NS

NS P > 0.05

Relation of Part A to Part B

Solubility and percent water absorption of soy products in simple system tests were demonstrated to increase generally as pH increased. The lower scores for mouthfeel in the soy dips prepared from pH 5.0 base products were attributed to decreased solubility of the soy proteins at this pH.

Panel oiliness scores may be related to emulsion stability. Panel oiliness scores were significantly higher (indicating increased oil detection) for products prepared at pH 5.0 than for products prepared at pH 6.0. Emulsified oil mean values for soy products in simple systems at 4°C as a function of pH (Table 12, page 62) indicated that soy dispersions (P-D and P-100₂) prepared at pH 5.0 emulsified less oil than corresponding soy dispersions prepared at pH 6.0.

Panel oiliness scores might be expected to be related also to fat absorption. Fat absorption of soy products was not measured with variations in pH. However, a relationship between panel oiliness scores and fat absorption values possibly is suggested by the lack of significant differences in both the panel oiliness scores and the fat absorption values (on protein weight basis) for P-D and P-100₂.

With simple systems, apparent viscosity values of P-D dispersions were higher at pH 5.0 than at 6.0. With the P-D products, viscosity as measured by viscometer and the panel scores indicated more viscous products at pH 5.0 than at 6.0. Dispersions of P-100₂ exhibited increased apparent viscosity in simple systems as pH increased from 5.0 to 7.0. The effect of pH on viscosity of Promosoy dispersions

was less dramatic than that of P-D dispersions. In addition Promosoy dispersions had lower viscosity than P-D. In spite of these differences in P-D and P-100₂ viscosity responses to pH change in simple systems, the products made from P-D and P-100₂ responded similarly to change in pH, as indicated by both panel and Brookfield assessment of viscosity. In other words, P-D performed as predicted from the simple systems study and P-100₂ did not. Combined effect of the low viscosity and low pH-sensitivity of Promosoy (relative to Promine-D) and the possibility of interactions among the product constituents could override the response to pH that would be predicted by behavior of the Promosoy simple systems. The soy dips are more complex systems than the dispersions on which viscosity measurements were made in the first part of the study. Possibly other constituents in the Promosoy base product that contributed to viscosity were affected more by pH than was the Promosoy.

CHAPTER V

SUMMARY

Two commercial forms of soy protein products, Promine-D (a general purpose soy isolate) and Promosoy-100 (a fine-grind soy concentrate), with protein contents on a moisture-free basis of approximately 97 and 72% respectively, were studied. Part A of the study involved a systematic investigation of protein solubility, hydration capacity, emulsion properties, fat absorptivity, and thickening function of the soy products in simple systems at pH levels of 5.0, 6.0, and 7.0 and at temperatures of 4°C, ambient (22-25°C), and 90°C. The soy protein products were compared on both equal sample weight and equal protein bases. Part B involved evaluation of the functional performance of the soy products, compared on an equal protein basis, in a food system. Base products prepared at pH 5.0 and 6.0 and held at 4 and 90°C were evaluated for emulsion stability and apparent viscosity. Dips formulated from the base products were held and evaluated only at 4°C by a consumer panel for viscosity, mouthfeel, oiliness, flavor, and general acceptability. The findings of Part A were related to those of B to evaluate the degree to which the simple system measurements could predict functional performance of the soy protein products in the food system selected.

The isolate (P-D) was more soluble than the concentrate (P-100) at all pH-temperature combinations, as indicated by nitrogen solubility

indices (NSI). NSI values of the soy products generally increased as the pH of the dispersion increased. Solubility of P-D samples increased as temperature increased from 4°C to ambient. The NSI response of Promosoy to a similar temperature increment depended on the basis of comparison, equal sample weight or equal protein. NSI values increased for both P-D and P-100 as the temperature was increased from ambient to 90°C. Differences in NSI values attributable to soy, pH, temperature, and all interactions were significant ($P < 0.0001$).

Hydration capacity, expressed as percent water absorption, generally paralleled solubility. The effects of soy, pH, temperature, and all interactions on water absorption were significant ($P < 0.0001$).

Promine-D, the isolate, was a more effective emulsifier than Promosoy. The soy products differed in their overall response to pH and temperature. Generalization is complicated further by a strong interdependence of pH and temperature effects and by the dependence of Promosoy's emulsifying performance on its use on the equal sample weight or equal protein basis relative to Promine-D. The effects of soy, pH, temperature, and all two-factor interactions were significant ($P < 0.0001$). The three-factor interaction was significant at $P < 0.05$ or $P < 0.0001$ depending on the basis of expression.

Percent fat absorption of Promine-D was greater than that of Promosoy at the as-is pH (7.0) at all temperatures studied. In the absence of water, it was not feasible to vary the pH in the fat absorption measurements. Maximum fat absorption of P-D samples occurred at ambient temperature, whereas that of Promosoy samples

occurred at 4°C. The fat absorption response of Promosoy to temperature depended on its use on the equal sample weight or equal protein basis relative to P-D. The effects of temperature and the soy-temperature interaction were significant ($P < 0.0001$) for all bases of expression, with the exception of soy on fat absorption expressed on the protein weight basis.

Promine-D and Promosoy-100 were compared as to dispersion viscosity only on the equal protein basis. P-D dispersions exhibited greater apparent viscosity than did Promosoy dispersions at all pH-temperature combinations. P-D dispersions decreased and P-100 dispersions increased in apparent viscosity as the pH increased from 5.0 to 7.0. For both the isolate and the concentrate, the apparent viscosity was minimal at ambient temperature and increased slightly at 4°C and dramatically at 90°C. Differences in apparent viscosity attributable to soy, pH, temperature, and all interactions were significant ($P < 0.0001$).

Of the measurements made on simple systems, emulsion stability and viscosity were applicable to the base products used for dips. In addition, the consumer panel evaluated the dips themselves from the standpoint of oiliness and viscosity, as well as smoothness, which is closely related to solubility.

All base product emulsions were stable when held at 4°C. P-D products were unstable at 90°C, particularly at pH 5.0, whereas P-100 products were stable. The consumer panel rated dips made with Promosoy

as more oily than those made with P-D, but the dips presented to the panel had been held only at 4°C.

Contrary to the results with simple systems, P-D base products were less viscous than corresponding P-100 products. Similarly to the results with simple systems, apparent viscosity of P-D base products decreased with increased pH. Contrastingly to the results with simple systems, apparent viscosity of P-100 base products increased with increased pH. Apparent viscosity of base products made with both soys was higher at 90°C than at 4°C; this response paralleled the temperature response of both soys in simple systems. Differences in apparent viscosity attributable to soy, pH, temperature, and all interactions were significant ($P < 0.0001$). The consumer panel rated both P-D and P-100 dips as more viscous at pH 5.0 than at 6.0 ($P < 0.0001$).

Mouthfeel, representing smoothness of the dispersion, was rated higher at pH 6.0 than at 5.0 ($P < 0.0012$). This response paralleled the solubility results for simple systems.

The panel preferred the flavor of dips prepared at pH 5.0. They also gave these dips higher overall acceptability ratings than those prepared at pH 6.0.

Many interactions were observed throughout the study. In addition, simple and complex systems sometimes differed in their response to variations in pH and temperature. Therefore, extreme caution is needed in extrapolation of results from simple systems to food systems.

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APPENDIXES

APPENDIX A

pH ADJUSTMENTS

Table 26—Proportions of HCl and distilled water used for pH adjustments

Measurement	Soy	Desired pH	HCl (N)	Total volume dispersing medium (ml)	Volume HCl used for pH adjustment (ml)	Distilled H ₂ O in dispersing medium (ml)
Solubility and water absorption	P-D	5.0	0.096	50	5.12	44.88
	P-D	6.0	0.096	50	2.10	47.90
	P-100 ₁	5.0	0.096	50	4.66	45.34
	P-100 ₁	6.0	0.096	50	1.90	48.10
	P-100 ₂	5.0	0.096	50	6.99	43.01
	P-100 ₂	6.0	0.096	50	2.91	47.09
Emulsion properties	P-D	5.0	0.096	30	5.10	24.90
	P-D	6.0	0.096	30	0.62	29.38
	P-100 ₁	5.0	0.096	30	4.95	25.05
	P-100 ₁	6.0	0.096	30	0.65	29.35
	P-100 ₂	5.0	0.096	30	7.25	22.75
	P-100 ₂	6.0	0.096	30	1.25	28.75
Thickening function	P-D	5.0	2.8	300	6.1	293.9
	P-D	6.0	2.8	300	2.0	298.0
	P-100 ₂	5.0	2.8	300	8.5	291.5
	P-100 ₂	6.0	2.8	300	2.9	297.1
Base product	P-D	5.0	0.568	120	33.0	87.0
	P-D	6.0	0.568	120	3.4	116.6
	P-100 ₂	5.0	0.568	120	32.6	87.4
	P-100 ₂	6.0	0.568	120	2.8	117.2

APPENDIX B

SCORE CARD

NAME _____ DATE _____

Evaluate one sample for all quality attributes before going to the next sample. Check (✓) the term that best describes each characteristic of the product.

		SAMPLE CODE			
(Score Assigned)	VISCOSITY				
6	Very thick				
5	Moderately thick				
4	Slightly thick				
3	Slightly thin				
2	Moderately thin				
1	Very thin				
	MOUTHFEEL				
6	Very smooth				
5	Moderately smooth				
4	Slightly smooth				
3	Slightly grainy				
2	Moderately grainy				
1	Very grainy				
	OILINESS				
4	Very oily (coats mouth)				
3	Moderately oily				
2	Slightly oily				
1	Not oily at all				
	FLAVOR*				
6	Very desirable				
5	Moderately desirable				
4	Slightly desirable				
3	Slightly undesirable				
2	Moderately undesirable				
1	Very undesirable				

		SAMPLE CODE			
OVERALL ACCEPTABILITY (Consider all characteristics by which (Score you would usually evaluate a food.) Assigned)					
5	Very good				
4	Good				
3	Fair				
2	Poor				
1	Very poor				

*Describe each sample in terms of flavor attributes that you can identify (e.g., strong, bland, sour, bitter, unidentified "off"-flavor, after-taste).

VITA

The author was born in Ozark, Alabama, on August 11, 1946. From 1952 to 1963 she attended elementary school and high school in Greenville, Alabama. In 1963 her family moved to Pensacola, Florida, where she attended Pensacola High School and was graduated in 1964. The following fall she attended Pensacola Junior College, and in May, 1966, she received the Associate of Science degree in Home Economics. In the fall of 1966 she entered the University of Alabama and was graduated with the Bachelor of Science degree in Home Economics. That summer she accepted a research assistantship at The University of Tennessee and was graduated with the Master of Science degree in Food Science in August, 1969. Following marriage to Mr. H. Wayne Hutton in August, 1969, the couple moved to Ithaca, New York, where the author had accepted a teaching position at Cornell University. In September, 1970, a son, John Whetstone, was born and the author returned to The University of Tennessee to initiate work toward the Doctor of Philosophy degree. In July, 1971, a second son, Derek Wayne, was born. The author began teaching at Georgia College, Milledgeville, Georgia, in September, 1972. In August, 1973, she accepted an Instructorship at The University of Tennessee and continued work toward the Doctor of Philosophy degree.

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