

To the Graduate Council:

I am submitting herewith a dissertation written by Carl Jaundoo entitled "Solubility and Dispersion Viscosity of Soy Protein Isolates as Influenced by pH and Sucrose in Model and Food Systems." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Home Economics.

Ada Marie Campbell
Ada Marie Campbell, Major Professor

We have read this dissertation
and recommend its acceptance:

John A. Payne
Harold S. Melton
Mayorie P. Penfield

Accepted for the Council:

L. Evans Gath
Vice Chancellor
Graduate Studies and Research

SOLUBILITY AND DISPERSION VISCOSITY OF SOY PROTEIN
ISOLATES AS INFLUENCED BY pH AND SUCROSE IN
MODEL AND FOOD SYSTEMS

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ABSTRACT

Three commercial soy isolates, Pro Fam S-970, Promine F and Supro 710, were studied. Part A involved the investigation of protein solubility and dispersion viscosity of the isolates in simple models at 3⁰C at pH levels of 3.8, 3.3 and 2.8, attained by additions of citric acid solution. The effects of addition of sucrose at varying levels on solubility and dispersion viscosity of the isolates at the given pH levels were studied also. In Part B the findings of Part A were applied to functional performance of the isolate Supro 710 in a food system. A citrus flavored carbonated soy beverage was made from the isolate and subjected to objective and sensory evaluation. For the calculation of nitrogen solubility index (NSI), the total nitrogen contents of aqueous extracts and of the dry unextracted samples were determined by the standard microKjeldahl method. The objective determination of the apparent viscosity of dispersions of both the simple model and the food system was made with the Cannon-Fenske Routine viscometer, #100. The Quantitative Descriptive Analysis (QDA) method was used for sensory evaluation of the product.

In Part A the main effects of pH and sucrose on NSI were significant for all soy protein isolates; the pH-sucrose interaction was significant for Pro Fam S-970 and Promine F. The solubility of each isolate increased as the dispersion pH was decreased from 3.8 to 2.8. Solubility of each isolate decreased with the addition of sucrose to the dispersions.

The apparent viscosity of isolate dispersions also was affected by both pH and sucrose. A small increase in apparent viscosity of

the dispersions was found for each isolate as the pH of the dispersion was reduced from 3.8 to 2.8. The addition of sucrose to the dispersions also resulted in a small increase in the apparent viscosity.

In Part B, the results of the objective measurement of apparent viscosity were similar to those obtained for the model system in Part A. In the sensory evaluation, both pH and sucrose had significant effects on the individual parameters and on the overall acceptability of the beverage. As could be expected, decreased pH resulted in increased perception of tartness and decreased perception of sweetness; increased sucrose concentration resulted in decreased perception of tartness and increased perception of sweetness. The extent of the effects of sucrose on both tartness and overall acceptability depended on the pH level. The ratings of overall acceptability in relation to the values for specific parameters indicated that the panelists liked a low degree of tartness and a high degree of sweetness.

The combination of a sucrose concentration of either 12 percent with pH 3.8 or 15 percent with pH 3.8 or 3.3 appears to be optimum for this product. A beverage with 12 or 15 percent sucrose at pH 3.8 could contain about 2.2 g soluble protein per 100 ml and one with 15 percent sucrose at pH 3.3 could contain about 2.5 g soluble protein per 100 ml. The rating of borderline acceptability of a soy beverage with any of those pH-sucrose combinations suggests the feasibility of developing such a product.

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CHAPTER I

INTRODUCTION

The pressure of today's growing population combined with the current migration patterns poses a real threat to the health and welfare of many of the world's peoples (Nagy et al., 1978). It is predicted that by the year 2000, the world's population will reach seven billion, with about 80 percent of the human race living in Asia, Africa and Latin America (Nagy et al., 1978). The growth rate of 2.5 percent for these regions, as compared with 1 percent for the developed countries, imposes a critical problem of food supply in countries that can least afford increased population growth (Prager and Duncan, 1976).

To meet the basic caloric requirements in less developed countries it is projected that a caloric increase of 50 percent for the world would be required. In certain areas such as India and Brazil the increases would have to be 100 percent while in Pakistan the figure would be closer to 130 percent. Altschul in 1969 emphasized the desperate need for these increases in the developing countries where the majority of the population consumes diets of inadequate nutritional quality, and at least 20 percent are undernourished because of limited caloric intake. In the decade since, the number of malnourished has risen to a half-billion and is expected to reach 1.3 billion by the year 2,000 (Anon., 1980). According to "The Global Report to the President", the situation is expected to get worse unless immediate steps are taken to combat an already critical situation (Anon., 1980).

The concern for protein in the diet, the unavailability of animal proteins to millions and the expected further limitations of animal protein sources have led to increased use of plant proteins. In addition, there has been growing realization that production of traditional sources of proteins is rapidly approaching the full potential capacity (Fischer, 1974).

Among the plant protein sources available for fabricating food products are the oilseeds, particularly the soybean. Soybeans are an attractive source of protein from the standpoint of cost, quality and quantity. The plant originated in Eastern Asia, where for centuries it has been cultivated and utilized as a food item (Waggle and Kolar, 1979).

The soybean's structure is typical of legumes, having the hull and the cotyledon as the major parts. An epidermis on the cotyledon contains the protein and the oil cells. The composition of the soybean is approximately 8 percent hull, 90 percent cotyledon and 2 percent hypocotyl. Of particular interest to food processors and nutritionists is the oil and protein content of the soybean. It has been reported that the protein and oil contents of the soybean are approximately 42 and 20 percent, respectively (Waggle and Kolar, 1979). Although the oil has been used for a long time, the effective food use of soy proteins has been slow in coming.

Soybeans are classified according to color, with yellow soybeans being the major commercial class. In the food industry soybeans of grades numbers 1 and 2 are widely used (Waggle and Kolar, 1979). From these grades of soybeans, three general categories of food ingredients are produced. These are recognized by their different

chemical and physical properties but more importantly, by their protein content. Flour and grits, the least refined, have a minimum protein content of 50 percent on a dry weight basis. Soy concentrates are more refined and contain approximately 70 percent protein, while isolates, which are the most refined, have a protein content of about 90 percent (Wolf, 1970).

The wide use of soy protein isolates is related to their acceptable sensory qualities, favorable amino acid content and relatively light color. Soy isolates are particularly important to the food scientist from the standpoint of their functional roles in the fabrication and supplementation of various foods. Soy protein isolates have good dispersibility and storage stability (Waggle and Kolar, 1979; Thompson, 1977).

The importance of plant proteins in human nutrition is evidenced by the continued investigation of their functional properties, often in simple models (Coffman and Garcia, 1977; Fleming et al., 1974; Huffman et al., 1975). However, for the proper functional characterization, systematic studies of the proteins in model and selected food systems are necessary. According to Hermansson (1979), such an experimental design is instrumental in providing functional information and also may be regarded as giving a "fingerprint of the protein." Such studies, with a pattern of data rather than individual measurements, provide information that often reduces the number of tests required in protein applications in various products. Assessment of function in a food system requires incorporation of the ingredient of interest into a food formulation and production of the finished product (Johnson, 1970); however, it should be possible to increase the

predictability of performance of proteins in food systems. The importance of studying a protein ingredient in relation to other ingredients under various treatment conditions is borne out by studies involving plant proteins in different formulations (Betschart et al., 1979; Hutton and Campbell, 1977a,b). The study reported herein was part of a systematic evaluation of soy proteins in formulated foods as influenced by other ingredients. The objectives were:

(1) to evaluate protein solubility and dispersion viscosity of three soy protein isolates, supplied by different manufacturers, in simple models at 3°C and at pH levels of 3.8, 3.3 and 2.8, attained by addition of citric acid solution;

(2) to study the effects of addition of sucrose at varying levels of solubility and dispersion viscosity of the isolates at 3°C and at the above pH values; and

(3) to evaluate objectively and subjectively the functional performance of one of the isolates in a food system (carbonated beverage).

CHAPTER II

REVIEW OF LITERATURE

I. FUNCTIONAL PROPERTIES OF SOY PROTEINS

Soybeans, the source of one of the most attractive of plant proteins from the standpoint of cost and protein content, are rarely used in home food production outside of the Orient. The processed soybean, however, has considerable application in the food industry. In almost every case, the soy proteins are used as replacements for costly animal derived ingredients as extenders and as supplements in many foods such as those used in food programs. The underlying consideration of the use of these proteins is their compatibility with other food system ingredients from either a functional or aesthetic standpoint. Soy proteins have been used extensively for their functional contributions in almost every type of food product from dairy types, beverages, confections and dietary products to bread, a universal food.

The functional application of soy proteins in these food products is made possible by the behavior of the proteins under various treatment conditions. In every type of food product, selected functional properties of the proteins were exploited so that the food item was not adversely affected by the incorporation of the soy proteins. Use of soy proteins for a more aesthetic purpose may be seen in the development of synthetic caviar and, to a lesser extent, steaks containing spun soy fibers.

In processes where soy proteins are used to improve the nutrient content of a food item, care must be taken to develop a product that looks and tastes good. Even in poorer societies, people will buy an

appealing product rather than one that is nutritionally good if a choice is given. As a consequence, the choice of soy type for the incorporation of soy proteins in various formulations is specific for the product.

According to Kinsella (1976), the functional properties of a protein may be regarded as any physicochemical properties that may influence the processing and behavior of the protein in a food system as evaluated by the quality attributes of the final product. These often involve complex interactions among the composition, structure, conformation and other physicochemical properties of the protein, other food ingredients and various treatment conditions. Among the more important functional properties of proteins are wettability, dispersibility and solubility, viscosity and emulsification capacity (Claus, 1974).

Protein Solubility

Any study of proteins and the influence of various environmental treatment conditions on their functional properties requires a knowledge of the characteristics of the proteins. It has been reported that about 90 percent of the protein in soybeans, consisting mostly of globulins, exists as dehydrated storage protein, with the principal components being the 7S and 11S fractions (Kinsella, 1979). The 7S proteins have molecular weights ranging between 141,000 and 171,000 daltons. The 7S fraction also contains a carbohydrate content of around 4.0-5.2 percent. Although compactly folded, the 7S components are known to have large unstructured regions internally. The 11S fraction, glycinin, is rich in glutamine and asparagine residues but

low in tryptophan, methionine and cysteine, with the basic hydrophobic amino acids residing internally in the polypeptide. Exploitation of the differences in the properties and behavior of these globulins has made possible the preparation of proteins enriched in 7S and 11S fractions (Kinsella, 1979).

Effect of processing. Whereas there is a general method of extraction of soy isolates, the specific processing technique employed influences the nature and amount of individual proteins in the extracts and the individual and composite behavior of the proteins. Among the factors having an effect on the functionality of the proteins are the solvent used, ionic strength, pH, temperature and duration of extraction. Solubility, a highly desired functional property, is especially vulnerable to prolonged exposure during isoelectric precipitation, with a gradual loss of solubility as the treatment time increases (Kinsella, 1976).

One method commonly used in soy protein extraction is the precipitation of the 11S fraction at pH 6.4 from a dilute Tris buffer (0.03 M, pH 8, low ionic strength, 0.07) extract of soy flour. The 7S fraction is next precipitated from the supernatant at pH 4.8. This procedure employs the sensitivity of the different fractions, 7S and 11S, to ionic strength in the isoelectric range. At pH 6.0, the 11S shows minimum solubility in Tris buffers below 0.03 M, whereas the 7S is quite soluble (Kinsella, 1979).

Achieving the final form of the protein, a powder, entails drying the extract. Kinsella (1976) stated that solubility of proteins decreases during drum drying, while freeze drying has been shown to

cause minimal denaturation and actually gives a product that is loosely textured and easily dispersed in aqueous solutions. Regardless of the process used in isolation of proteins, Nash and Wolf (1967) reported that commercial protein samples exhibit large variations in solubility and ultracentrifugal behavior. They suggested that these variations were indicative of extensive irreversible modification during isolation.

Effect of experimental conditions. The behavior of plant proteins under various experimental conditions has been investigated by several authorities in recent years (Lin and Humbert, 1974; McWatters and Holmes, 1979a,b; Nash and Wolf, 1967; Shen, 1976a,b; and Sosulski et al., 1976). One functional property evaluated by these investigators was protein solubility as influenced by differing treatments, including centrifugation conditions and temperature.

The effect of centrifugation on protein solubility of five isolates was investigated by Shen (1976a). He found that with one isolate (E, Figure 1) the solubility of the protein decreased smoothly from 48 to 38 percent as the log of centrifugal force x time increased from 5.5 to 9.5. Whereas there was a noticeable decrease in soluble nitrogen as the centrifugal force increased, the smoothness of the slope of the curve suggested the presence of aggregates exhibiting sedimentation coefficients with random distribution. With three other isolates (B, C and D, Figure 1) reductions in solubility were not observed until very high centrifugation conditions [$\log (f \times t) = 8.0$] were attained, and from that point the reductions for the three isolates were 10, 9 and 3 percent, respectively. For these isolates,

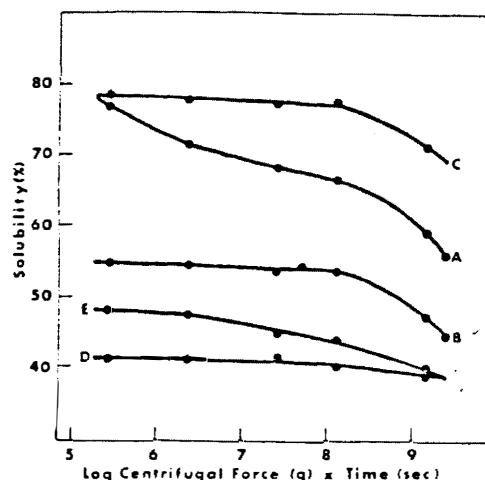


Fig. 1--The effect of centrifugation on protein solubility: A, B, C, D and E isolates (Shen, 1976a).

Shen (1976a) suggested that the small loss of solubility in the low centrifugation range reflected the absence of significant amounts of very fast sedimenting particles in their composition. The curve for isolate A, on the other hand, showed declines in solubility both in low and in high centrifugation ranges; the first inflection suggested that isolate A contained fast sedimenting particles. Information such as this is useful in selecting centrifugation conditions for various applications requiring different degrees of protein solubility.

It is generally accepted that high solubility is a good indication of low heat treatment, although in some instances this generalization may be misleading (Kinsella, 1979). The effect of temperature on the functionality of the protein is partly due to the alteration of the physical structure of the 11S fraction.

Shen (1976a) reported the effect of temperature on the solubility of five isolates. The isolates were allowed to reach the desired equilibrium temperature (25-62°C) in a shaker bath over a

2 hr period. This was followed by centrifugation at room temperature. His results showed that the greatest increase in solubility of most isolates was within the temperature range of 30-40°C. With the exception of isolate C (Figure 2), which was essentially unchanged in solubility over the temperature range, the isolates increased in solubility 7-14 percent as the temperature was increased from 30 to 40°C. Beyond 40°C, however, the solubility curves for isolates B and D tended to plateau. Isolate E showed a gentle linear increase in solubility over the temperature range studied. This response to temperature agrees with the behavior of proteins as reported by Kinsella (1979), who stated that as the temperature increases to 70°C, there is a gradual dissociation of the 11S fraction into smaller subunits followed by slow aggregation. Beyond 70°C, there is a rapid dissociation accompanied by precipitation as 90°C is approached.

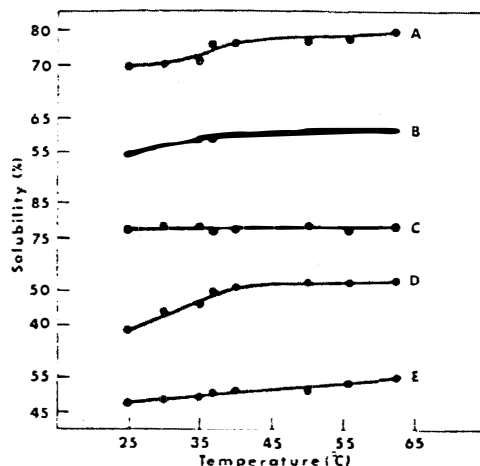


Fig. 2--The effect of temperature on protein solubility: A, B, C, D and E isolates (Shen, 1976a).

Continued heating beyond 100°C, however, is followed by an increase in soluble proteins because of dissociation and degradation.

Effect of pH and ionic strength. Whereas the effect of pH on nitrogen solubility has been established, continued investigation of pH on this functional property has occupied the attention of several investigators. This is probably because the pH and ionic strength of an aqueous solvent have even greater effects on the solubility profile of soy proteins than do other factors (Kinsella, 1979). McWatters and Holmes (1979a) evaluated the influence of pH and salt concentration on the nitrogen solubility of soy flour over a pH range of 2.0-10.0. Soy flour dispersions (2 percent suspensions, w/w) were prepared with distilled water, 0.1 M NaCl (low salt) or 1.0 M NaCl (high salt) solutions and blended for 1 min. Adjustments in pH were accomplished with the use of 6 N HCl and 1.0 N NaOH. They found that at the isoelectric point of soy proteins, between pH 4.0 and 5.0, nitrogen solubility in water and in 0.1 M NaCl solution was very low (Figure 3). As the pH moved away from the isoelectric point in either direction, there was a substantial increase in nitrogen solubility for water and 0.1 M NaCl solutions. However, the solubility curve for 1.0 M NaCl solutions showed a quite different response to pH as can be seen in Figure 3; the curve for 1.0 M NaCl solution tends to have a broad maximum in the pH range 4.5-7.0 rather than a minimum at pH 4.5.

Solubility profiles similar to those of McWatters and Holmes (1979a) were obtained by Thompson (1977), who determined protein solubility of mung bean and soybean isolates, and by Volkert and

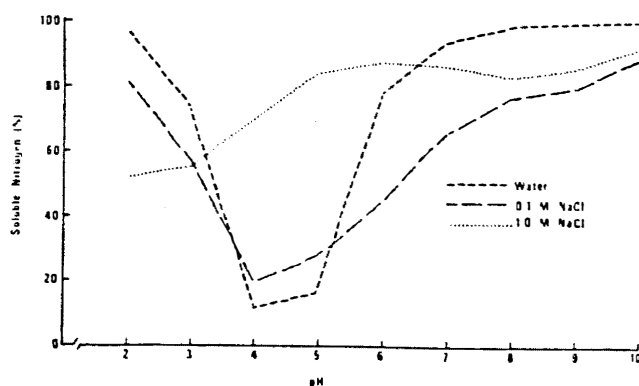


Fig. 3--Nitrogen solubility of soy flour suspended in distilled water, 0.1 M NaCl, and 1.0 M NaCl (2% suspensions, w/w) in the pH range 2.0-10.0 (McWatters and Holmes, 1979a).

Klein (1979), who reported on four soy products. In the former study Thompson adjusted 1 percent dispersions over a pH range of 2.0-11.0 using either 1 N HCl or 1 N NaOH. She found that nitrogen solubility was higher at very alkaline pH levels than at acid pH levels, with minimum solubility at pH 4.0, where there was 98 percent precipitation of nitrogen. In the study by Volkert and Klein (1979), a soy isolate, toasted and untoasted concentrates, and soy flakes were investigated as to the effect of pH on protein solubility. They found that overall the isolate had the greatest dispersibility or solubility followed in order by the untoasted concentrate, soy flakes and toasted concentrate. Citing the work of Hutton and Campbell (1977a) they concurred with these investigators in the explanation of the differences of solubility in soy products. Hutton and Campbell (1977a) in a study of the functional properties of a soy concentrate and a soy isolate in simple systems reported the nitrogen solubility of these products as a function of pH. They found that nitrogen solubility generally increased with increased pH from 5.0 to 7.0 and this was more noticeable for the isolate than for the concentrate. This difference in solubility

was attributed to a greater extent of denaturation of the concentrate than of the isolate during processing. Further, there was a pH-temperature interdependency. Although protein solubility was consistently higher at 90°C than at 4°C, the extent of the effect of temperature was dependent on pH as well as on the type of soy product.

Ionic concentration has a large influence on nitrogen solubility even at constant temperature and pH. It is believed that the mechanism of the influence of ionic treatment involves electrostatic solvation and salting in and salting out phenomena (Kinsella, 1979). At a constant pH within the range 4.5-7.0, protein solubility in aqueous solutions increased as the salt concentration increased, a phenomenon referred to as salting in (van Megen, 1974). Continued increase beyond a certain ionic concentration, however, had an adverse effect with a decrease in protein solubility.

The solubility profile of a soy protein isolate (SPI) as a function of ionic strength at selected pH values (Figure 4) was reported by Shen (1976b). He found that at pH 2.0 (C), increasing the ionic concentration resulted in a sharp salting out effect and a consequent decrease in solubility from 67 to 20 percent before solubility bottomed out at an ionic strength of 0.5 M. At pH 6.8 (A), the salting out effect was much smaller and leveled off at an ionic strength of 0.2 M. At pH 4.7 (B), however, increasing the ionic strength resulted in a large salting in effect that increased the solubility from 2 to 38 percent before leveling off at 0.65 M ionic strength. At zero ionic strength native soy proteins, with an isoelectric point of around pH 4.5, showed "the classical aqueous-pH-solubility profile" (A, Figure 5).

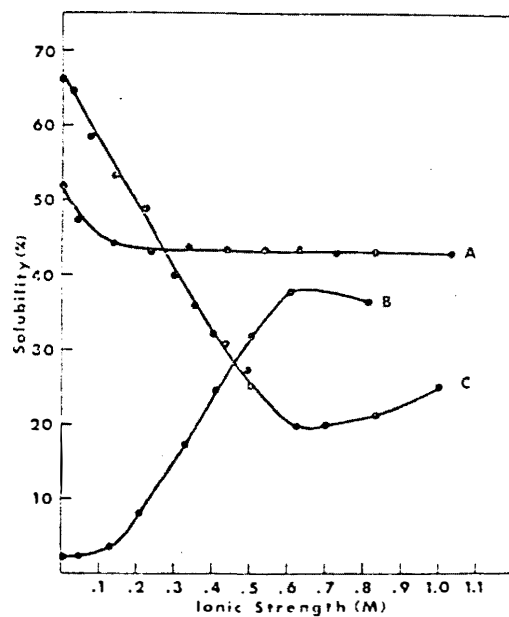


Fig. 4--Ionic strength-solubility profile of SPI at pH 6.8 (A), 4.7 (B), and 2.0 (C) (Shen, 1976b).

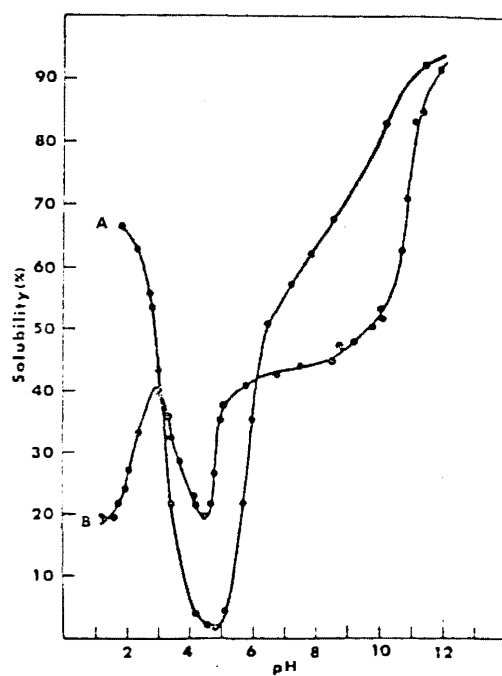


Fig. 5--pH-solubility profile of SPI in H₂O (A) and in 0.5 M ionic strength solution (Shen, 1976b).

The lower solubility in the 0.5 M ionic strength solution than in water at pH levels below 3.0 and above 6.0 was attributable to the salting out effect in these ranges; the higher solubility observed in the solution than in water between pH 3.0 and 6.0 was attributable to the salting in effect. McWatters and Holmes (1979a) found nitrogen solubility to be greater in 1.0 M NaCl than in 0.1 M NaCl over most of the pH range (Figure 3). They also found that water facilitated the greatest extraction at pH 3.0 or below and pH 7.0 or above, with almost 99 percent soluble nitrogen in aqueous dispersions at pH 10.0.

Viscosity

Viscosity as a functional property is critical in many food systems and is of practical interest in fluid foods such as beverages, soups and batters. Kinsella (1976) observed that the flow properties of protein dispersions are governed by the molecular shape and size, protein solubility and environmental factors. Many proteins absorb water and as they do, they usually swell. This physical alteration in shape and size effects changes in hydrodynamic properties that result in an increase in viscosity.

Low viscosity is characteristic of highly soluble nonswelling proteins such as albumins and globulins. According to Kinsella (1976) dispersions of proteins with high initial swelling exhibit a concentration-dependent viscosity, probably varying with the extent of solvation of partially solvated particles. High viscosity is typical even at low concentration of proteins with limited swelling capacity.

Relation to solubility. The relationship between viscosity and solubility is dependent upon the complex and dynamic nature of proteins. In the solid state, spatial constraints on the polypeptide impose a rigid structure. During solvation, however, the protein molecule swells, unfolds and becomes flexible. The degree of interaction of the protein with the solvent is reflected by its rheology and its solubility index. This alteration of the physical structure of the protein by its unfolding and swelling increases the hydrodynamic volume thereby decreasing the distance between the protein molecules and consequently increasing the viscosity (Lee and Rha, 1979). Whereas the mere presence of protein will increase the viscosity of the dispersion relative to that of the solvent, the degree of effect is dependent upon a number of factors including the amount of protein in solution.

Lee and Rha (1979) reported on the relationship between solubility and viscosity of soy protein. They found that an increase in solubility at pH values lower than 3.5 and higher than 6.0 was associated with an increase in viscosity. Between pH 3.5 and 6.0, however, the relationship was not evident (Figure 6). They concluded that within this range, at and near the isoelectric point, aggregation of the polypeptides shields the core from maximum hydration.

As pH was lowered from 6.5 to 5.5, (Figure 6) an increase in viscosity was observed. With further reductions in pH to the isoelectric point at 4.5, aggregation was completed; a slight decrease in viscosity between pH 5.5 and 4.5 was followed by a sharp reduction between pH 4.5 and 3.5, after which dispersion took place resulting in an increase in viscosity. The changes in viscosity over the pH

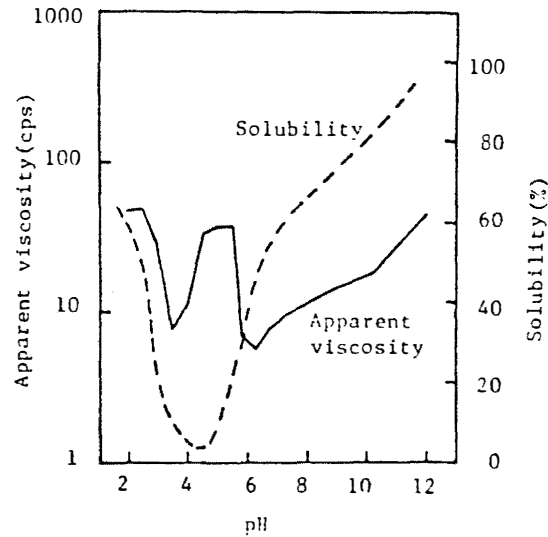


Fig. 6--Changes in apparent viscosity and solubility of soybean protein isolate dispersion with pH (Lee and Rha, 1979).

range studied were related to particle size as well as to the amount of soluble protein (Lee and Rha, 1979).

Environmental factors affect the viscosity of aqueous dispersions of soy proteins. These influences include the effect of processing of the isolate, experimental conditions, temperature, pH, ionic strength and concentration.

Effect of processing. While solubility profiles have been used extensively to study the effect of denaturation of proteins on solubility, the optical rotation and intrinsic viscosity can be just as informative in providing similar information (Shen, 1976b). Shen (1976b) reported on the optical rotation and intrinsic viscosity of a laboratory prepared acid precipitated soy protein isolate and a commercial isolate. The relative viscosities of solutions of soluble soy protein, varying from 3 to 20 mg/ml in concentration, were determined at 35°C and intrinsic viscosities were calculated. The solutions

had intrinsic viscosities of 4.8 and 5.5 cm³/g. These values, when compared with the intrinsic viscosities of certain globular proteins were indicative of proteins in a native globular state. This conclusion is supported by the intrinsic viscosity value of 22.0 cm³/g for completely denatured proteins. Intrinsic viscosities between 4.8 and 22.0 cm³/g would, therefore, be indicative of the degree of denaturation of the proteins.

Effect of experimental conditions. Lee and Rha (1979) investigated the influence of size of particles, as affected by the shear rate, on the flow properties of a commercial soy isolate in an aqueous dispersion at pH 7.0. Samples were subjected to shear rates from a relatively low 100 sec⁻¹ to a high of 5600 sec⁻¹. They found that the viscosity of dispersions sheared at the low rate was much higher than that of the others. This was related to particle size; when the dispersions that were treated with the low shear rate were subjected to the higher shear forces, both particle size and dispersion viscosity decreased. While it was evident that particle size was directly related to the viscosity of the dispersion, they pointed out that other factors were involved. These included particle shape and interaction among particles.

Effect of temperature. The effect of temperature on the viscosity of a soy isolate was investigated by Circle et al. (1964). Aqueous dispersions of 8, 10 and 12 percent isolate by weight were heated in a VISCO/amylo/GRAPH at the rate of 1.5°C per min. They found that below 60°C, thinning occurred as the dispersions warmed up beyond room temperature. Between 60 and 70°C, thickening became

evident, with an obvious effect at 65°C for the 12 percent dispersion. For the 8 percent dispersion, however, increased viscosity was barely noticeable. This latter finding is particularly important in the formulation of protein-based beverages in that it suggests the feasibility of using up to 8 percent soy protein isolate even in products where low viscosity is desired or essential.

Effect of pH and ionic strength. In considering the functionality of proteins, obtaining data over a range of experimental conditions is vital, especially when the effects of pH are studied. Profiles of the protein over a range of treatment conditions are more meaningful than single measurements. Hutton and Campbell (1977b) reported on the influence of pH in a range of 5.0 to 7.0 on the dispersion viscosity of a soy concentrate and a soy isolate at 4°C, ambient temperature (22-25°C) and 90°C. As the pH was increased from 5.0 to 7.0 the overall effects were increased viscosity of the concentrate dispersion and decreased viscosity of the isolate dispersion. However, the effects of pH were dependent on temperature.

Shemer et al. (1978) also studied the behavior of a soy protein isolate at different pH levels. In the investigation of the functional properties of the isolate it was observed that as the pH of the dispersion increased, there was a reduction in viscosity from 200,000 cps at pH 4.39 to under 20,000 cps at pH 6.0.

Decreases in the apparent viscosity of soy dispersions have been reported also as a result of reduced dissociation of 11S globulins at low ionic strength. By stabilizing the quaternary structure of soy isolates, sodium chloride has been known to decrease the viscosity

of dispersions (Kinsella, 1979). The practical application of this response of soy isolates to ionic concentration can be advantageous in the formulation of certain products where low viscosity may be required.

Effect of concentration. Soy proteins in the isolate form are being used increasingly as nutritional and functional ingredients in many foods. Since isolates contain more protein than the flour or the concentrate smaller amounts can often be used to obtain the desired functionality. The apparent viscosity of soybean flour, concentrate and isolate at dispersion concentrations of 5, 10, 15 and 20 percent was reported by Fleming et al. (1974). They noted that as the concentration of the soy products increased, the viscosity of the slurries, except that of the concentrate, increased exponentially. Although the viscosity of the concentrate dispersion was ten times as great as that of the flour in the 20 percent slurry, their viscosities were similar at low concentrations. The viscosity of the isolate was consistently higher than that of the flour and concentrate at all concentrations. They concluded that, in general, viscosity increased with the protein content of the dispersion. Exponential increases in the viscosity of soy dispersions of increasing concentrations have been reported also by Circle et al. (1964).

II. INFLUENCE OF ADDED INGREDIENTS ON FUNCTIONAL PROPERTIES

While soy proteins have made an impact on the food industry, their application in food systems has not advanced correspondingly with their functionality and potential as evidenced by numerous

studies (Kinsella, 1979). Even with increased use in a wide variety of products, their application has been influenced by the variability of soy protein preparations, their less than desired organoleptic properties and the conservative nature of the consumer.

Further, while numerous investigations of the functional properties have been reported, the task of evaluating these properties in food systems has been largely neglected. The desirability of assessing the functionality of proteins in model and food systems has been suggested by Hutton and Campbell (1977b). These investigators concluded that while it is possible to increase the predictability of performance of soy proteins from the findings with model systems, caution should be exercised in the extrapolation of these findings to actual food systems. Model systems seldom duplicate the conditions that occur in actual food systems, such as pH, ionic strength, temperature treatments, physical manipulations and chemical and physical interactions.

Common ingredients used in food preparation include sodium chloride and sucrose. Fleming et al. (1974) reported that the dispersion viscosity of sunflower flour and isolate was greater in 5 percent sodium chloride solutions than in water. The significance of this finding has special importance in ground meat products in which the aqueous phase contains a significant concentration of salt.

El-Gedaily (1979) found that protein solubility decreased and then increased with increasing sugar concentration in model systems. Neucere and Conkerton (1978) investigated the solubility of peanut protein isolates in acidic sucrose buffers. Peanut proteins were separated by ion-exchange chromatography to yield five fractions.

The relative protein solubilities of the five fractions were determined in 1.0 ml of citrate buffer, pH 3.0, containing 0.25 M or 0.5 M sucrose. Greater solubility was observed at 0.5 M than at 0.25 M sucrose concentration. The authors suggested that modification of the tertiary and quaternary structures was influential in the resulting differences in protein solubility. They concluded that these physical alterations of the proteins were influenced by the sucrose at an acidic pH.

III. PROTEINS IN BEVERAGES

The pressure of world population on the production of adequate supplies of nutritious food places considerable emphasis on the maximization of available resources. Plant proteins and soybeans in particular are increasingly employed in food systems to improve food quality from either a functional or a nutritional aspect. With regard to the functional application of plant proteins, very often a range of properties may be involved. In beverages for example, a highly soluble protein exhibiting low viscosity and high clarity would be desirable (Kinsella, 1979). Because of the complexity of the protein molecule itself, this heterogeneous requirement can often be met by a single protein type, for example soybean proteins.

Beverages form an important part of the total caloric intake of all segments of society (Altschul, 1969). In 1976 the per capita consumption in the U.S. was 34.2 gallons of soft drinks, 32.5 gallons of coffee and 24.5 gallons of milk (Szczesniak, 1979). Although protein was not added to soft drinks until recently, protein-containing beverages are increasingly making their appearance on the market.

Protein-based beverages usually contain dairy whey, soy or a combination of both. Beverages containing soybean proteins may be categorized into several classes. These include the traditional unfermented or fermented soy milks, simulated milks, still beverages and carbonated beverages (Circle, 1974).

The incorporation of soy proteins into traditional food products requires protein properties that are compatible with the ingredients being supplemented or replaced and that at the same time do not have a detrimental effect on the texture or quality of the product (Waggle and Kolar, 1979). The high specificity required in some of these applications is found only in the highly refined isolate.

The development of protein-containing beverages requires a highly soluble protein (Circle, 1974). Although solubility in the acidic range would be of paramount importance in carbonated beverages, other functional properties are equally important. Kinsella (1979) suggested that the protein should be able to form a clear or translucent solution that has low viscosity, blandness and stability over a range of pH, ionic strength and temperature.

An investigation into the effect of processing of soybeans on the suspension stability of a protein fortified beverage has been reported by Priepke et al. (1980). The authors found that beverages homogenized at a total pressure of 4,000 psi or less exhibited visible settling, whereas beverages subjected to a total pressure of 5,000 psi or more were stable. They concluded that a minimum total homogenization pressure of 5,000 psi was required to prevent visible settling and that a strong relationship between homogenization pressure and suspension stability exists.

With the wide appeal of beverages in the diet of man, it is prudent to consider fortification and supplementation of these products. Soy proteins are ideally suited to meet the criteria necessary for successful application in food systems. From a nutritional standpoint, soy proteins compare favorably with other plant proteins. They are high in lysine, the first limiting amino acid in many cereals.

Beverages of the various categories such as fermented or unfermented milk, simulated milks, still and carbonated beverages provide a good medium for the incorporation of soy proteins. However, soybean milk is entirely an aqueous extract of whole soybeans. In its early development, soy milk was often tainted with a "beany" off-flavor. With continued refinement of processing technique a far more acceptable product is now being produced (Glicksman, 1971). Soybean milk and cow's milk have approximately the same concentration of protein and their amino acid composition is similar (Leiner, 1977). Although soy protein is deficient in the sulfur containing amino acids, supplementation of soy milk with methionine raises its nutritive value to the same level as that of cow's milk. The availability of soy milk is fortuitous, in that it provides an alternative to human or cow's milk in the feeding of infants who may be allergic to the latter types, or when the economic considerations might be prohibitive (Leiner, 1977).

In the developing countries, where transportation of goods is often difficult and may be dependent upon seasonal climatic conditions, the need for light and nonperishable goods is critical. This consideration has stimulated the development of dry type products, among them a soybean based beverage. The functional requirements of the ingredients

of these products include wettability and dispersibility of the proteins and also of the finished product. In products where hot water is required for reconstitution, the taste and aroma of soy protein become very important (Claus, 1974), as consumer rejection of products with a detectable soy aroma is not uncommon (Schutte, 1979).

Bookwalter et al. (1975) investigated the storage stability of a dry soybean based beverage fortified with DL-methionine. The dry soybean beverage base was prepared with various levels of methionine and kept at 49, 37 and 25°C for time intervals from 0 to 12 months. They found that the flavor score for the fortified beverage base was slightly lower than that of the control without methionine. The fortified beverages were rated significantly lower initially and after 1 month at 49°C and after 12 months at 25°C. They suggested that the lower ratings obtained under these conditions may have resulted from a higher DL-methionine fortification than has been used in other soy blended foods, rather than from inherent product instability.

While plant proteins continued to offer hope for improving the diet of many of the world's needy, proteins of animal origin are still the primary source in the developed areas. In the U.S., the development of the dairy industry has indirectly created an environmental problem in the disposal of cheese whey. In the processing of cottage or cheddar type cheese, there are 90 pounds of fluid whey produced for every 10 pounds of cheese produced (Holsinger et al., 1973).

Use of the whey as feed for pigs was sufficient in the past but with the tremendous increase in cheese manufacture, there is an

urgent need to develop methods either for the disposal of the whey or utilization in commercial products. This is of special importance with regard to the acid whey produced as a result of the manufacture of cottage cheese (Holsinger et al., 1973).

A possible use for whey proteins is in the fortification of soft drinks (Fresnel, 1978; Holsinger et al., 1973). Some success in this endeavor has been achieved in Europe where a product containing whey protein has been on the market for nearly thirty years. Holsinger et al. (1973) reported a study of the fortification of soft drinks with proteins isolated from cheese whey. Fortified beverages with 0.5 and 1 percent whey protein were evaluated. They found that as the pH of the beverage moved away from the isoelectric point of the proteins, the nitrogen solubility increased (Figure 7). At the

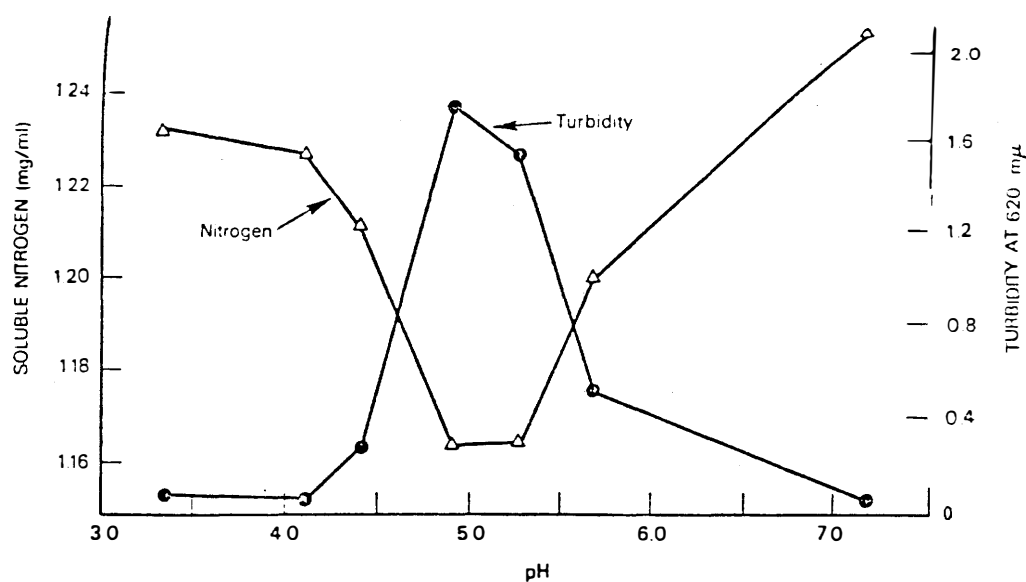


Fig. 7--Nitrogen solubility and turbidity of whey proteins as a function of pH (Holsinger et al., 1973).

isoelectric point, a low solubility was accompanied by a high turbidity. In the pH range typical of carbonated beverages, they reported an unexpected clearing of the protein solutions. They concluded that this was attributable to the greater resistance of whey proteins to thermal denaturation at pH 3.5 than at higher pH levels. They suggested that this information supports the contention that whey proteins can be utilized in soft drinks. The results of the sensory evaluation of the products by an experienced panel indicated that there were no dislikes for the products, even though some beverages neared the indifferent response at the 1 percent protein concentration.

Very often in the formulation of food products ingredients are used to complement each other. Soy proteins, because of their relatively high nutritive value, are often used as such. With soy in combination with whey proteins, nutritious products having desirable textural qualities can be made. Wei et al. (1976) and Wilding (1979) reported on the practicality and potential of a soy-whey beverage.

The cost of many world food programs is being carefully scrutinized for possible reductions. Milk, a major item in these programs, has suffered from periods of glut and shortage. To maintain viable programs that would provide considerable improvement to the diet of millions, efforts have been aimed at developing formulated products that use cheap and plentiful raw materials. Soy-whey-milk blend is one such product.

Wilding (1979) reported on the development of a soy-whey drink mix. The product, in powder form, is high in protein, fat and calories; it has a PER of 2.1 as compared to 2.5 for casein and

according to the author has been readily accepted in Asia, Africa and Central America.

The ubiquitous distribution of soft drinks, the successful cultivation of soybeans around the world and the continued acceptance of protein beverages in Europe support the feasibility of development of carbonated soy beverages. Mustakas (1974,1976), Russo (1969) and Weisberg (1972) reported the development of soy beverages containing either soy protein concentrate or the isolate. In a study of a soy beverage made from the concentrate (Mustakas, 1976), it was found that in 10 and 12 percent dispersions the soy beverages had food value comparable to that of cow's milk. The beverage had acceptable organoleptic qualities even after storage at 77°F for 6 months. The product was stable throughout the storage period. The soy beverage containing the isolate (Mustakas, 1974) yielded a bland product that had smooth mouthfeel and was low in viscosity. The author suggested that the addition of vitamins, minerals and flavoring to a beverage base could result in high quality beverages.

Commercial products containing soybean proteins have been test marketed in several countries often with favorable results. In Latin America, Puma, a soy protein beverage, was readily accepted in Guyana (Weisberg, 1972). Saci and Vitasoy, products manufactured by the Coca Cola Company, have met with reasonable success in Brazil and Hong Kong, respectively (Russo, 1969; Wilding, 1970).

The successful introduction of protein-containing carbonated beverages is dependent upon a number of factors, not the least of which is product safety. However, while the addition of protein might be

expected to reduce the shelf life of beverages, it is generally recognized that the combination of carbon dioxide and citric acid is one that is highly unfavorable to the growth of fungi, yeast, molds, bacteria and algae (Gardner, 1966). In consideration of the desirable properties of soy proteins in food systems such as beverages, it is anticipated that soybeans as a protein source will continue to occupy a prominent position (Wilding, 1970).

CHAPTER III

PROCEDURES

I. SOURCE OF SOY PROTEIN ISOLATES

Three soy isolates from different commercial sources were selected for use in this study (Table 1). According to the suppliers' technical manuals, the isolates had the proximate analyses given in Table 2. The isolates in Pro Fam S-970 and Promine F were obtained in 11.25-kg bags whereas the Supro 710 was obtained in a 22.5-kg bag. They were placed in large plastic bags and stored at room temperature either in large plastic storage bins with lids or in hardboard barrels with tight covers. Moisture determinations (AOAC, 1975) were made initially and at regular intervals throughout the study.

II. PLAN OF STUDY AND MEASUREMENTS

This study was divided into two parts. Part A involved an investigation of solubility and viscosity of the isolates in a model system containing only the isolates and varied levels of citric acid and sucrose. Citric acid solution was added to produce pH levels of 3.8, 3.3 and 2.8. The effects of sucrose at levels of 9, 12, 15 and 18 g/100 ml dispersion medium were studied. In Part B the findings of Part A were related to the functional performance of an isolate in a carbonated beverage.

Part A: Model System

All samples of each isolate for both the model system and the food system were from the same lot. The functional properties of

Table 1--Identification of soy protein isolates by commercial source and description

Isolate	Supplier	Description
Pro Fam S-970	Grain Processing Corp. (Anon., 1979)	This isolate is highly soluble with a minimum 70 percent NSI.
Promine F	Central Soya Co. (Anon., 1978a)	Promine F is characterized by the low viscosity of its aqueous dispersions.
Supro 710	Ralston Purina Co. (Anon., 1978b)	"Supro 710 is a bland protein that is designed to impart a smooth mouth feel in solution." It is useful in applications where low viscosity is important.

Table 2--Proximate analyses of the soy protein isolates

	Pro Fam S-970	Promine F	Supro 710
	— — — — — — — — % — — — — — — — —		
Moisture	6.0	4.5	5.6
Protein, N x 6.25 (as-is)	87.4	91.5	86.8
Protein, N x 6.25 (moisture free basis)	93.0	95.8	92.0
Crude fiber	—	0.4	0.1
Ash	5.5	4.5	3.3

solubility and viscosity were studied under a factorial plan with three soy types, three pH levels and four sucrose levels. Data were collected under a complete randomized block design with two replications. The effects of pH and sucrose level and all interactions on solubility and viscosity were determined by means of analysis of variance. The sums of squares for the primary effects and interactions were partitioned with the use of polynomial equations. From these equations response surfaces for nitrogen solubility and viscosity were prepared with a Hewlett-Packard flatbed plotter.

Nitrogen solubility index. The nitrogen solubility index (NSI) of the three isolates was determined according to a modification of the method of Hutton and Campbell (1977a). Samples of soy isolates (1.20 g) and samples of sucrose as appropriate were weighed and transferred to labeled 100-ml centrifuge tubes. To each sample, 40 ml of dispersion medium (water and citric acid solution) were added. The amounts of citric acid solution (0.62 N) and water added to each isolate are given in Table 16 (Appendix A). Sucrose at levels of 9, 12, 15 and 18 g/100 ml dispersion medium was added to the isolate dispersions at each pH level. A small stirring bar (37.2 mm) was added to each sample. The samples were dispersed for 3 min on a Deluxe vibrating hand mixer at speed setting 5.5. Following the mixing, the tubes were placed in a shaker waterbath, Precision Model, speed setting 4.5 (125 cycles/min), with a water depth of 10 cm and a temperature of 3°C. Over a period of 1 hr the contents of the tubes were mixed every 15 min for 30 sec with the vibrating hand mixer. After extraction, the tubes were removed from

the waterbath and centrifuged at room temperature for 30 min at 1500 x G (International Model U Centrifuge). After centrifugation, the supernatant liquids were decanted into separate Erlenmeyer flasks and stored at 3°C until later. The residue for each sample was re-extracted for 1 hr with 40 ml distilled water at 3°C and then centrifuged at 1500 x G for 30 min. The supernatants from each sample were combined and filtered through Whatman No. 1 filter paper in a Büchner funnel under suction. Each extract was made to volume in a 100-ml volumetric flask for nitrogen determination.

For the calculation of the nitrogen solubility index (NSI), the total nitrogen content of the extracts and of the dry, unextracted samples was determined by the standard microKjeldahl method (AOAC, 1975). The nitrogen solubility index was calculated from the equation:

$$\text{NSI} = \frac{\text{N in H}_2\text{O soluble protein} \times 100}{\text{N in unextracted sample}}$$

and corrected for expression on the dry weight basis. The moisture content of the isolates tended to increase with time; therefore, the calculation of NSI on the dry weight basis was based on the current moisture content.

Viscosity. The procedure for preparing samples for the determination of the apparent viscosity was similar to that for preparing samples for nitrogen solubility determinations except that the re-extraction step was omitted. The same amounts of isolate, sucrose and dispersion medium were used for the extraction (Table 16, Appendix A). After mixing followed by centrifugation at 1500 x G

(International Model U Centrifuge) and filtration, the extracts were stored at 3°C until the viscosity was determined.

The Kinematic viscosity of the dispersions was determined with a Cannon-Fenske Routine viscometer No. 100. Flow time in seconds was multiplied by 0.015, the constant for the viscometer, to give Kinematic viscosity. The Kinematic viscosity of the dispersions (ν), expressed in centiStokes, was converted to dynamic or apparent viscosity (η), expressed in centipoises, with the equation $\nu = \eta/s$, where s is the density of the dispersions.

Part B: Food System

A carbonated beverage was chosen as the food system for studying the functional performance of a selected isolate. Beverages were prepared with all combinations of pH levels 3.8, 3.3 and 2.8, the four levels of added sucrose and one level of Supro 710, the most soluble isolate.

The beverage was prepared from an acid soluble soy dispersion. Preparation of the beverage base began with 6.0 g soy isolate in 100 g ml citric acid solution. Sucrose at levels of 9.0, 12.0, 15.0 and 18.0 g/100 ml was added to each dispersion as appropriate. As with the model system, citric acid solution (0.62 N) was substituted for water in predetermined amounts to obtain base solutions of pH 3.8, 3.3 and 2.8 (Table 17, Appendix A). The beverage base was made by mixing the dispersions for 3 min initially on a Magne stir, speed 9. The dispersions were placed in a 3°C shaker waterbath. Over a period of 1 hr each dispersion was mixed on the Magne stir every 15 min at speed 9, for 30 sec. The dispersions were left to stand for 24 hr at 3°C. This allowed the insoluble solids to either precipitate or form a layer above the acidified solution. The acidified solution was collected by vacuum filtration through Whatman No. 1 filter paper.

This method of preparation for the beverage had the advantage that it removed the insoluble protein which contributes to a gritty texture, and produced a clear acidified solution with acceptable taste and mouthfeel (Hempenius et al., 1974; Hempenius and Chandler, 1975).

Because only the soluble protein was used in the beverage, the protein content varied with the various treatments. To the acidified solution (beverage base) obtained, a mixture of orange color and flavor extract, orange #77 (The Virginia Dare Extract Co. Inc.), was added. The beverages were carbonated (1.5 g dry ice/100 ml product) and were bottled in 32-oz plastic bottles.

In the preliminary work it was observed that the pH level affected appearance and flavor; therefore, adjustments were made in the amount of extract added to the beverages at each pH level. These adjustments were based on the manufacturer's recommendations, the protein content of the beverages and subjective evaluations of various levels of extract added to the beverages at each pH level. The subjective evaluations of levels of extract involved informal trials of several combinations with several of the panelists. After these trials and discussion with the group, levels of 0.8, 1.0 and 2.0 ml/100 ml product at pH 3.8, 3.3 and 2.8, respectively, were selected. In a study of the relative sweetness of fructose and sucrose in lemon beverages, Cardello et al. (1979) found the subjective approach adequate in the preparation of beverages of equivalent color. In this study, however, since color was not a characteristic to be evaluated, more emphasis was placed on flavor.

Viscosity. Measurement of the kinematic viscosity was made at 3°C. As for the model system, the kinematic viscosity was converted to dynamic viscosity. The data were analyzed by analysis of variance.

Sensory evaluation. A panel of volunteers was selected for the evaluation of the product. The volunteers were screened for discrimination among concentrations of citric acid and sucrose solutions. Citric acid and sucrose solutions of 0.1, 0.2, 0.3 and 0.4 M and 0.26, 0.35, 0.43 and 0.52 M, respectively, were given to each volunteer to rank in order of increasing concentration.

According to Pangborn (1963), threshold concentration for citric acid solution for 50 percent identification was 0.00001 M. When the concentration of the solution was increased to 0.00004 M in Pangborn's study there was a 70 percent correct identification.

Since the beverage was to be prepared from a 0.62 N (0.2 M) citric acid solution, 0.1, 0.2, 0.3 and 0.4 M citric acid solutions together with a control of water were given in random order to the first five volunteers during the screening. Because of the tartness of the solutions, the volunteers had a difficult time in the evaluation of solutions beyond 0.1 M concentration; therefore, only a 0.1 M solution and water were given to the remaining volunteers. All samples were served at 3°C because the product that was to be evaluated would be consumed at 3°C.

Sucrose solutions were given to each volunteer during the same session. The four solutions, of 0.26, 0.35, 0.43 and 0.52 M, were presented randomly to each member, who was asked to rank them in order of increasing concentration. All samples were coded with three-digit numbers generated from a random numbers table. The sucrose concentrations

were selected to represent those used in the product to be evaluated and were intended to familiarize each volunteer with degrees of sweetness without any interaction of sweetness and tartness.

After three sessions, 15 panelists were selected to participate in the study. The selection was based upon the ability to discriminate among the solutions. The Quantitative Descriptive Analysis (QDA) method (Stone et al., 1974) was used to evaluate the following characteristics of the product: viscosity, tingliness, sweetness, citrus flavor, tartness, flavor intensity, bitter aftertaste and sweet aftertaste. The panelists also were asked to indicate the overall acceptability of each sample. Evaluation consisted of placing on a 15-cm horizontal line for each characteristic, a vertical bar at a point that best represented the intensity of a particular characteristic as perceived by the panelist (Appendix B). The order of sample presentation was randomized within each replication and within the set of samples presented to each panelist at each session. The samples were coded with three-digit numbers generated from a random numbers table. In each replication the 12 samples were served during two sessions, at each of which six samples were evaluated.

Data were obtained from the score cards by assigning numerical values from 0 to 6.00 to the points checked for each characteristic. The data were analyzed by analysis of variance.

CHAPTER IV

RESULTS AND DISCUSSION

I. PART A: MODEL SYSTEM

Protein Solubility (NSI)

The influences of pH and sucrose on protein solubility can be seen in Table 3. Tables 4-6 represent the analyses of variance for Pro Fam S-970, Promine F and Supro 710, respectively. The main effects of pH and sucrose were significant at the level $P < 0.0001$ for all the isolates, as was the pH-sucrose interaction for Pro Fam S-970 and Promine F. The complex nature of the relationships is indicated by the significant polynomial terms. The equations are presented in Appendix C. The response surfaces for the three isolates are shown in Figures 8-10.

Under similar treatment the magnitude and range of NSI values apparently differed among the isolates. Although the data were not analyzed for the effect of isolate, the least soluble isolate appears to have been Promine F, with NSI means ranging from 4.7 to 14.9 percent. For Pro Fam S-970 and Supro 710, the ranges were 3.0-26.6 and 38.8-65.7 percent, respectively. The response surface for isolate Supro 710 is quite different from those for Pro Fam S-970 and Promine F in both shape and height.

Effect of pH. Solubility of each isolate increased as the pH of the dispersion decreased from pH 3.8 to 2.8. Increasing NSI is to be expected as the pH of the dispersion moves away from the isoelectric point of the protein. This increase was most noticeable

Table 3--NSI mean values^a for Pro Fam S-970, Promine F and Supro 710 as a function of pH and sucrose levels

Isolate	Sucrose ^b	pH				Mean
		3.8	3.3	2.8		
		— — — — — — — % — — — — — — —				
Pro Fam S-970	9	4.4	10.7	26.6		13.9
	12	3.7	8.7	24.8		12.4
	15	3.4	8.3	21.7		11.1
	18	3.0	7.8	20.4		10.4
Mean		3.6	8.9	23.4		
Promine F	9	5.1	8.9	14.9		9.6
	12	4.9	8.5	14.1		9.2
	15	4.8	7.9	13.9		8.9
	18	4.7	7.7	12.2		8.2
Mean		4.9	8.3	13.8		
Supro 710	9	41.2	49.4	65.7		52.1
	12	40.5	48.2	64.9		51.2
	15	39.7	47.4	63.7		50.3
	18	38.8	46.8	62.6		49.4
Mean		40.1	47.8	64.2		

^aEach value is the mean for two replications.

^bg sucrose/100 ml dispersion medium.

Table 4--NSI mean square values and significance of F-ratios for
Pro Fam S-970

Source	df	Mean Square	
Rep	1	0.0004	NS
pH	2	1106.3512	****
Linear (L)	1	2083.9326	****
Quadratic (Q)	1	128.7697	****
Sucrose (s)	3	39.5600	****
Linear	1	116.1776	****
Quadratic	1	1.0271	**
Cubic (C)	1	1.4752	***
pH x s	5 ^a	5.3311	****
L pH x L s	1	20.1325	****
L pH x Q s	1	3.2843	****
L pH x C s	1	0.4938	*
Q pH x L s	1	0.2034	NS
Q pH x Q s	1	2.5416	****
Error	18	0.0905	

* P < 0.05.

** P < 0.01.

*** P < 0.001.

**** P < 0.0001.

NS P > 0.05.

^aThe interaction Q pH x C s was insignificant and pooled with the error term.

Table 5--NSI mean square values and significance of F-ratios for Promine F

Source	df	Mean Square	
Rep	1	0.0199	NS
pH	2	232.4242	****
Linear (L)	1	453.9509	****
Quadratic (Q)	1	10.8975	****
Sucrose (s)	3	6.3288	****
Linear	1	18.6885	****
Quadratic	1	0.2779	**
Cubic (C)	1	0.0201	NS
pH x s	6	1.8736	****
L pH x L s	1	9.2379	****
L pH x Q s	1	0.0678	NS
L pH x C s	1	0.4291	**
Q pH x L s	1	1.1657	****
Q pH x Q s	1	0.1562	*
Q pH x C s	1	0.1851	*
Error	17	0.0326	

* P < 0.05.

** P < 0.01.

*** P < 0.001.

**** P < 0.0001.

NS P > 0.05.

Table 6--NSI mean square values and significance of F-ratios for
Supro 710

Source	df	Mean Square	
Rep	1	0.4486	NS
pH	2	1606.4847	****
Linear (L)	1	2973.4167	****
Quadratic (Q)	1	239.5526	****
Sucrose (s)	3	52.7224	****
Linear	1	127.4740	****
Quadratic	1	25.5886	****
Cubic (C)	1	5.1047	**
pH x s	6	9.4633	NS
L pH x L s	1	0.7512	NS
L pH x Q s	1	0.0185	NS
L pH x C s	1	0.0259	NS
Q pH x L s	1	13.9718	****
Q pH x Q s	1	31.2136	****
Q pH x C s	1	10.7987	****
Error	17	0.3590	

** P < 0.01.

**** P < 0.0001.

NS P > 0.05.

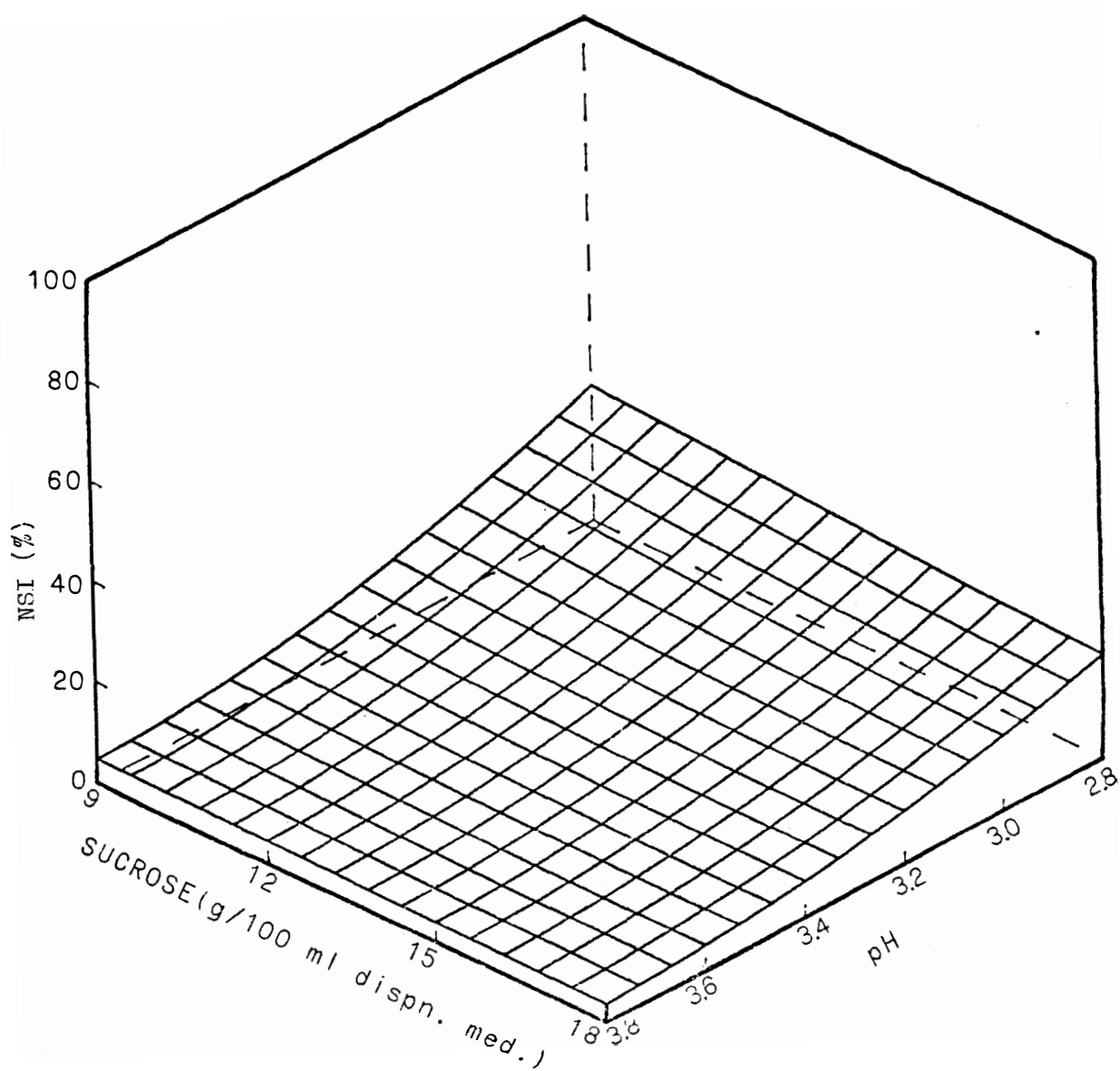


Fig. 8--NSI response surface for Pro Fam S-970 with variations in sucrose and pH levels.

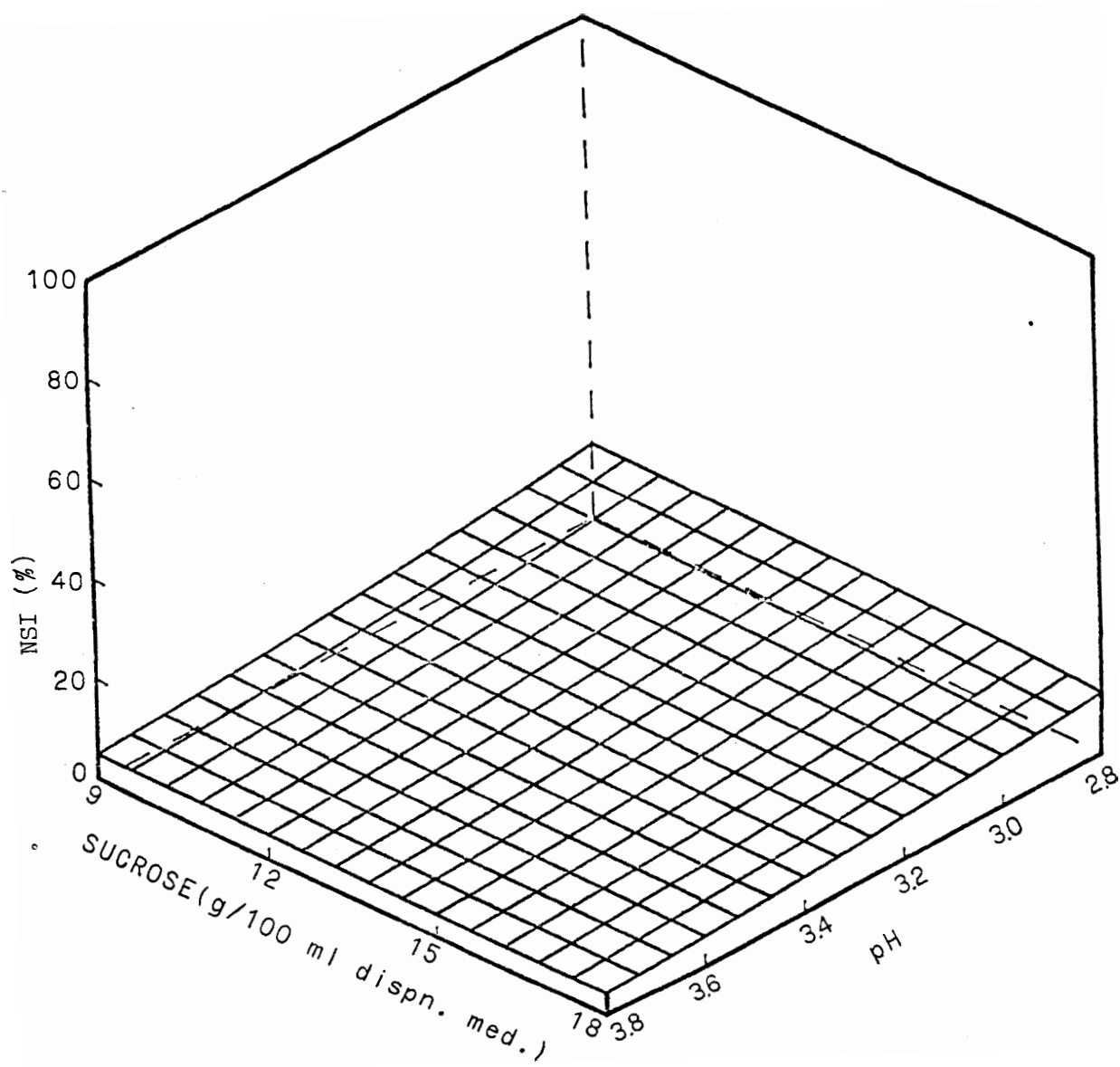


Fig. 9--NSI response surface for Promine F with variations in sucrose and pH levels.

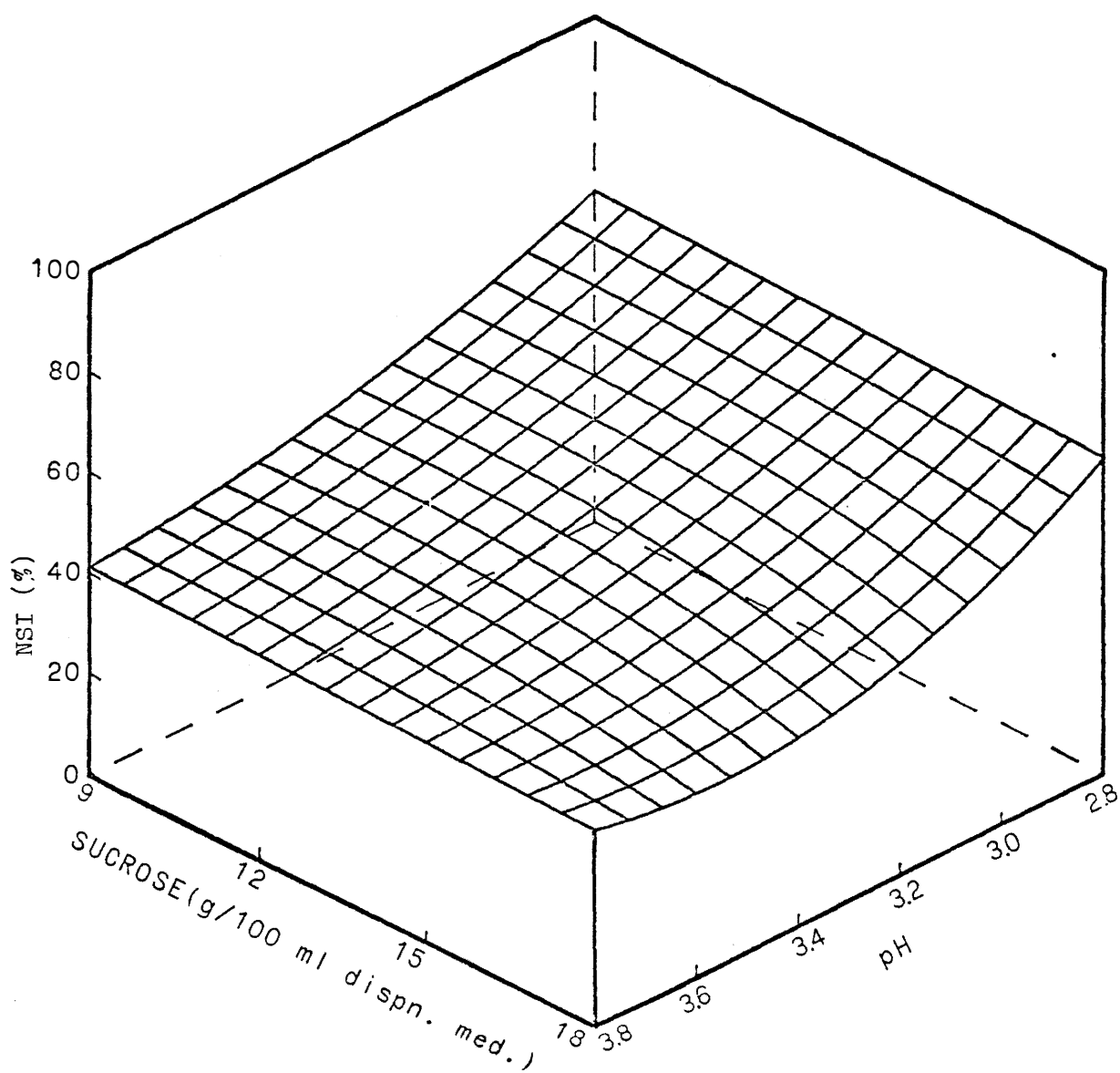


Fig. 10--NSI response surface for Supro 710 with variations in sucrose and pH levels.

for the isolate Pro Fam S-970. Although all isolates are similar in their chemical composition, it is a common occurrence that isolates from different commercial sources differ in their physical properties. This difference in behavior is especially noticeable in the solubility index, because solubility is particularly sensitive to prolonged exposure during isoelectric precipitation.

Effect of sucrose. Solubility of each isolate decreased with the addition of sucrose to the dispersions. The mean decrease in solubility was about 25, 14 and 5 percent for Pro Fam S-970, Promine F and Supro 710, respectively. The significant interaction between pH and sucrose for the NSI of Pro Fam S-970 and Promine F reflects the extent to which the magnitude of the effect of sucrose on NSI depended on the pH level. On a percentage basis, the effect of sucrose on the NSI of Pro Fam S-970 decreased with decreasing pH; the effect of sucrose on the NSI of Promine F increased with decreasing pH.

Viscosity

The mean values for apparent viscosity of the isolate dispersions as affected by pH and sucrose are presented in Table 7. The results of the analyses of variance are in Tables 8-10. Although the mean apparent viscosity of the dispersions was small (ranging from 1.9 to 3.1 cps) and differences, therefore, were small, the differences in viscosity were consistent; pH level and sucrose concentration significantly ($P < 0.0001$) affected apparent viscosity of the dispersions of all three isolates. The pH-sucrose interaction was significant only for Supro 710. The response surfaces for the three isolates are shown in Figures 11-13.

Table 7--Apparent viscosity mean values for Pro Fam S-970, Promine F and Supro 710 as a function of pH and sucrose levels

Isolate	Sucrose ^a	pH										Mean
		3.8										
		—	—	—	—	—	—	—	cps ^b	—	—	—
Pro Fam S-970	9	1.9								2.3		2.1
	12	2.1								2.5		2.3
	15	2.2								2.6		2.4
	18	2.3								2.7		2.5
Mean		2.1								2.5		
Promine F	9	2.0								2.2		2.1
	12	2.2								2.4		2.3
	15	2.3								2.6		2.5
	18	2.6								2.8		2.7
Mean		2.3								2.5		
Supro 710	9	2.2								2.5		2.4
	12	2.4								2.8		2.6
	15	2.5								2.9		2.7
	18	3.0								3.1		3.0
Mean		2.5								2.8		

^ag sucrose/100 ml dispersion medium.

^bEach value is the mean for two replications.

Table 8--Apparent viscosity mean square values and significance of F-ratios for Pro Fam S-970

Source	df	Mean Square	
Rep	1	< 0.0001	NS
pH	2	0.4118	****
Linear	1	0.7841	****
Quadratic	1	0.0395	****
Sucrose (s)	3	0.6785	****
Linear (L)	1	2.0096	****
Quadratic (Q)	1	0.0215	****
Cubic (C)	1	0.0043	*
pH x Sucrose	5 ^a	0.0015	NS
L pH x L s	1	0.0005	NS
L pH x Q s	1	0.0024	*
L pH x C s	1	0.0009	NS
Q pH x L s	1	0.0015	NS
Q pH x Q s	1	0.0032	*
Error	18	0.0005	

* P < 0.05.

**** P < 0.0001.

NS P > 0.05.

^aThe interaction Q pH x C s was insignificant and pooled with the error term.

Table 9--Apparent viscosity mean square values and significance of F-ratios for Promine F

Source	df	Mean Square	
Rep	1	0.0003	NS
pH	2	0.1377	****
Linear (L)	1	0.2576	****
Quadratic (Q)	1	0.0177	***
Sucrose (s)	3	0.8364	****
Linear	1	2.4786	****
Quadratic	1	0.0302	****
Cubic (C)	1	0.0003	NS
pH x s	5 ^a	0.0072	NS
L pH x L x	1	0.0000	NS
L pH x Q s	1	0.0028	NS
L pH x C s	1	0.0109	**
Q pH x L s	1	0.0042	*
Q pH x Q s	1	0.0183	****
Error	18	0.0007	

* P < 0.05.

** P < 0.01.

*** P < 0.001.

**** P < 0.0001.

NS P > 0.05.

^aThe interaction Q pH x C s was insignificant and pooled with the error term.

Table 10--Apparent viscosity mean square values and significance of F-ratios for Supro 710

Source	df	Mean Square	
Rep	1	< 0.0001	NS
pH	2	0.1431	****
Linear (L)	1	0.2832	****
Quadratic (Q)	1	0.0029	NS
Sucrose (s)	3	1.2996	****
Linear	1	3.8030	****
Quadratic	1	0.0572	****
Cubic (C)	1	0.0387	****
pH x s	6	0.0268	****
L pH x s	1	0.0284	****
L pH x Q s	1	0.0616	****
L pH x C s	1	0.0357	****
Q pH x L s	1	0.0107	**
Q pH x Q s	1	0.0007	NS
Q pH x C s	1	0.0237	****
Error	17	0.0010	

** P < 0.01.

**** P < 0.0001.

NS P > 0.05.

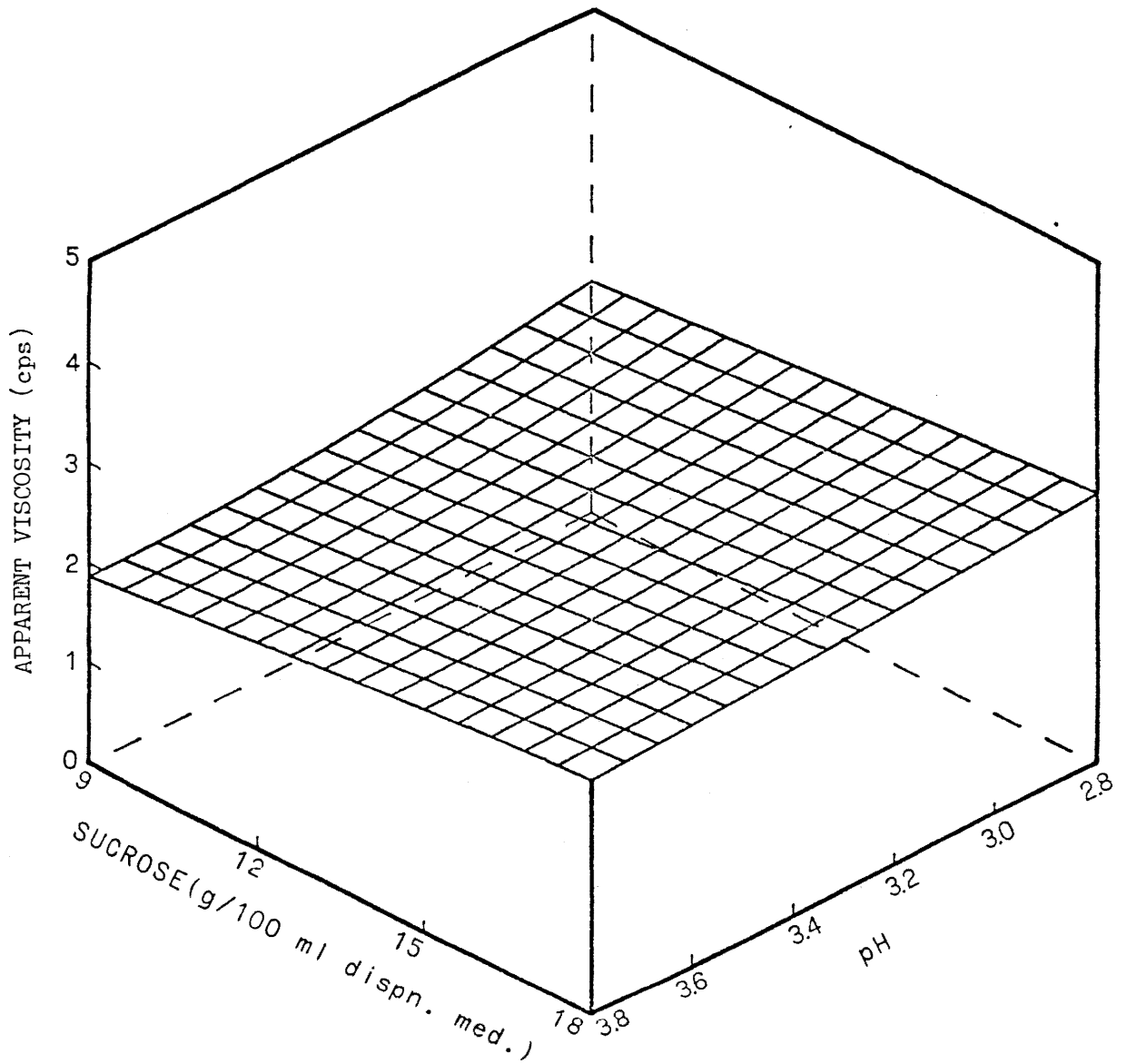


Fig. 11--Apparent viscosity response surface for Pro Fam S-970 with variations in sucrose and pH levels.

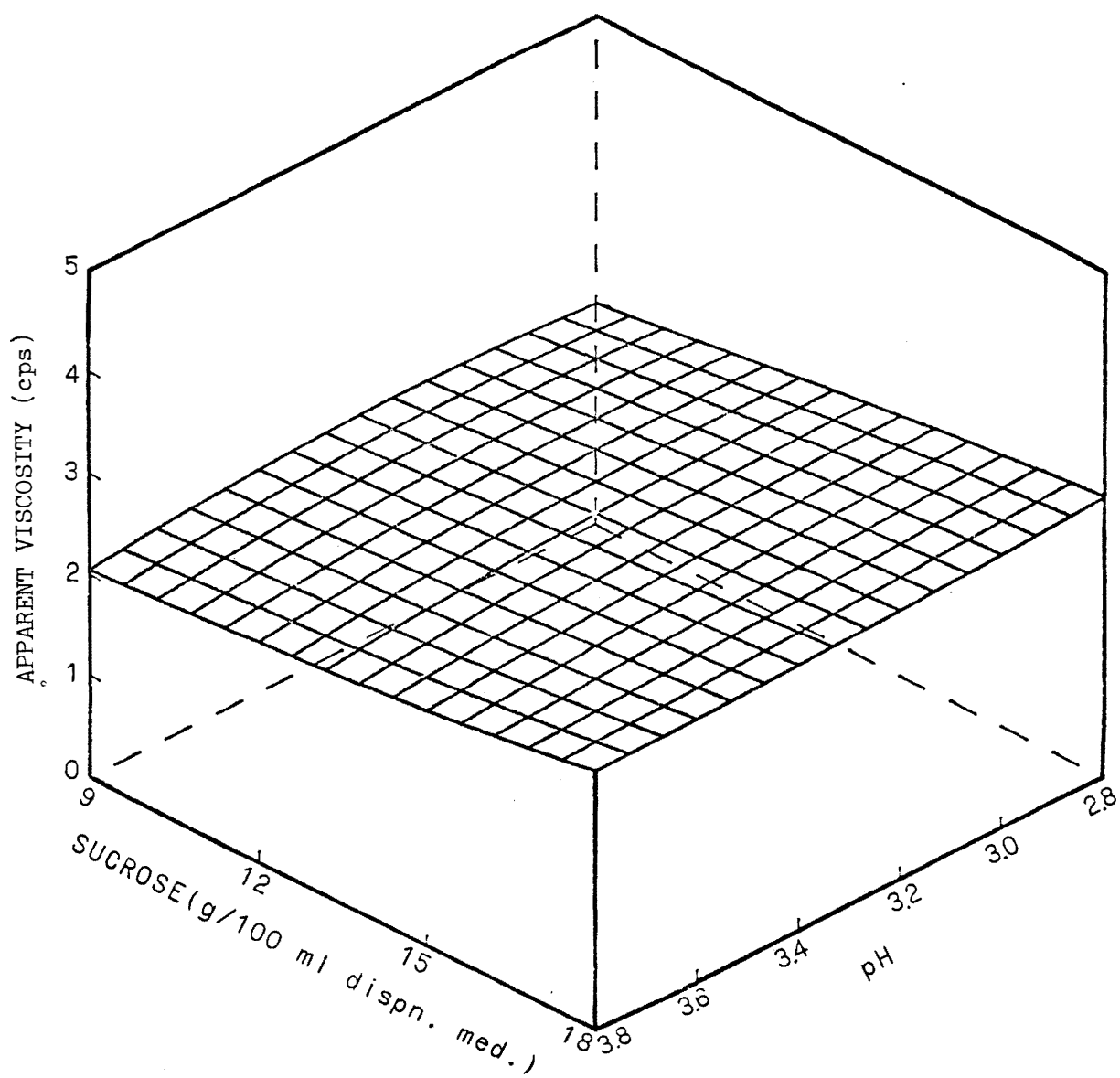


Fig. 12--Apparent viscosity response surface for Promine F with variations in sucrose and pH levels.

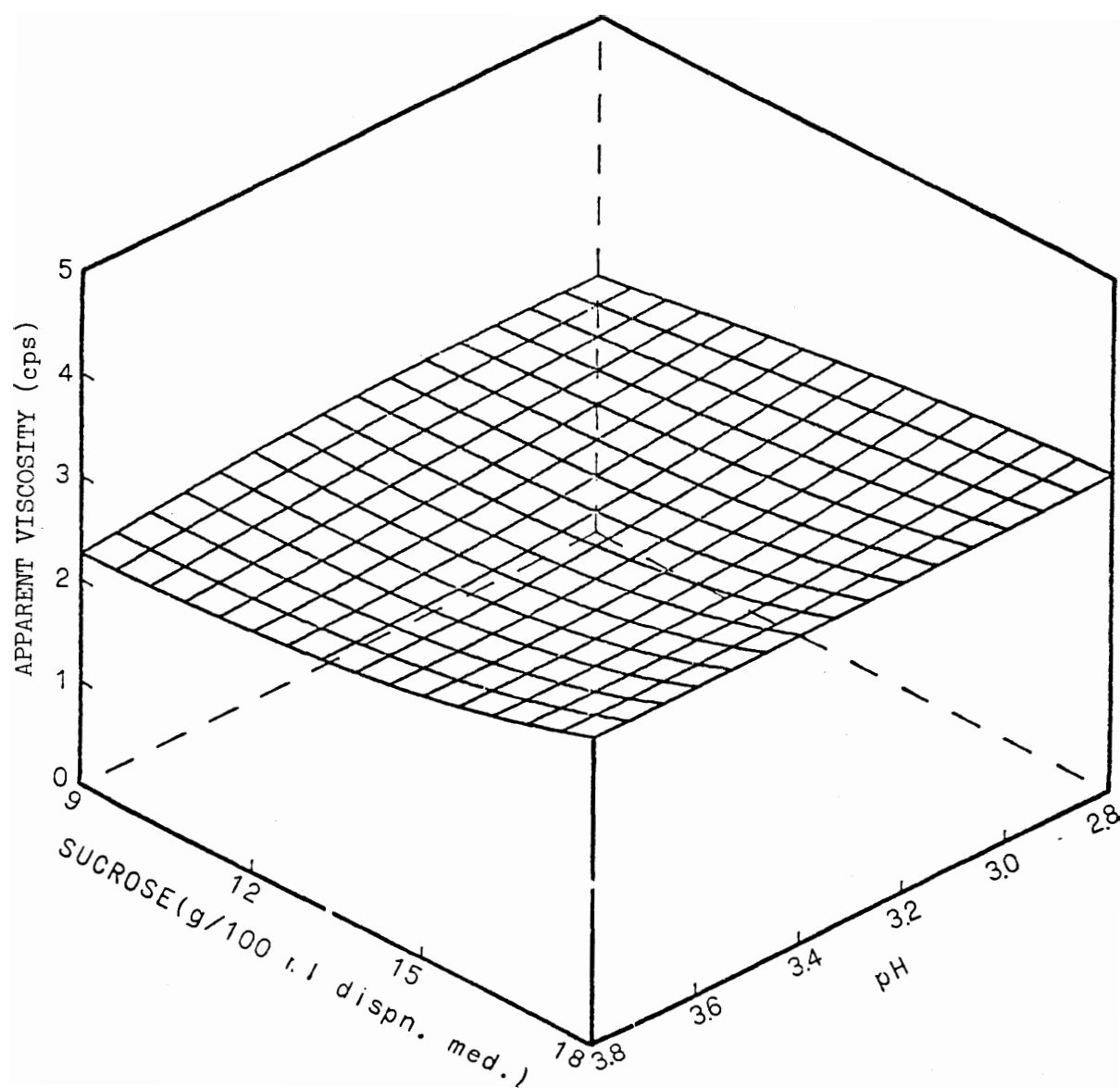


Fig. 13--Apparent viscosity response surface for Supro 710 with variations in sucrose and pH levels.

Effect of pH. A small increase in the apparent viscosity of the dispersions was found for each isolate as the pH of the dispersion was reduced from pH 3.8 to 2.8 (Table 7). It should be remembered that viscosity measurements were made not on slurries of specified amounts of isolate and dispersion medium but on dispersions of the soluble protein from the slurries. Thus the increasing apparent viscosity with decreasing pH probably reflects the increasing concentration of protein in solution with decreasing pH (e.g. 3.6 and 23.4 percent of the suspended isolate at pH 3.8 and 2.8, respectively, for Pro Fam S-970, as seen in Table 3, page 39).

Effect of sucrose. The addition of sucrose to the dispersions resulted in a small increase in the apparent viscosity (Table 7). Although the overall increases were only 0.4-0.6 cps, the percentage increases were 19, 28 and 25 for the isolates Pro Fam S-970, Promine F and Supro 710, respectively. Increases in viscosity of a solution with the addition of a solute should be expected and the small increase in viscosity in this case probably is attributable to the sucrose concentration itself rather than to an effect on soy protein isolate.

II. PART B: FOOD SYSTEM

From the results with the model system, it was decided that the isolate Supro 710 would be most suitable for application in the food system. The choice was made in consideration of NSI of the isolates; Supro 710 had the highest solubility. It was believed that the relatively high amount of soluble protein of Supro 710, as compared to Pro Fam S-970 and Promine F, would have a greater potential for improving the nutritional value of a beverage.

Viscosity

The mean values for the apparent viscosity of the product are presented in Table 11. The results of the analysis of variance are in Table 12. The main effects of pH and sucrose were significant at the level $P < 0.0001$, as was the pH-sucrose interaction. As with the model system, there was a small increase in the apparent viscosity of the dispersions as the pH of the dispersions was reduced from pH 3.8 to 2.8 (Table 11). Also in agreement with results for the model system was an increase in apparent viscosity with increasing sucrose concentration. The response surface for the apparent viscosity of the food product is shown in Figure 14. The response surface is almost identical in shape to that for the same isolate in the model system. The model system showed a high degree of predictability for the food system, as was to be expected because the food system is only slightly more complex than the model system.

Sensory Evaluation

The mean values for the sensory characteristics and overall acceptability of the product are presented in Table 13. The results of the analysis of variance are in Table 14.

The pH level had a significant effect ($P < 0.0001$) on every characteristic and on overall acceptability of the product. The increased viscosity with decreased pH is in agreement with the findings for the objective measurements in both the model system and the food system. Tingliness, according to Szczesniak (1979), is related to the sensation of pain or pressure caused by CO_2 bubbles. With the addition of dry ice to the products the sensation of carbonation was evident in all the products evaluated. The increased acid concentration apparently contributed to the sensation of pain.

Table 11--Apparent viscosity mean values as a function of pH and sucrose content of beverage containing soy protein isolate Supro 710

Sucrose ^a	3.8	3.3	2.8	Mean
	— — — — — — — — cps ^b — — — — — — — —			
9	2.3	2.7	2.8	2.6
12	2.5	2.8	2.9	2.7
15	2.7	2.8	3.2	2.9
18	3.2	3.4	3.5	3.4
Mean	2.7	2.9	3.1	

^ag sucrose/100 ml dispersion medium.

^bEach value is the mean for two replications.

Table 12--Apparent viscosity mean square values and significance of F-ratios for soy beverage containing Supro 710

Source	df	Mean Square	
Rep	1	0.0000	NS
pH	2	0.4384	****
Sucrose	3	0.7491	****
pH x Sucrose	6	0.0154	****
Error	11	0.0003	

****p < 0.0001.

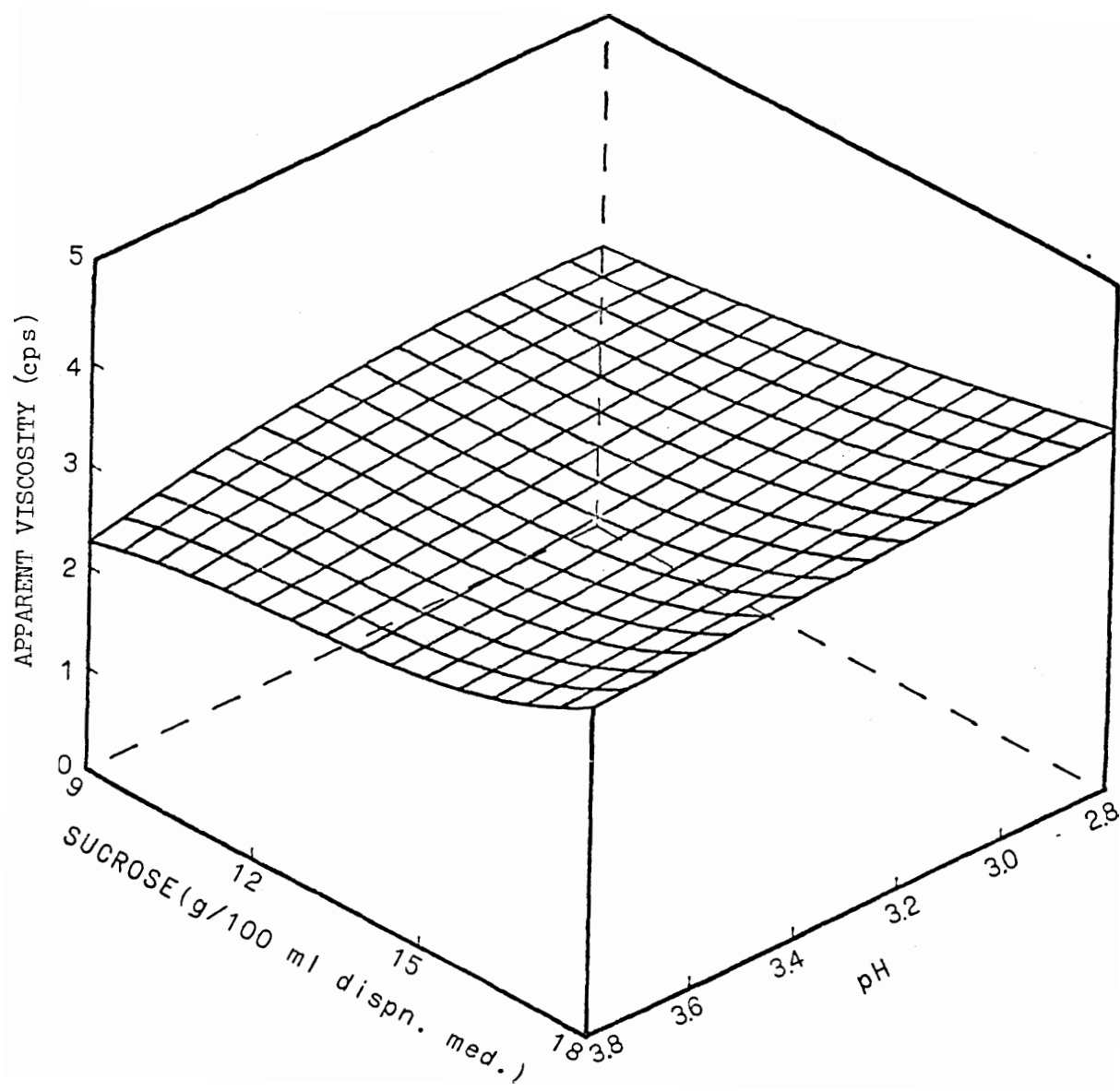


Fig. 14--Apparent viscosity response surface for soy beverage with variations in sucrose and pH levels.

Table 13--Mean values^{a,b} of sensory characteristics of soy beverage as a function of pH and sucrose levels

pH	Sucrose ^c	Viscosity	Tingly	Sweet	Citrus Flavor	Tart	Intense Flavor	Bitter Aftertaste	Sweet Aftertaste	Overall Acceptability
3.8		1.5	1.7	3.5	2.9	1.9	2.8	1.5	2.9	2.8
3.3		2.0	2.3	2.3	3.6	3.7	3.8	2.8	1.9	2.2
2.8		2.6	3.1	1.0	4.0	5.1	4.6	3.7	0.8	1.1
	9	2.0	2.4	1.7	3.2	3.8	3.8	3.3	1.3	1.5
	12	2.1	2.3	2.1	3.5	3.6	3.8	2.7	1.7	1.9
	15	2.1	2.3	2.6	3.7	3.5	3.7	2.3	2.1	2.4
	18	1.9	2.4	2.7	3.6	3.3	3.7	2.3	2.3	2.3

^a0 = weak; 6 = strong for all characteristics except overall acceptability where 0 = not at all, and 6 = very much so.

^bEach value in the upper portion of the table is the mean for 120 judgments (4 levels of sucrose x 15 panelists x 2 replications); each value in the lower portion of the table is the mean of 90 judgments (3 pH levels x 15 panelists x 2 replications).

^cg sucrose/100 ml dispersion medium.

Table 14--Mean square values and significance of F-ratios for sensory parameters of soy beverage

Source	df	Viscosity	Tingly	Sweet	Citrus Flavor	Tart	Intense Flavor	Bitter Aftertaste	Sweet Aftertaste	Overall Acceptability
pH	2	41.1676 ****	59.3221 ****	183.4827 ****	36.1207 ****	298.4500 ****	93.8352 ****	146.1964 ****	137.0601 ****	91.6599 ****
Sucrose (s)	3	0.4542 NS	0.1348 NS	20.9142 ****	3.2835 **	4.3047 **	0.2716 NS	17.9867 **	20.0220 ****	13.6487 ****
Rep (R)	1	0.0181 NS	24.3620 ****	0.0504 NS	1.7921 NS	7.3903 **	12.0817 ****	2.2658 NS	1.1133 NS	0.0192 NS
Panelist (P)	14	24.6946 ****	18.4439 ****	6.1271 ****	15.1072 ****	13.3268 ****	15.9166 ****	20.4241 ****	5.5497 ****	7.0020 ****
pH x s	6	0.3396 NS	1.6624 NS	1.1987 NS	2.0323 **	3.2922 ***	0.9864 NS	4.6873 **	1.5694 NS	4.2386 ***
pH x P	28	4.5908 ****	5.8249 ****	1.5815 *	2.9967 ****	2.2152 ****	2.7385 ****	6.9010 ****	2.9778 ****	3.7025 ****
P x s	42	0.4906 NS	0.9383 NS	1.2180 NS	1.0705 **	0.7412 NS	0.8123 NS	1.2566 NS	1.1158 NS	0.4747 NS
P x R	14	1.6076 ****	3.8409 ***	1.6077 NS	2.2759 ***	1.0918 NS	0.6725 NS	3.3693 **	1.5648 NS	2.5537 **
Error	154	0.5208	1.2458	0.9626	0.5394	0.8076	0.6526	1.3742	0.8099	0.9600

* P < 0.05.

** P < 0.01.

*** P < 0.001.

**** P < 0.0001.

NS P > 0.05.

It should be pointed out that the addition of orange flavor extract and dry ice resulted in a decrease of the pH of the beverages within 24 hr from pH 3.8, 3.3 and 2.8 to 3.7, 3.2 and 2.7, respectively.

The decreased sweetness and sweet aftertaste with decreasing pH also is to be expected because tartness tends to counteract sweetness and vice versa. The increasing scores for citrus flavor and intensity of flavor with increasing pH, are not surprising because acidity is a large component of citrus flavor. The increase in tartness with decreased pH level is an inevitable effect of increased acidity. The bitter aftertaste and its relation to pH may be more indirect. The beverages with decreasing pH levels had an increasing amount of soy protein and although the isolate was described by the manufacturer as being bland, there was a noticeable bitter aftertaste especially at pH 2.8 where the protein concentration was greatest.

The influence of pH on the flavor characteristics probably included some enhancement of the acidic note contributed by the orange flavor extract. The different amounts of extract in beverages of different pH levels may not have been the correct amounts to just compensate for different protein concentrations.

Since pH had a significant influence on the sensory characteristics of the beverage, it is not surprising that the overall acceptability was related to pH level. The panelists apparently liked the least tart beverage.

Although the addition of sucrose resulted in a significant increase ($P < 0.0001$) in the apparent viscosity of both the model system and the food product as measured objectively, the judges did not perceive a difference. There were no significant effects of

sucrose on tingliness or intensity of flavor of the beverages. As would be expected, increasing sucrose concentration resulted in an increase in perceived sweetness and sweet aftertaste and a decrease in tartness, bitter aftertaste and citrus flavor.

The amount of added sucrose not only had a significant effect on various individual characteristics but also was influential in the assessment of overall acceptability. The highest scores for overall acceptability were associated with the highest degrees of sweetness.

Two-way tables are shown only for tartness and overall acceptability because these were considered the most important of the characteristics for which a pH-sucrose interaction ($P < 0.0001$) was observed. The mean values are presented in Table 15.

The increased perception of tartness was very evident with decreasing pH overall, a situation that is to be expected. The addition of sucrose resulted in a decreased perception of tartness, also an effect that is to be expected. The significant interaction reflects the differing effects of sucrose at different pH levels; the effect of sucrose on tartness was a dramatic decrease at pH 3.3 but not at the other pH levels.

Similarly, although acceptability increased overall with increased sucrose content, the extent of the effect of sucrose depended on the pH level. Figure 15 represents the overall acceptability of the beverage as a function of pH and sucrose content. The combination of either a sucrose concentration of 12 percent with pH 3.8 or 15 percent with pH 3.8 or 3.3 appears to be optimum

Table 15--Mean values^a for tartness and overall acceptability of soy beverage as a function of pH and sucrose levels

		pH			
	Sucrose ^b	3.8	3.3	2.8	Mean
Tartness	9	2.1	4.3	5.1	3.8
	12	1.8	3.9	5.1	3.6
	15	1.6	3.7	5.2	3.5
	18	2.1	3.0	4.8	3.3
	Mean	1.9	3.7	5.1	
Overall Acceptability	9	2.5	1.5	0.6	1.5
	12	3.0	1.8	1.0	1.9
	15	3.1	3.0	1.2	2.4
	18	2.6	2.7	1.5	2.3
	Mean	2.8	2.3	1.1	

^aEach value is the mean for two replications.

^bg sucrose/100 ml dispersion medium.

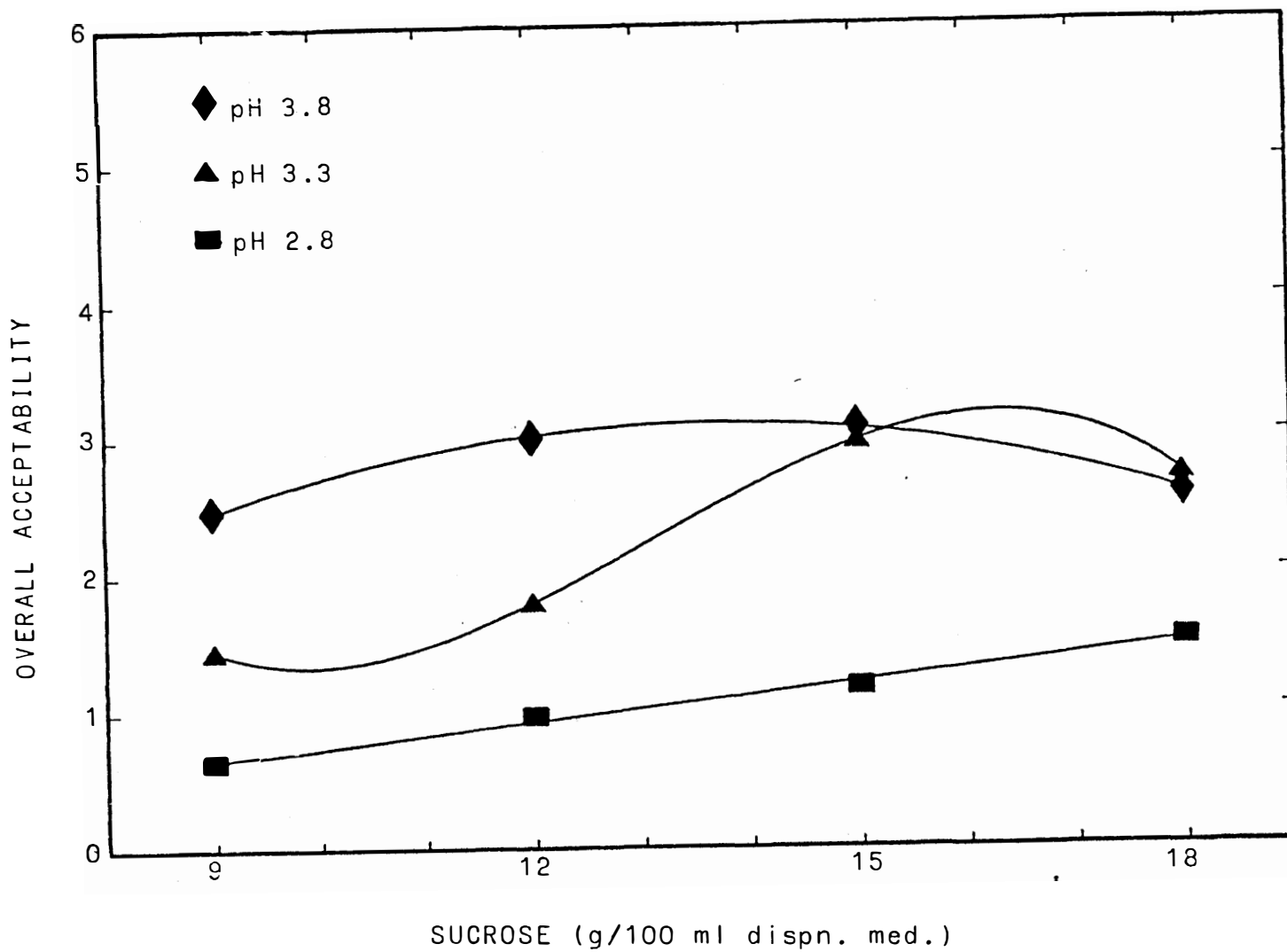


Fig. 15--The overall acceptability of soy beverage as a function of pH and sucrose levels.

for this product. The rating of borderline acceptability of a soy beverage with any of those pH-sucrose combinations suggests the feasibility of developing such a product.

Although the product was made from the soluble extract of the isolate, there was some settling of the protein after 24 hr. Priepke et al. (1980) found that subjecting soy beverages to a homogenization pressure of 5,000 psi or more prevented visible settling during storage. The beverage prepared in this study was not homogenized.

The acceptability of the beverages may have been borderline partly because of the tendency to settle. In addition, it is possible that the usual consumption of orange flavored beverages among the panelists is low, although Holsinger et al. (1973) reported orange flavor to be the most widely accepted citrus flavor.

With the relatively high cost of animal proteins as compared with plant proteins, the use of soy products in the U.S.A. probably will increase. At the present time, however, animal protein sources are still readily available and wide acceptance of soy products has not yet occurred. Thus the primarily American panel used in this study might not have been ideal. During the initial evaluation of six samples, an Asian consistently rated the samples higher than did the other panelists.

Among the objectives of this study was the evaluation of the functionality of an isolate in a food system. This portion of the study was stimulated in part by the concern for improving the diet with increased use of soy proteins. The results of the study indicate that the high solubility and low dispersion viscosity of the

isolate Supro 710 compared to Pro Fam S-970 and Promine F may be suitable for commercial exploitation in a beverage. A beverage with 12 or 15 percent sucrose at pH 3.8 could contain about 2.2 g soluble protein per 100 ml and one with 15 percent sucrose at pH 3.3 could contain about 2.5 g soluble protein per 100 ml. Such a beverage, if fortified with Vitamin C and DL-methionine could contribute to the nutritional improvement of the diet in underdeveloped areas.

CHAPTER V

SUMMARY

The study was part of a systematic evaluation of soy protein isolates in formulated foods as influenced by other ingredients and was in two parts. Part A involved an investigation of protein solubility and dispersion viscosity of three soy isolates, Pro Fam S-970, Promine F and Supro 710, in simple models at 3°C and at pH levels of 3.8, 3.3 and 2.8, attained by the additions of citric acid solutions. The effects of addition of sucrose at varying levels on solubility and dispersion viscosity of the isolates at the given pH levels were studied also. In Part B the findings of Part A were applied to functional performance of a selected isolate in a citrus flavored carbonated soy beverage.

Protein solubility of each isolate increased as the dispersion pH decreased from 3.8 to 2.8. The main effects of pH and sucrose on solubility were significant for all soy protein isolates: the pH-sucrose interaction was significant for Pro Fam S-970 and Promine F ($P < 0.0001$). Solubility of each isolate decreased with the addition of sucrose to the dispersions.

The apparent viscosity of isolate dispersions was affected by both pH and sucrose ($P < 0.0001$). A small increase in apparent viscosity of the dispersions was found for each isolate as the pH of the dispersion was reduced from 3.8 to 2.8. The addition of sucrose to the dispersions also resulted in a small increase in the apparent viscosity.

In Part B, the results of the objective measurement of apparent viscosity were similar to those obtained for the model system in Part A. In the sensory evaluation both pH and sucrose had significant effects on the individual parameters and on the overall acceptability of the beverage. Decreased pH resulted in increased perception of tartness and decreased perception of sweetness; increased sucrose concentration resulted in decreased perception of tartness and increased perception of sweetness. The extent of the effects of sucrose on both tartness and overall acceptability depended on the pH level. The ratings of overall acceptability in relation to the values for specific parameters indicated that the panelists liked a low degree of tartness and a high degree of sweetness.

The combination of a sucrose concentration of either 12 percent with pH 3.8 or 15 percent with pH 3.8 or 3.3 appears to be optimum for this product. A beverage with 12 or 15 percent sucrose at pH 3.8 could contain about 2.2 g soluble protein per 100 ml and one with 15 percent sucrose at pH 3.3 could contain about 2.5 g soluble protein per 100 ml. The rating of borderline acceptability of a soy beverage with any of those pH-sucrose combinations suggests the feasibility of developing such a product.

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APPENDIXES

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APPENDIX A

TABLES

Table 16--The amounts of citric acid solution and water added to
1.20 g isolate for NSI determination

			pH	
Soy		3.8	3.3	2.8
Pro Fam S-970	citric acid ^a	5.0	9.0	26.0
	and H ₂ O (ml)	35.0	31.0	14.0
Promine F and Supro 710	citric acid ^a	6.0	11.0	26.0
	and H ₂ O (ml)	34.0	29.0	14.0

^a0.62 N citric acid solution.

Table 17--The amounts of sucrose, citric acid solution and water added to 6.0 g Supro 710 for preparation of beverage base containing four levels of sucrose

pH		sucrose ^a			
		9	12	15	18
3.8	citric acid ^b (ml)	27.0	27.0	27.0	27.0
	H ₂ O (ml)	73.0	73.0	73.0	73.0
3.3	citric acid ^b (ml)	48.5	48.5	48.5	48.5
	H ₂ O (ml)	51.5	51.5	51.5	51.5
2.8	citric acid ^b (ml)	96.0	96.0	96.0	96.0
	H ₂ O (ml)	4.0	4.0	4.0	4.0

^ag sucrose/100 dispersion medium.

^b0.62 N citric acid solution.

APPENDIX B

SCORE CARD

Score card^a - carbonated citrus flavored soy beverage

Name:

Date:

Product: Carbonated citrus flavored
soy beverage

Code:

Instructions:

Take a sip of water provided. Swish it in your mouth and swallow. Please do not rinse your mouth or sip the water again until you have completely finished evaluating all characteristics on the score card. You will be given 6 samples to evaluate in this series. In front of you is one product sample. Evaluate each characteristic listed below, by placing a vertical line across the horizontal line at a point that best describes that characteristic of the sample. Take enough sample at a time to evaluate each characteristic carefully.

Character-
istic:

Weak

Moderate

Strong

Viscous

Tingly

Sweet

Citrus flavor

Tart

Intense
flavor

Bitter
aftertaste

Sweet
aftertaste

Not at all

Very much so

Overall
acceptability

^aLines were 15 cm long on the actual score card.

APPENDIX C

POLYNOMIAL EQUATIONS

Polynomial Equations

Nitrogen solubility index

Promine F

$$Y = 143.686 - 69.722 \text{ pH} + 8.767 \text{ pH}^2 - 22.061 \text{ sucrose} + 2.425 \text{ sucrose}^2 - 0.079 \text{ sucrose}^3 + 12.769 \text{ pH} \times \text{sucrose} - 1.410 \text{ pH} \times \text{sucrose}^2 + 0.046 \text{ pH} \times \text{sucrose}^3 - 1.827 \text{ pH}^2 \times \text{sucrose} + 0.202 \text{ pH}^2 \times \text{sucrose}^2 - 0.007 \text{ pH}^2 \times \text{sucrose}.$$

Pro Fam S-970

$$Y = 242.565 - 115.665 \text{ pH} + 14.027 \text{ pH}^2 + 17.046 \text{ sucrose} - 1.206 \text{ sucrose}^2 + 0.012 \text{ sucrose}^3 - 9.680 \text{ pH} \times \text{sucrose} + 0.587 \text{ pH} \times \text{sucrose}^2 - 0.003 \text{ pH} \times \text{sucrose}^3 + 1.365 \text{ pH}^2 \times \text{sucrose} - 0.072 \text{ pH}^2 \times \text{sucrose}^2.$$

Supro 710

$$Y = 359.856 - 162.790 \text{ pH} + 20.874 \text{ pH}^2 + 63.905 \text{ sucrose} - 12.209 \text{ sucrose}^2 + 0.526 \text{ sucrose}^3 - 39.896 \text{ pH} \times \text{sucrose} + 7.587 \text{ pH} \times \text{sucrose}^2 - 0.327 \text{ pH} \times \text{sucrose}^3 + 6.070 \text{ pH}^2 \times \text{sucrose} - 1.152 \text{ pH}^2 \times \text{sucrose}^2 + 0.050 \text{ pH}^2 \times \text{sucrose}^3.$$

Apparent viscosity, model system

Promine F

$$Y = 0.723 + 0.941 \text{ pH} - 0.183 \text{ pH}^2 - 1.271 \text{ sucrose} + 0.112 \text{ sucrose}^2 - 0.002 \text{ sucrose}^3 + 0.694 \text{ pH} \times \text{sucrose} - 0.054 \text{ pH} \times \text{sucrose}^2 - 0.090 \text{ pH}^2 \times \text{sucrose} + 0.006 \text{ pH}^2 \times \text{sucrose}^2.$$

Pro Fam S-970

$$Y = 6.583 - 2.568 \text{ pH} + 0.330 \text{ pH}^2 + 0.489 \text{ sucrose} - 0.037 \text{ sucrose}^2 - 0.262 \text{ pH} \times \text{sucrose} + 0.021 \text{ pH} \times \text{sucrose}^2 + 0.034 \text{ pH}^2 \times \text{sucrose} - 0.003 \text{ pH}^2 \times \text{sucrose}^2.$$

Supro 710

$$Y = 0.890 + 0.660 \text{ pH} - 0.103 \text{ pH}^2 - 4.921 \text{ sucrose} + 0.777 \text{ sucrose}^2 - 0.027 \text{ sucrose}^3 + 3.000 \text{ pH} \times \text{sucrose} - 0.463 \text{ pH} \times \text{sucrose}^2 + 0.016 \text{ pH} \times \text{sucrose}^3 - 0.441 \text{ pH}^2 \times \text{sucrose} + 0.067 \text{ pH}^2 \times \text{sucrose}^2 - 0.002 \text{ pH}^2 \times \text{sucrose}^3.$$

Apparent viscosity, food system containing Supro 710

$$Y = -34.011 + 28.698 \text{ pH} - 5.510 \text{ pH}^2 + 2.979 \text{ sucrose} + 0.138 \text{ sucrose}^2 - 0.010 \text{ sucrose}^3 - 3.232 \text{ pH} \times \text{sucrose} + 0.025 \text{ pH} \times \text{sucrose}^2 + 0.004 \text{ pH} \times \text{sucrose}^3 + 0.756 \text{ pH}^2 \times \text{sucrose} - 0.025 \text{ pH}^2 \times \text{sucrose}^2.$$

Overall Acceptability

pH 2.8

$$Y = -0.0193 + 0.093 \text{ sucrose}$$

pH 3.3

$$Y = 27.898 - 6.730 \text{ sucrose} + 0.546 \text{ sucrose}^2 - 0.014 \text{ sucrose}^3$$

pH 3.8

$$Y = -2.263 + 0.783 \text{ sucrose} - 0.029 \text{ sucrose}^2.$$

VITA

The author was born in Guyana and educated under the British system in Berbice, Guyana. He passed the General Certificate Examinations, Oxford and Cambridge University and London University, at the ordinary and advanced levels. He was employed in the Ministry of Education in several capacities, including Assistant Accountant, from October 1964 to November 1973. He attended Knoxville College from 1973 to 1976, where during 1975-76, he was a Fellow of the National Science Foundation. After graduation with a Bachelor of Science (summa cum laude) in Biology, he was admitted to The University of Tennessee, Knoxville, in the Fall of 1976. He received the Master of Science degree with a major in Food Science in March 1978. In December 1980, the requirements for the Doctor of Philosophy with a major in Food Science and a minor in Food Technology were completed. He is a member of the Institute of Food Technologists, the American Association of Cereal Chemists and the American Oil Chemists Society. He was elected to the honor societies Beta Kappa Chi, Omicron Nu and Phi Tau Sigma.

He is the second son of Mr. and Mrs. Albert E. Jaundoo of Rosignol, Guyana.