Composition, Nutritional, and Functional Properties, and Quality Criteria of Soy Protein Concentrates and Soy Protein Isolates

KARL F. MATTIL, Food Protein Research and Development Center,
Texas A&M University, College Station, Texas

ABSTRACT

The available commercial soy protein concentrates and soy protein isolates afford the food processor concentrated sources of protein with some interesting and varied functional properties. Each class of products is mild to bland in flavor and light in color. The concentrates contain at least 70% protein and the isolates 90%. The nutritional quality of the proteins is fair to good and can be excellent either by supplementation with 1.5% methionine or by appropriate blending with other sources of proteins. The concentrates provide the food manufacturer with products where a high protein content for unit of volume or wt is needed. The isolates are available for uses where the functional properties reside solely in the protein and the nonprotein components may interfere. The adaptability of the proteins to modification by controlled processing conditions has made it possible for the manufacturers to produce a diversity of products that should be of interest to practically all food formulators.

INTRODUCTION

In preparing for this presentation, a choice had to be made between two alternative approaches. The first alternative was to follow the traditional path of reviewing the literature and summarizing the state of the art as it is recorded in scientific publications. In effect, this would be a summarization of what can be done and what is scientifically possible. The other alternative was to examine what is being done commercially by an analysis of the soy protein concentrates and isolates that are being marketed in the U.S.

This presentation is based upon the second alternative. Letters were written to seven U.S. corporations that were known or believed to manufacture soy protein concentrates and isolates. They were requested to submit samples of each of their products along with copies of any pertinent product specifications and performance brochures. They also were invited to supplement this with specific information that could be useful in preparing this manuscript. Each of the companies responded in a cooperative manner, and the material received from them constitutes a substantial portion of this manuscript. Samples of eight different commercial concentrates and 11 isolates were received.

Some of the data that will be reported are taken directly from the literature supplied by the corporations. Other data are based upon analyses in our laboratories in the rather short period of time between the arrival of all the samples and the deadline for the preparation of this manuscript.

TABLE I

Ranges of Analytical Characteristics Claimed by Manufacturers of Soy Protein Concentrates[a] and Isolates[b]

Characteristic	Concentrates (percent)	Isolates (percent)
Protein (N x 6.25 = MFB)	70.0-72.6	90.0-97.7
Fat	0.3-2.0	0.2-1.2
Moisture	2.6-8.0	3.9-7.0
Ash	3.0-5.8	2.5-4.5
Crude fiber	2.9-5.0	0.01-0.2
Minerals		
Calcium	0.22-0.67	0.14-0.39
Phosphorus	0.45-0.87	0.8-0.9
Sodium	0.01-1.25	0.15-1.5
Potassium	0.3-2.1	0.07-1.0
Iron	0.01	0.014[c]
Sulfur	0.44[c]	—
Heavy metals (ppm)	<1	0.3

[a]Eight products.
[b]Eleven products.
[c]Two products.

ANALYTICAL CHARACTERISTICS

The ranges of analytical characteristics claimed by the manufacturers in their literature are shown in Table I. Of course, the critical analysis is that for nitrogen, which by use of the 6.25 factor is converted to protein. This analysis generally is used in defining the soy protein concentrates and isolates. The concentrates on a moisture free basis contain at least 70% protein, the isolates 90%. There is a rather wide variability in most of the other components. This variability probably results from a composite of the natural variability of biological materials, differences in the processes employed, and the inherent variability of analytical methodology.

The principal minerals are calcium, phosphorus, sodium, and potassium. Both the concentrates and the isolates could be considered significant sources of calcium and iron. The available iron is reported to have a relative biological value in the range of 55-69.

The amino acid compositions of three representative soy protein concentrates are shown in Table II. With one exception, there is a remarkable similarity among the three concentrates. By this single analysis one of the concentrates did appear to be lower than the others in lysine. It is important to emphasize that there was only time for a single analysis so that it was not possible to confirm this difference by replication.

The amino acid compositions of six representative soy

TABLE II

Amino Acid Composition of Some Commercial Soy Protein Isolates (g/16 g N)

Amino acid	I-6	I-8	I-10	I-13	I-14	I-15
Lysine	5.4	5.4	5.7	5.4	5.5	5.6
Threonine	3.5	3.5	3.3	3.1	3.2	3.0
Valine	4.7	4.6	4.4	4.2	5.0	4.6
Methionine	1.1	1.1	1.2	1.2	0.9	1.0
Isoleucine	4.6	4.5	4.4	4.3	4.4	4.4
Leucine	7.6	7.8	7.6	7.3	7.6	7.4
Phenylalanine	5.1	5.2	5.2	5.0	4.9	5.2
PER[a]	1.7	—	—	1.75	1.1-1.2	1.6

[a]Protein efficiency ratio claimed by manufacturer.

TABLE III

Amino Acid Composition of Several Commercial Soy Protein Concentrates (g/16 g N)

Amino acid	C-1	C-3	C-5
Lysine	5.1	5.8	5.8
Threonine	3.7	3.7	3.8
Valine	4.7	4.8	4.7
Methionine	1.3	1.2	1.2
Isoleucine	4.5	4.5	4.6
Leucine	7.8	7.9	8.0
Phenylalanine	5.1	5.1	5.1

protein isolates are shown in Table III. In this case some variability is noted. Again, these are single analyses. Threonine varies from a low of 3.0 to a high of 3.5%; valine from 4.2-5.0. Methionine, which is a critical amino acid in these products, ranged from 0.9-1.2. We have sufficient confidence in these single assays to suggest that they do, indeed, indicate that commercial soybean protein isolates are not identical in their amino acid compositions. This is confirmed partially by the protein efficiency ratios (PER) claimed by the manufacturers in their literature. Note that there appears to be a correlation between the quantity of methionine found in the sample and the PER claimed by the manufacturer for the product. While this finding of a correlation may, in this case, simply be fortuitous, it will be pointed out later that methionine is the critical amino acid in the soy protein isolates.

A composite of all of the amino acid data is shown in Table IV. Again, this shows that the ranges are rather small and that there is a considerable amount of overlapping of the concentrates and the isolates. On the average, the isolates appear to contain a somewhat lower proportion of the essential amino acids than do the concentrates. However, the differences are all small. This is really rather remarkable when one considers the number of different manufacturers involved, the different natures of the processes, and all of the potentials for variability. It would be fair to conclude that the similarities in the amino acid compositions of these commercial products are more impressive than their differences.

It would be a major error to conclude that all soy protein concentrates are alike and that all soy protein isolates are alike. In fact, there are some rather substantial differences. Some of the differences are deliberate. For example, some manufacturers will put out pairs of products, one being deliberately high in protein solubility and the other low.

ORGANOLEPTIC ATTRIBUTES

All of the manufacturers strive to produce colorless, odorless, and flavorless products. They succeed to varying degrees. According to their brochures and literature, which can be confirmed by visual observation, colors will vary from off-white to light tan, flavor from bland to mild cereal, and odor from none to mild cereal. In particular, there appears to be a vigorous competition among the manufacturers to produce the most flavorless product in either class. In general, they are probably more concerned about flavor and odor than they are about color. It can be safely assumed, however, that they do everything they can within the limitations of their raw material and processes to produce the lightest possible colors.

These organoleptic attributes have various degrees of importance, depending upon the food system in which the isolates or concentrates are going to be used. In a system where flavor, color, and odor are critical, the food manufacturer would be well advised to evaluate all of the available products in his food system. The products are sufficiently different that, in a given system, one may be good and another may be poor. It could be misleading to extrapolate from the flavor of the product per se or its flavor in a given food system to its probable flavor acceptability in a different food system. Most people who are experienced in food product development are aware of the phenomenon of flavor compatibility. For example, it is conceivable that, in a specified food system, a totally bland isolate or concentrate may downgrade a desired flavor by dilution, whereas a mildly flavored counterpart might be sufficiently compatible with the desired flavor to be a preferred component in the system.

There are some substantial physical-chemical differences among the concentrates and isolates. These are reflected in a variety of functional properties. For example, some manufacturers produce isolates and concentrates with both high and low protein solubility. Some products are sold at the isoelectric pH and others are neutralized. Others may be modified by enzymatic or other means to induce specific properties. The objective of the manufacturers is to produce a diversity of products specifically designed to fulfill a variety of product needs. One company alone sent us samples of five different soy isolates that they now have available and said that a sixth is in the experimental stage.

We know of no analytical tests that will characterize the concentrates and isolates adequately so that a potential user can determine which would be best for his purposes. There are many tests that have been and can be used. Evidence is lacking that these tests correlate positively with performance in specific food systems. As a matter of fact, in at least one food system, meat emulsions, where such correlations have been tested, diametrically opposed results and conclusions have been reported. Therefore, we have chosen to make only a few of these tests, principally to make the point that there are substantial differences among the concentrates and the isolates.

TABLE IV

Amino Acid Compositions—Ranges and Averages Commercial Soy Protein Concentrates[a] and Isolates[b] (g/16 g N)

	Ranges		Averages	
Amino acid	Concentrates	Isolates	Concentrates	Isolates
Lysine	5.1-5.8	5.4-5.7	5.6	5.5
Threonine	3.7-3.8	3.0-3.5	3.7	3.3
Valine	4.7-4.8	4.2-5.0	4.7	4.6
Methionine	1.2-1.3	0.9-1.2	1.2	1.1
Isoleucine	4.5-4.6	4.3-4.6	4.5	4.4
Leucine	7.8-8.0	7.3-7.8	7.9	7.6
Phenylalanine	5.1-5.1	4.9-5.2	5.1	5.1

[a]Three products.
[b]Six products.

TABLE V

Some Functional Properties of Commercial Soy Protein Concentrates

Concentrates	Protein soluble[a] at			NSI[b]	PDI		pH of 5% dispersion	Oil emulsification capacity (g oil/mg N)
	pH 2	pH 6	pH 7					
C-1	31	17	22	—	—[c]	—[d]	6.8	2.7
C-2	—	—	—	—	—	—	—	—
C-3	52	39	54	64	90	98	6.8	2.8
C-4	39	29	36	36	10	69	—	2.6
C-5	27	1	2	—	—	—	5.1	1.2

[a]Given in percentage.

[b]Nitrogen solubility index, Texas A&M University analysis.

[c]Protein dispersibility index claimed by manufacturer.

[d]Protein dispersibility index, Texas A&M University analysis.

SAMPLE TESTING

Table V shows some of the physical-chemical characteristics or functional properties of several protein concentrates. A notable and characteristic difference is in the amount of protein nitrogen soluble at several pH's. These analyses point up two important differences. The first is the difference between the products, and the second is the difference between the results obtained by different methodology. The protein solubilities reported here were obtained under relatively mild extraction conditions. One part of the protein product was dispersed in 80 parts water, the pH was adjusted, more water added to become an equivalent of 100 parts water, the mixture was held at 37.5 C for 40 min, and shaken on a laboratory shaker at room temperature for 30 min. Three glass beads were inserted in each flask to improve the agitation. The mixture then was centrifuged at 2000 rpm for 20 min, filtered, and aliquots of the filtrate analyzed for dissolved nitrogen. Each figure reported is the average of two complete replications.

These rather mild extraction conditions reflect the amount of protein that is readily soluble. It is clear that sample C-5 is different from the others. C-1 and C-3 are listed by the manufacturers as soluble protein concentrates and C-4 and C-5 as low solubility concentrates. This characterization is not totally reflected in the solubility data that we obtained.

Note that sample C-3 was reported by the manufacturer to have a protein dispersibility index (PDI) of ca. 90, while C-4 was said to have a PDI of 10. This disparity with our results caused some concern. Of course, protein dispersibility by definition is inherently different from protein solubility. The protein dispersibility test includes a vigorous cutting action which tends to produce a finely dispersed emulsion. In the protein solubility test, as we run it, the filtrate is clear, while in the PDI test it is milky. Therefore, the PDI would be expected to yield the highest possible number.

However, this reasoning could not explain all the differences between the manufacturer's data and those we obtained. Consequently, we ran PDI's on the two samples and found a PDI of 98 for sample C-3 and 69 for sample C-4. As an additional confirmation, we ran a nitrogen solubility index (NSI), which is intermediate in rigorousness of extraction between the PDI and our regular method of running nitrogen solubilities. The NSI values that we obtained for C-3 and C-4 were 64 and 36, respectively.

Another test that commonly is considered by some to be significant, particularly those in emulsion technology, is the oil emulsification capacity of proteins. Note in this characteristic that sample C-5 again was markedly different from the others. It is not clear whether this difference was due to the lower pH of sample C-5 or its lower nitrogen solubility.

Similar data are shown in Table VI for the soy protein isolates. Again, there are wide differences among the products with the solubility ranging from 7-96 at pH 6 and from 17-100 at pH 7. These solubility data also differed, with one exception, from the PDI's claimed by the manufacturers.

We have several comments to make based upon these data. First, the products do differ substantially. Second, the products differ in their response to extraction procedures. The NSI's for two of the samples were closely similar to the solubilities obtained by our extraction procedure at pH 7. In two other samples the NSI gave figures that were 17 and 20% higher. Third, in all of the concentrates and isolates analyzed by us, the PDI result was from 22-34 units higher than the NSI. Fourth, one must be cautious in comparing reported protein solubilities.

Among the isolates only I-8 was markedly lower than the others in oil emulsion capacity. Sample I-13 stood out as superior to the others. Time did not permit obtaining all the assays on all of the products, which is obviously regrettable. There is some temptation to speculate whether oil emulsion capacity correlates better with protein solubility or with the pH of the isolates. Unfortunately, there are too many gaps in the data to warrant any conclusion.

In many food systems in which they are used, the soy protein concentrates and isolates replace other proteins, commonly of animal origin. Therefore, there is some concern about the nutritional quality of these products as food proteins. Criticism often is leveled at these and other vegetable proteins because their amino acid patterns are not as well balanced to human needs as are those proteins from animal origin. This kind of criticism tends to lead to the thinking that a protein product that does not have a biological value equivalent to that of animal protein may not be fit for use in foods. If carried to its extremes, this kind of reasoning would class rice, wheat, corn, and all the other important cereals, which provide the bulk of the world's protein, as unfit for food formulation. It ignores the reality that human diets are not based upon single components and that proteins from two or more sources may act in a complementary way such that two or more inadequate proteins may blend to provide a well-balanced amino acid pattern.

There have been some striking examples of this reported for soy protein concentrates and isolates. For example, a loaf of bread based entirely on wheat flour was reported to have a PER of 1.1. When sufficient soy protein concentrate was added to the formula so that the protein in the bread was 50% from wheat and 50% from soy, the PER was increased to 2.5. In 7 week rat feeding experiments, the wt gains were 39 g for the wheat bread and 156 g for the bread made from a wheat-soy blend. The PER of the soy concentrate alone was reported to be 2.4 and the wt gain 125 g, or 31 g less than the blend. Obviously, the blend of the two vegetable proteins was superior to either one alone.

One of the major new uses of soy products in the U.S. is as blends with ground meat in school lunches. Up to 30% replacement of meat is permitted and this, of course,

TABLE VI

Some Functional Properties of Commercial Soy Protein Isolates

Isolates	Protein soluble[a] at			NSI[b]	PDI		pH of 5% dispersion	Oil emulsification capacity (g oil/mg N)
	pH 2	pH 6	pH 7					
I-6	51	36	53	70	88[c]	92[d]	6.5	2.9
I-7	---	---	---	—	20	—	—	2.7
I-8	63	7	50	—	—	—	4.3	1.1
I-9	---	---	---	—	—	—	7.0	2.9
I-10	25	11	17	—	—	—	—	—
I-11	43	29	42	62	70	94	—	3.1
I-12	98	90	100	—	—	—	—	—
I-13	100	96	98	—	95+	—	7.0	3.7
I-14	70	38	50	54	75	81	6.8	2.7
I-15	33	21	27	31	70	61	6.9	2.7

[a]Given in percentage.

[b]Nitrogen solubility index, Texas A&M University analysis.

[c]Protein dispersibility index claimed by manufacturer.

[d]Protein dispersibility index, Texas A&M University analysis.

caused some questions about the quality of the protein of the blend, as compared with the all meat. There are at least two reports that bear upon this, one related to a concentrate and the other to an isolate. In the case of the concentrate, the PER of the blend was identical to that of the all meat product. An interesting experiment was reported in which a protein isolate was added at graded levels from 5-25% in a meat mixture. The data show no change in the PER of the meat as the result of adding 5, 10, 15, or 25% of the soy protein isolate.

In those instances where supplementation with other sources of protein is not likely, the quality of the concentrate and isolate per se becomes more important. While the concentrates normally will average higher in PER than the isolates, there is enough variability within each class that the food processor for whom this is a matter of concern should make his own independent investigations. The PER's of both the concentrates and the isolates can be improved markedly by adding 1.5% methionine. With the added methionine, PER's have been reported from 2.1-2.5 for isolates, and from 3.1-3.2 for concentrates.

Quality control is a constant challenge to the manufacturers of soy protein concentrates and soy protein isolates. They recognize this and exercise the same care as found in a well-run dairy plant. Consequently, they can write specifications calling for maximum bacterial counts from 10,000-100,000/g, negative for organisms, such as *Escherichia coli, Salmonella, Staphylococci,* and well within NCA standards for thermophilic spores.

It appears that maintaining a consistent protein solubility is the greatest challenge in quality control. This is not surprising when one considers the inherent variability of the raw material, the sensitivity of proteins to heat, the unit operations in the processes, the overriding requirement for microbial control, the normal variability of operating control equipment, and the human factor. The data shown here clearly have not established that there is any substantial variability in the protein solubility of any one product. They do, however, suggest a rather high probability of significant variability. If this were a matter of importance to a food processor, he would need to determine what level of protein solubility is optimum for his product, how much variability he can tolerate, and, finally, what the batch-to-batch variability is in those products that meet his requirements.