THE SOYBEAN AS A CHEMICAL FACTORY

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The soybean is indeed a chemical factory!

When seed is planted, the miracle of plant growth begins and the result is a new crop genetically true to the original seed.

In this paper, we will examine extensively the soybean resulting from a season's growth cycle. The main emphasis will be on the chemical composition of the product soybeans; however other benefits must be noted: for example, the value of the plant matter as it decays and adds tilth to the soil, and the legume plant's ability to enrich nitrogen in the soil.

However, we will focus specifically on the soybean itself and its chemical makeup consisting of fiber, protein, carbohydrate, oil, minerals and ash, lecithin and gums, vitamins, sterols, and numerous microconstituents.

For many years the soybean has been cultivated for production of food and feed materials and for the value derived from separated components of the bean. Diverse societies have learned to use soybeans in numerous food products - as whole beans, and in fermented products. Further, soybeans are a source of valuable food materials. Through modern processing plants, the bean can be fractionated into useful products. Thanks to the techniques of analytical chemistry, the bean and its components can be characterized by their chemical constituents. In that sense, the soybean truly is a chemical factory. Subsequent speakers will discuss processing conditions and resulting products and their importance in food, feed and derivatized products.

The composition and quality of soy products depend on many factors: genetics, growing conditions, storage, processing, and both physical and chemical treatments.

Variability begins with the many varieties of soybean seed available for planting. Several hundred varieties, each with somewhat different growing, yield or product characteristics, have been identified in the worldwide seed collections. Wright (3), for example, has reported soybean seed that range from 28% to 46% in protein, 11% to 23% in oil, 33% to 60% linoleic acid in the oil, 41% to 67% of total carbohydrate as sucrose as well as similar ranges for other sugars. Methionine amino acid content varied as much as 30% - from 1.3% to 1.7% of the protein in the seed.

Generally the farmer selects seed for planting based on yield rather than on composition or some other factor.

Allowing for genetic variability within the seed is only part of the explanation for yield or for quality of the crop.

Krober and Cartter (1) observed that non-nodulating varieties grown on soils low in nitrogen gave low yields and were low in protein. In fact, the methionine content of the protein ranged from 1.1% to 1.5% with the tendency for the higher protein seed to contain more methionine. The use of different strains of Rhizobium in the innoculation (or absence of innoculant) of the seed caused the protein content to vary from 28.5% to 45.5%. The methionine content was found to range from 1.3% to 1.7% of protein.

Weather and soil during the growing season also are factors in soybean composition: temperature, rainfall, date and type of planting, length of growing season, soil type and drainage, and the use of various soil amendments, fertilizers and herbicides. It becomes obvious that the final crop composition will depend upon the genetic makeup of the seed itself. Further, all factors related to the agronomy practices and weather conditions will relate to the extent of plant stress and ultimately to both yield and composition of the crop.

Even in the maturation stages, weather conditions may lower the quality of soybeans. Rain and dampness can cause molds to grow rapidly turning soybeans brown. A hard frost could prematurely stop growth and cause freeze damage to the beans leaving them green in color with low protein, low oil, and high carbohydrate. Indeed, green beans can lead to green salad oil if the processor doesn't employ extreme measures.

Even after harvest the conditions of storage have an impact on quality and condition. Grain stored too damp and at warm temperatures may be subject to heating - that is, the natural growth of microorganisms and the subsequent rise of temperature within the pile of grain. Severe heating has a negative effect on color, free fatty acid content, and oil quality. The length of storage before use is also a factor, although perhaps less troublesome with soybeans than with cereal crops. Nevertheless, the tripsin inhibitor content of damaged beans has been reported to increase with storage beyond six months time. Poor storage conditions cause product quality problems. Further, our experience shows us that long term storage of weather damaged beans does increase costs and problems in the processing plant and reduces product yield.

One example of potential storage problems would be the temperature humidity dynamics of a grain storage silo. If beans are put into a storage tank in the moderately warm harvest period, they will stay warm. As the winter temperatures prevail, the exterior wall of the silo becomes cold. As the cold penetrates the silo, the silo wall and outermost part of the grain become cold. Moisture, originally distributed evenly throughout the beans will migrate through the grain piles toward the cold condensing areas. In the spring and summer, the reverse happens. By then the soybean pile is cold in its center and as the exterior of the silo warms the moisture tends to be driven from the outside of the pile of beans toward the very cold center. This only illustrates that during storage, moisture levels can at times exceed safe levels with respect to mold growth.

The machinery used in collecting and moving grain causes breakage of intact soybeans and leads to oxidation and an increase in the free fatty acids content. Exhaustive studies have shown that there are optimum temperature/ moisture conditions to minimize the cracking and breakage of soybeans during handling. Other studies have shown that the free fatty acid content is generally related to the amount of breakage: 1% for whole beans and up to 10% for particle fines.

Saio et. al. (2) reported on the effect of time, moisture, and temperature of storage on the change in color, acid value and nitrogen solubility index (NSI) soybeans. They found that color darkened, NSI decreased, and acid value increased with time, temperature, and relative humidity. The interaction of proteins with carbohydrates is therefor another possibility during storage and processing and may ultimately affect protein quality.

We can conclude, then, that factors in quality and composition include seed genetics and agronomic practice. To this must be added that control of storage conditions both on the farm and while in the custody of the grain processing companies.

Todays modern soybean processing plant will process between three and four million pounds of soybeans daily, or roughly 75,000 bushells or 2500 acres of soybeans each day. Further, it is not uncommon to have in excess of one million bushels of bean storage at the processing plant. The wide fluctuations previously cited tend to be for single beans, groups of genetically the same beans, or a parcel of beans subjected to unusual conditions. The shear size of the processing plant allows co-mingling of varieties and beans with different histories which will minimize fluctuations in the major component quantities by blending.

While other speakers in this symposium will discuss soybean processing to get specific fractions, I would like to give you a brief overview on the general processing steps.

The preparation of beans for processing is important to achieve good hull removal. Beans should be dried carefully to shrink the kernel from the hull. When properly conditioned, the beans are sent through corrugated cracking rolls (0.075 inch clearance). Beans are cracked into six to eight pieces as cracked beans go over screen shakers hulls are removed in primary and secondary aspirators. Hulls generally are high fiber with some protein and are toasted and ground for use in animal feeds.

Cleaned cracked meats go into a conditioning cooker which raises moisture and temperature to approximately 77°C. Conditioned particles are then pressed between flaking rolls to a thickness of .005 to .010 thousandths of an inch in order to facilitate rapid extraction of the oil with a solvent, generally hexane.

After sufficient contact time with the hexane to reduce the residual oil to a low level, the spent flakes are desolventized to remove residual hexane. Because of the importance of subsequent heat treatment, a description of the two methods of removing solvent from extracted flakes is important.

The standard DT (desolventizer-toaster) uses live steam to drive off hexane.

A system called a flash desolventizer or vapor desolventizer, (also referred to as a white meal system) produces a less heat treated product.

In the DT steam is used to vaporize hexane.

In the Flash desolventizer, hexane wet flakes go directly from the extractor to super heated vapor blown at high velocity through a long tube. Hexane boiling b.p. 160°F is heated under pressure to 240 to 280°F. As this vapor is blown through the tube, flakes are conveyed in and picked up by the vapor stream.

Figure 1 outlines procedures for the manufacture of full fat and defatted soy flours from whole soybeans. In preparing full fat soy flour, the solvent extraction step is omitted. The cracking and dehulling will remove soybean hulls. Table 1 shows the comparison of soybeans, soybean meal, and dehulled soybean meal in their proximate composition. The protein content rises from 41.1 in full soybeans to 49.4 in meal due to the removal of the fat component. In the dehulled soybean meal, the protein is further enhanced because of the removal of some of the crude fiber contained in the hull.

The fat content of soybeans is about 20% and tends to fluctuate depending on growing season and some of the agronomic factors cited earlier. While soybean oil contains a number of minor fatty acid components, the primary fat components are palmitic 11.5%, stearic 4.0%, oleic 24.5%, linoleic 53%, and linolenic 7%. Current genetic selection research at several universities has lowered the linolenic content closer to 3.5 to 4% in some varieties and, in a different direction, plant molecular genetisists are seeking to understand and thereby be able to modify the enzyme system in order to avoid the production of saturated fatty components in the soybean complex.

The carbohydrate content of dehulled soybean meal is given in Table 2 with ranges again indicative of the variations in growing conditions, varieties, and analytical techniques. The total carbohydrate in the dehulled soybean meal would fall between 30 and 38%.

Defatted soybean meal ground to flour consistency (Table 3) is described as soy flour and would have approximately the same protein content of slightly over 50%, low moisture content with some moisture being lost during the grinding step, low total residual fat, and would contain approximately 33.5% total carbohydrates. Please note that on edible soy flour total bacteria count must be under 10,000 count/gm, and product must be negative in salmonella.

Earlier reference was made to some processing steps that were carried out in order to achieve the inactivation of certain enzymes that have a deleterious effect on flavor, and anti-nutritional components that tend to interfere with the pancreatic/tripsin digestion of proteins. Figure 2 shows that both lipoxiginase and peroxidase are considered to have a negative influence on flavor development and that trypsin inhibitor activity must be considered in determining the amount of heat treatment given to soybean materials.

Table 4 shows the affect of various lengths of heat treatment involving live steam at 100°C on the nitrogen solubility index, the trypsin inhibitor activity, the protein efficiency ratio, and the ratio of pancrease weight to

100gm of body weight of animals. Note that in each case the longer the heat treatment, the lower the nitrogen solubility index, the lower the trypsin inhibitor activity, and the increase in the protein efficiency ratio.

The principle components of the soybean, namely the fat, protein, and carbohydrate components, have been discussed. The next schematic, Figure 3 shows the conversion of defatted soyflour into a variety of further processed materials that go into human and animal feed compositions. One example is in the addition of lecithin to soyflour at several different levels. The example given in Table 5 of 3%, 6%, and 15% will demonstrate the decrease in protein and the increase in fat component as lecithin is added back to soyflour. Figure 4 refers to the cooking time in minutes to the decrease in the content in the lysine content of soybean meal. The figure shows that the destruction of lysine is much more rapid at either 16% or 12% moisture than it is at 4%. Moist heat treatment caused protein denaturation at a faster rate. Figure 5 correlates cooking time with the decrease in trypsin inhibitor activity and again shows that at 0% moisture trypsin inhibitor is quite resistant to protein denaturation while at 12%, 16%, or even 8% trypsin inhibitor activity decreased rapidly.

In Figure 6 the cooking time is related to the urease index and also again shows a very decided falloff in urease index at the higher moisture levels with cooking time.

Subsequent speakers will refer to the functionality of various soy protein fractions and will stress the importance of these functionality properties in water absorption, fat absorption, emulsification capacity, protein binding capacity, adhesiveness or viscosity, and other functional properties.

Proteins are made up of amino acids in sequence and it is the balance of amino acids that makes soybeans a particularly attractive food material. Thus far, only total protein has been addressed. Within the protein family there are a group of lower molecular weight proteins constituting the enzymes and the tripsin inhibitor and hemagglutination activity factors. Also identified and characterized are various globulin fractions, namely the 2.3S, 2.8S, 7S, and 11S globulin or glycinin protein fractions, in addition to the lectins and other smaller molecular weight proteins. These protein components vary in molecular weight and amino acid sequence.

The total protein component of soybeans can be analyzed for its amino acid composition. The crude protein of defatted dehulled soy flour will analyze from approximately 18% of its total protein as glutamic acid down to cystine at less than 1% of the protein total.

Since many of these analyses require the hydrolysis of the protein and other components in order to identify the individual amino acid or fatty acid, it is interesting to note that all combinations of carbohydrates and proteins, fats and proteins, and fats and carbohydrates exist in the soybean. Further there is an ash component of about 6% in soybean meal. This mineral content has been analyzed for each of the elements and most of them are present even if in extremely small quantities.

Moreover, the soybean contains many minor constituents including vitamins, phytic acid, a few glycosides that have been identified, saponins, phenolic constituents, and phospholipids.

During this symposium I am making available a detailed list that shows the compositional analysis of soybeans with the individual components identified and quantified and the reference to the investigator who performed the analysis.

As this list was compiled it became very obvious that not only is the soybean a very useful, high protein and high energy product, but it is the consequence of the photosynthetic process that works like a chemical factory to turn air, water, and nutrients into a complex chemical material.

1. Krober, A.O., and J. L. Cartter, Cereal Chem. 42-43:320 (1966).

2. Saio, et. al., Cereal Chem. 57:77 (1980).

3. Wright, K. N., Feedstuffs 40:18 May 4 (1968).

4. World Soybean Research Conference III. 12-17 August 1984. Proceedings edited by R. Shibles. Westview Press, Inc., Boulder, CO 80301.

5. Composition of Soy Flour: A Bibliography of Analytical Data. Fulmer, R. W., Unpublished.

MANUFACTURE OF FULL FAT AND DEFATTED SOY FLOUR

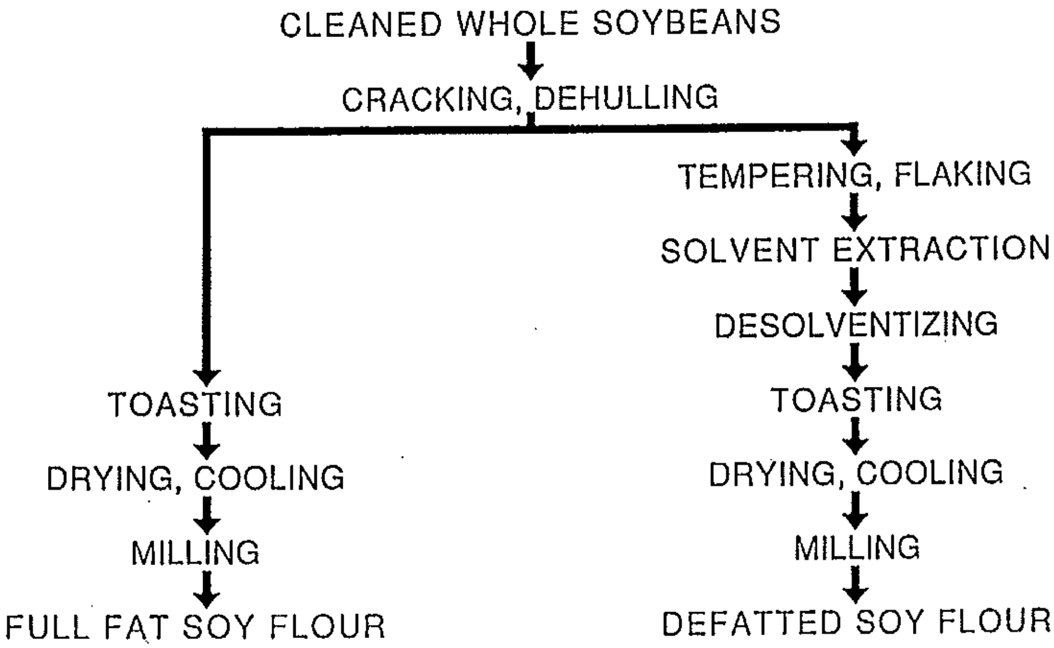


Figure 1

PROPERTY MEASUREMENT USED TO CONTROL PROCESSING OF EDIBLE SOY FLOUR

CONTROL MEASUREMENT	PROPERTY AFFECTED FLAVOR	NUTRITIVE VALUE
LIPOXYGENASE	+	-
PEROXIDASE	+	-
NSI	-	+
PDI	-	+
UREASE	-	+
TI	-	+
AVAILABLE LYSINE		+

NSI = nitrogen solubility index
PDI = protein dispersibility index
TI = trypsin inhibitor

Figure 2

THE USE OF SOY FLOUR AS A SUBSTRATE FOR
FURTHER PROCESSED FOOD INGREDIENTS

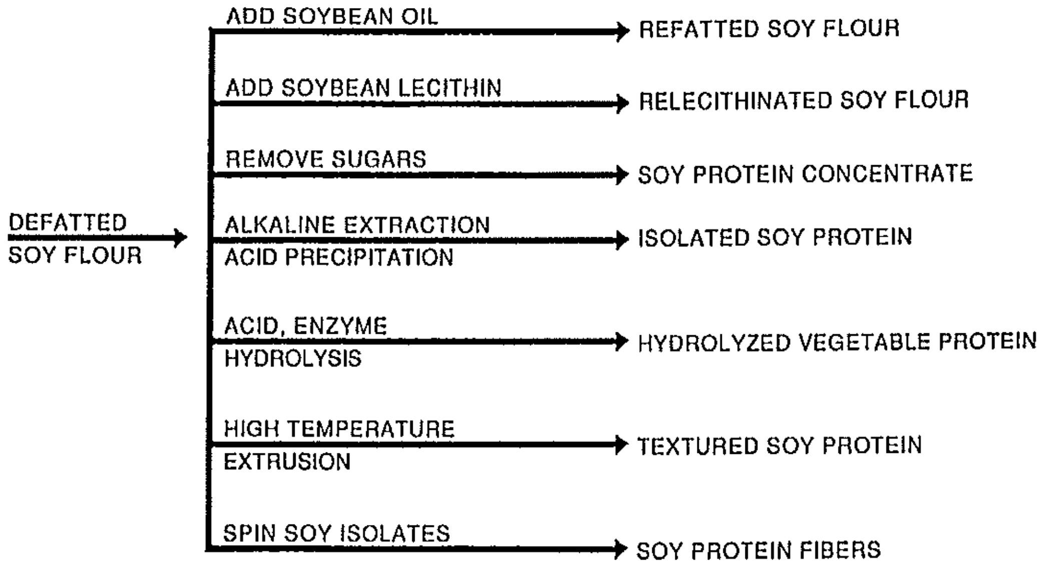
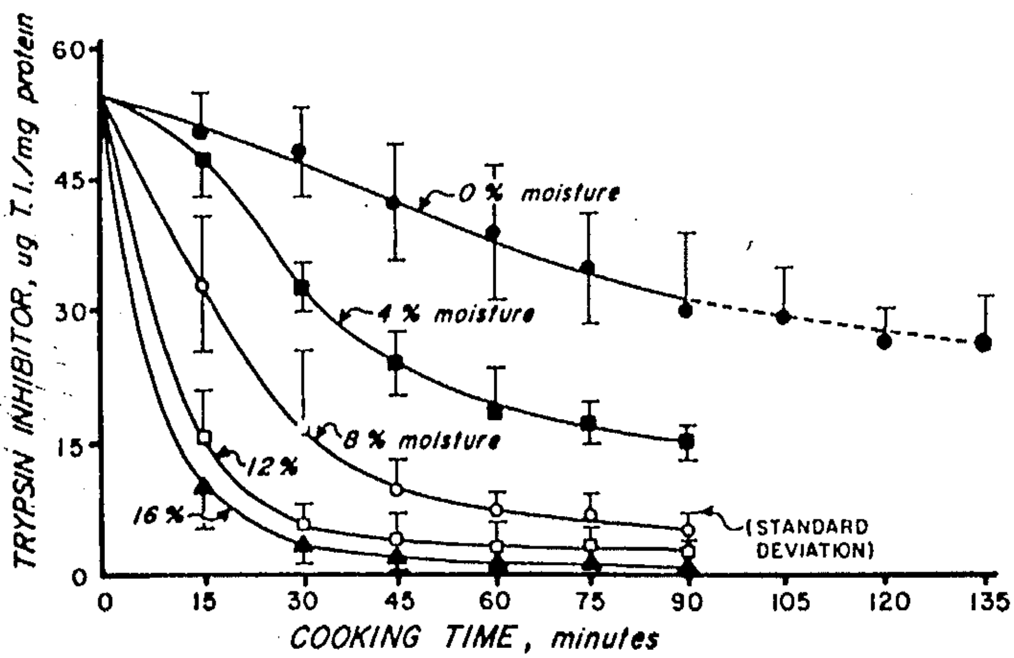
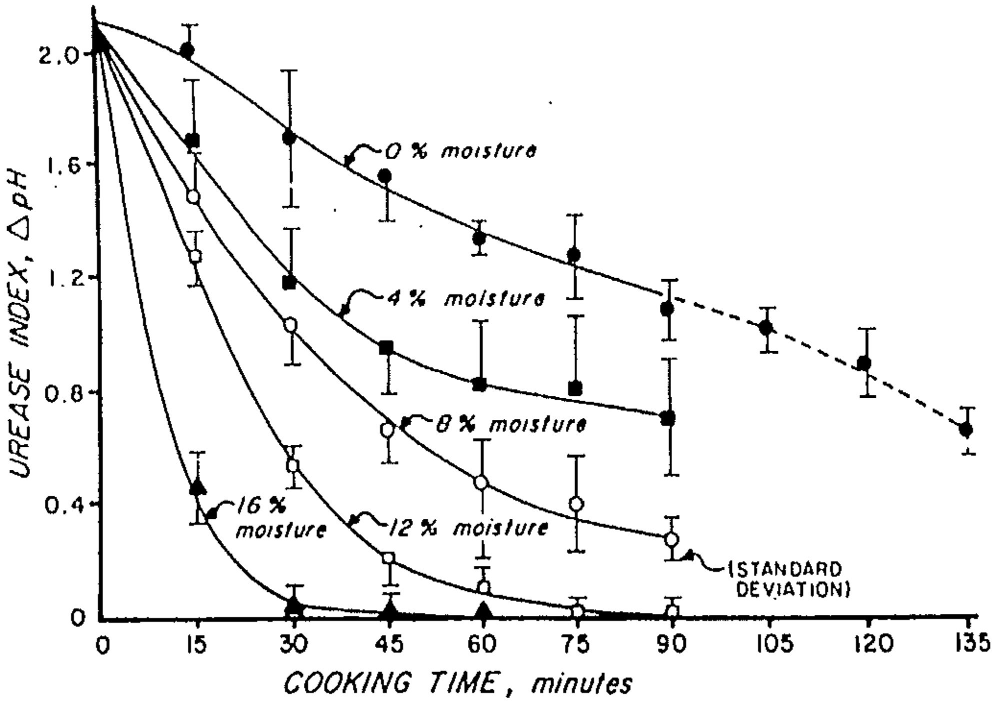


Figure 3



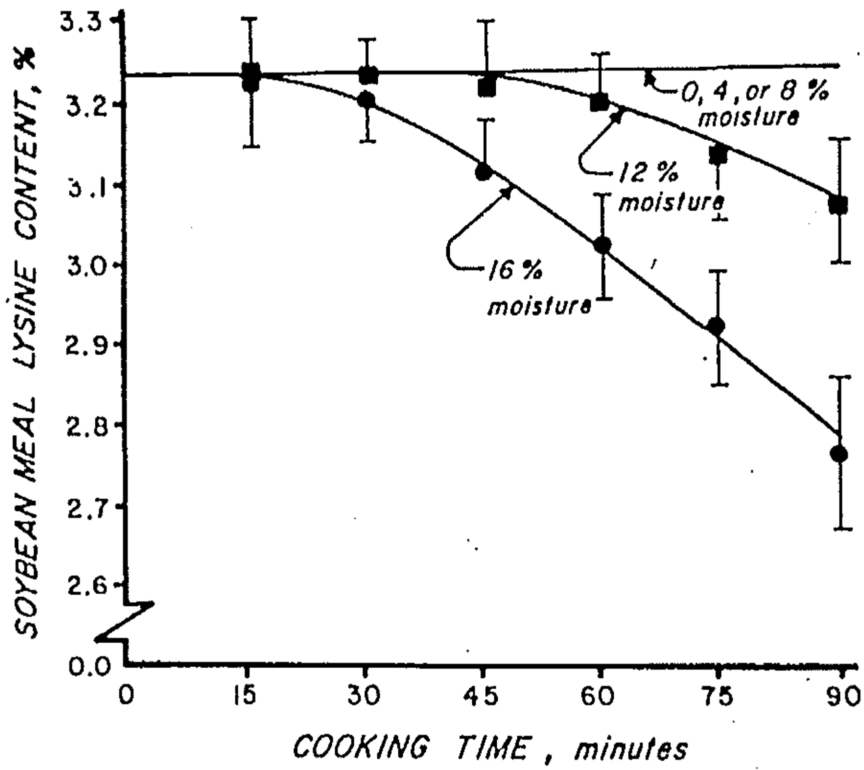
Composite data of experiments 1 and 2 showing the effect of moisture and cooking time on soybean meal trypsin inhibitor contents.

Figure 4



Composite data of experiments 1 and 2 showing the effect of moisture and cooking time on soybean meal urease index.

Figure 5



Effect of moisture and cooking time on total lysine content of soybean meal.

Figure 6

PROXIMATE COMPOSITION OF SOYBEANS, SOYBEAN MEAL, AND DEHULLED SOYBEAN MEAL ON A DRY MATTER BASIS
(NRC, 1977)

COMPONENT	SOYBEANS	SOYBEAN MEAL	DEHULLED SOYBEAN MEAL
PROTEIN	41.1	49.4%	53.9
ETHER EXTRACT	20.0	0.9%	1.1
CRUDE FIBER	6.1	8.2%	4.3
ASH	5.4	5.9%	6.5
NITROGEN-FREE EXTRACT	27.4	35.6%	34.2

Table 1

CARBOHYDRATE CONTENT OF DEHULLED SOYBEAN MEAL
(HONIG and RACKIS, 1979)

CONSTITUENT	% OF MEAL
OLIGOSACCHARIDE CONTENT, TOTAL	15
SUCROSE	6-8
STACHYOSE	4-5
RAFFINOSE	1-2
VERBASCOSE	TRACE
POLYSACCHARIDE CONTENT, TOTAL	15-18
ACIDIC POLYSACCHARIDES	8-10
ARABINOGALACTAN	5
CELLULOSIC MATERIAL	1-2
STARCH	0.5

Table 2

SOY FLOUR
TYPICAL ANALYSIS

		TEST METHOD
PROTEIN (N x 6.25)	52.5%	AOCS BC 4-49
MOISTURE	6.0%	AOCS BC 2-49
FAT (ETHER EXTRACT)	0.9%	AOCS BC 3-49
ASH	6.0%	AOCS BC 5-49
FIBER	2.5%	AOCS BC 6-49
CARBOHYDRATES	31.0%	BY DIFFERENCE
TOTAL BACTERIAL COUNT	<10,000/gm	FDA AEROBIC TEST METHOD
SALMONELLA	NEGATIVE	FDA STANDARD TEST

90, 70 OR 20 PDI
AOCS BA 10-65
100 OR 200 MESH

Table 3

PROCESSING AND NUTRITIONAL PARAMETERS OF HEAT-TREATED SOY FLOURS.

HEAT,[a] MIN	NSI[b]	TI, TIU/mg[c]	PER[d]	PANCREAS WT, g/100 g BODY WT
0	97.2	96.9	1.13	0.68
1	78.2	74.9	1.35	0.58
3	69.6	45.0	1.75	0.51
6	56.5	28.0	2.07	0.52
9	51.3	20.5	2.19	0.48
20	37.9	10.1	2.08	0.49
30	28.2	8.0	-	-

[a] Live steam at 100 C
[b] NSI = nitrogen solubility index
[c] TI = trypsin inhibitor and TIU = trypsin inhibitor units
[d] Protein efficiency ratio, corrected on a basis of PER = 2.50 for casein

Table 4

RELECITHINATED SOY FLOUR
TYPICAL ANALYSIS

	LECITHIN LEVEL 3%	6%	15%	TEST METHOD
PROTEIN (N x 6.25)	51.0%	50.0%	45.0%	AOCS BC 4-49
MOISTURE	5.0%	5.0%	4.2%	AOCS BC 2-49
FAT (ETHER EXTRACT)	3.0%	6.0%	15.0%	AOCS BC 3-49
ASH	5.8%	5.6%	4.9%	AOCS BC 5-49
FIBER	2.4%	2.3%	2.1%	AOCS BC 6-49
CARBOHYDRATES	32.0%	31.0%	27.5%	BY DIFFERENCE
TOTAL BACTERIAL COUNT	<10,000/gm	<10,000/gm	<10,000/gm	FDA AEROBIC TEST
SALMONELLA	NEGATIVE	NEGATIVE	NEGATIVE	FDA STANDARD TEST

Table 5