Soy Protein Products and Their Production

FRANK E. HORAN, Archer Daniels Midland Co., Decatur, Illinois

ABSTRACT

The soybean industry in the U.S. started in the first years of this century and was only 5,000,000 bushels just 50 years ago. This year it is expected to be over 1.5 billion bushels, reflecting a remarkable growth. Beans are processed primarily for soybean oil and for meal to be used in poultry and livestock feeds. Only ca. 3% soy protein is used in human food today. Special processing is required to prepare proteins to meet the various specifications of products for the food industry. Methods used to produce flour and grits, spun fibers, textured proteins, concentrates, and isolates are described.

INTRODUCTION

The populations of the world, including the developed, as well as the developing countries, are clamoring for more foods and particularly for more protein foods. History reveals that the soybean always has been an important human food in the diet of ancient China (1). Only in relatively recent times has the soybean been considered seriously as an edible food by western civilization. The fact that soy protein food products today rapidly are gaining acceptance in the diets of mankind and are increasingly being popularized by various news media should not divert us from the knowledge that soybeans have been a valuable human food for a long time.

From the hundreds of years before Christ when Asian people in their villages developed the art of converting soybeans into satisfying food dishes to the present moment, where there exists a wealth of sophisticated, technological knowledge, the soybean has traveled a long journey. As a food the soybean is moving from the small "cottage" industries to the expanding markets of the industrialized world.

After years of uncertainty in the activities of food technologists to bring stature to the soybean protein as a human food, recent achievements in technology and recent changes in the marketplace have set the soybean on a course, which brings to mind one of Goethe's poems, *A Prosperous Voyage:*

Now mists tear asunder,
The skies are much brighter,
And Aeolus loosens
The anxious ties.
Winds now blow gently,
The skipper gets busy.
Make haste, make haste!
The waves now are parted,
The distance comes nearer;
Now I behold land!

HISTORY OF THE SOYBEAN IN THE U.S.

Although soybeans were grown in the U.S. as early as 1804, they remained an agricultural curiosity for over a century. In Europe the greatest impetus given soybean cultivation was the work of Friedrich Haberlandt of Vienna in 1875. Results of this work undoubtedly created further interest in soybeans in the U.S. at the turn of the century. In 1924 (2), not quite 50 years ago, the total production of soybeans in the U.S. was slightly under 5 million bushels; in 1971 the U.S. production was somewhat over 1.1 billion bushels, which amounts to ca. two-thirds of the world production (Table I).

During these years, the value of the U.S. soybean crop has increased from ca. $11 million-$3.5 billion or ca. 300 times.

In Table II a comparison is made among the major

TABLE I

Soybean Production in the U.S., 1924-1971

	Acreage (1000 acres)	Yield (bushels/acre)	Production (1000 bushels)
1924	448	11.0	4,947
1971	42,409	27.6	1,169,361

TABLE II

World Soybean Acreage

	Acreage			
	(1000 acres)		(Percent of total)	
Area	1960	1970	1960	1970
U.S.	23,655	42,056	44	57
Brazil	424	2,940	0.8	4
U.S.S.R.	1,124	2,137	2	3
China mainland	23,000	19,768	43	27
Indonesia	1,364	1,691	3	2
Subtotal	49,567	68,592	93	94
World	53,250	73,168	100	100

TABLE III

World Soybean Production

	Production			
	(1000 bushels)		(Percent of total)	
Area	1960	1970	1960	1970
U.S.	555,307	1,123,740	59	66
Brazil	7,560	55,440	0.79	3
U.S.S.R.	8,230	22,154	0.87	1.3
China mainland	315,000	419,938	33	25
Indonesia	16,272	17,929	1.7	1
Subtotal	902,369	1,639,201	95	96
World	945,260	1,702,532	100	100

TABLE IV

U.S. Consumption of Soybean Meal as Animal Feed, 1972[a]

Animal	Tons (1000)	Percent of total
Poultry	5,523	42
Hogs	2,437	19
Beef cattle	1,735	13
Dairy cattle	1,365	11
Other	1,965	15
Total	13,025[b]	100

[a]See ref. 5.
[b]76% of total supply.

TABLE V

Value/Bushel of Soybeans Crushed[a]

Year beginning September	Oil		Meal	
	Value (dollars)	Percent of total value	Value (dollars)	Percent of total value
1947	2.22	53.0	1.97	47.0
1957	1.19	49.0	1.24	51.0
1967	0.91	33.3	1.82	66.7
1970	1.38	42.3	1.88	57.7

[a]See ref. 6.

TABLE VI

Average Composition of Soybean Seeds (Moisture-Free Basis)

Component	Whole soybeans (percent)
Crude protein	40.4
Crude fat	22.3
N-free extract + fiber	31.9
Ash	4.9

TABLE VII

Carbohydrate Portion (31.9%) of the Soybean Seed

Carbohydrate	Percent
Hulls	8.0
Soluble carbohydrates	
Sucrose	4.5
Raffinose	1.1
Stachyose	3.7
Arabinose	0.002
Glucose	0.005
Insoluble carbohydrates	14.6

TABLE VIII

U.S. Soybean Production, 1960 vs. 1970

States	(1000 bushels)		Percent of total	
	1960	1970	1960	1970
Arkansas	50,589	97,043	9	9
Illinois	129,298	210,800	23	19
Indiana	65,205	101,618	12	9
Iowa	66,274	184,600	12	16
Minnesota	40,755	82,124	7	7
Missouri	50,396	88,358	9	8
Ohio	36,726	68,799	7	6
Subtotal	439,243	833,342	79	74
Total	555,307	1,123,740	100	100

TABLE IX

Soybean Varieties Grown in Illinois in 1972

Variety	Percent of total
Wayne	30
Amsoy and Amsoy 71	16
Beeson	11
Corsoy	10
Cutler	6
Clark 63	5
Harasoy	2
Others	20

TABLE X

Commercial Types of Defatted Soy Flours

Heat treatment	Protein dispersible index	Relative protein efficiency (Casein: 100)
Negligible	90-95	40-50
Light	70-80	50-60
Moderate	35-45	75-80
Toasted	8-20	85-90

TABLE XI

Typical Composition of Soy Flours, Concentrates, and Isolates (Moisture-Free Basis)

Component	Soy flours	Concentrates	Isolates
Protein	56.0	72.0	96.0
Fat	1.0	1.0	0.1
Fiber	3.5	4.5	0.1
Ash	6.0	5.0	3.5
Carbohydrates (soluble)	14.0	2.5	0
Carbohydrates (insoluble)	19.5	15.0	0.3

TABLE XII

U.S. Producers of Edible Soy Protein Products

Company	Grits and flours	Concentrates	Isolates	Textured
ADM	x			x
Cargill	x			x
Central Soya	x	x	x	x
Far-Mar-Co	x	x		x
General Mills				x
Griffith Labs		x		x
Lauhoff Grain Co.	x			x
Miles Labs (Worthington)				x
National Protein	x			
Ralston Purina			x	x
A.E. Staley	x		x	x
Swift & Co.	x	x		x

producing countries of the world, using the years 1960 and 1970 as reference points. With the exception of mainland China, where the statistics may not be accurate, there is a world-wide increase in the production of soybeans. It is clear that the steadily increasing production in the U.S. dominates the scene (Table III).

What are the principal underlying factors controlling the emergence of this crop in the U.S. to its strong agricultural and economic position? Proper climatic and soil conditions have been extremely important, as well as the development of varieties adapted for specific agronomic situations. Likewise, improvements in mechanical equipment for harvesting soybeans were essential in lowering labor costs, thus permitting U.S. soybeans to be competitive with beans grown anywhere in the world.

In its early stages the growth of the soybean industry in the U.S. was influenced more by a shortage of oil and its relatively high price than the need for protein. The development of the soybean processing industry stems directly from World War I, when such a shortage of fats and oils existed in the U.S. that it was necessary to import Manchurian pressed soybean oil. After the war, fats and oils continued to be in great enough demand to encourage the development of a feasible commercial process for crushing domestic soybeans. Many of the early ventures were unsuccessful, but in the 1920's successful continuous solvent extractors for quantity production were developed in Germany, and these types later were introduced to the U.S. The two principal ones were the Hansa-Muhle (Bollman) percolation basket extractor and the Hildebrandt immersion extractor (3).

Although a number of continuous solvent extraction plants were in operation in Europe in 1934, the first large scale plant of this type in the U.S. was that of the Archer Daniels Midland Co., Chicago, Ill., which utilized the Hildebrandt extractor to process 100 tons (ca. 3000 bushels) of soybeans/day.

ECONOMIC IMPACT

To grasp the significance of the impact which soybean oil has had on the U.S. economy, one needs only to consider that in 1933 less than 500,000 lb soybean oil were utilized in the manufacture of margarine and likewise for shortening; in 1971, the quantities were 1.0 and 2.4 billion lb, respectively. Another striking comparison is that of the U.S./capita consumption of butter and margarine from 1949-1971. Butter has decreased from 10.5 lb to 5.1, and margarine has increased from 5.8 to 11.1.

As is typical with the processing of most agricultural materials, markets must be obtained for more than one product. At times, it is merely academic to state that one product is the sole object of a process and that everything else is a by-product. In the early history of soybean processing it was seen that the production of oil was the prime objective. However, developments eventually arose which established soybean meal as the major source of protein used in feeding poultry and livestock (Table IV).

It is a bare economic fact that for a commercial process to be practical, markets must be found for all products made and that a rather delicate balance must be maintained to prevent one product from becoming a glut on the market. In terms of the dollar value of the oil and meal components in a bushel of soybeans, it has been determined that, outside the early years of soybean processing, the

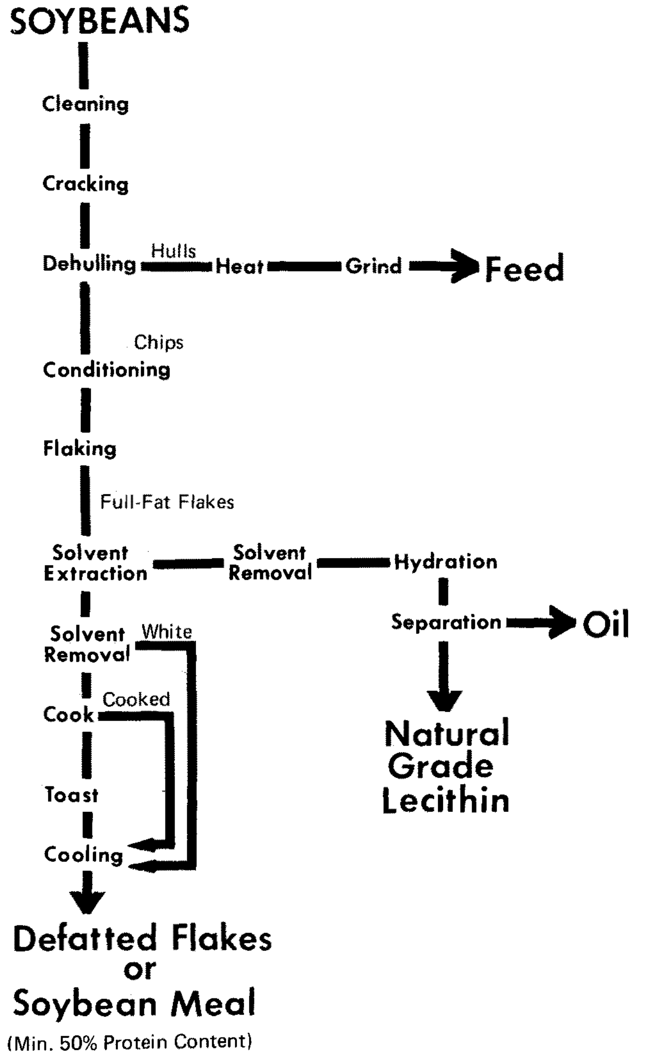

FIG. 1. Continuous solvent extraction of soybeans with hexane. See ref. 7.

TABLE XIII

Countries Producing Edible Soy Protein Products

Country	Grits and flours	Concentrates	Isolates	Textured
Argentina	x			
Australia	x			
Brazil	x		x	
Chile	x			
Colombia	x			
England	x			x
France	x			
Germany	x			
India	x			
Israel	x			x
Japan	x	x	x	x
Korea	x			
Taiwan	x			
Turkey	x			
Venezuela	x			

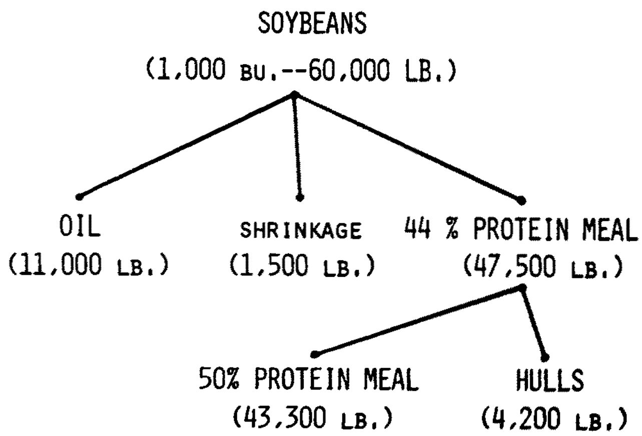

FIG. 2. Soybean processing yields.

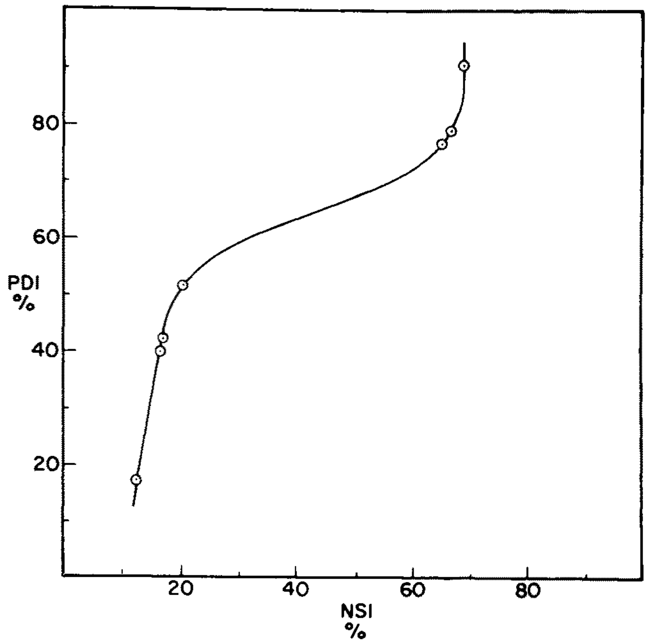

FIG. 3. Comparison of protein dispersible index and nitrogen solubility index.

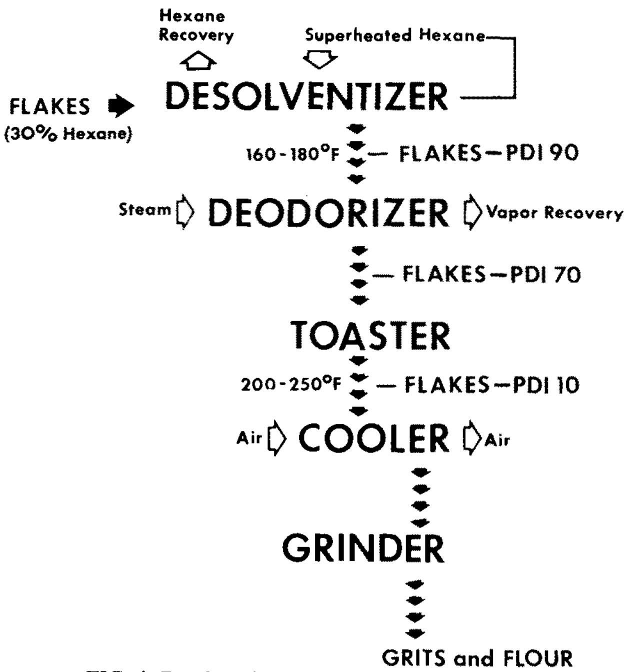

FIG. 4. Desolventizer-deodorizer-toaster system.

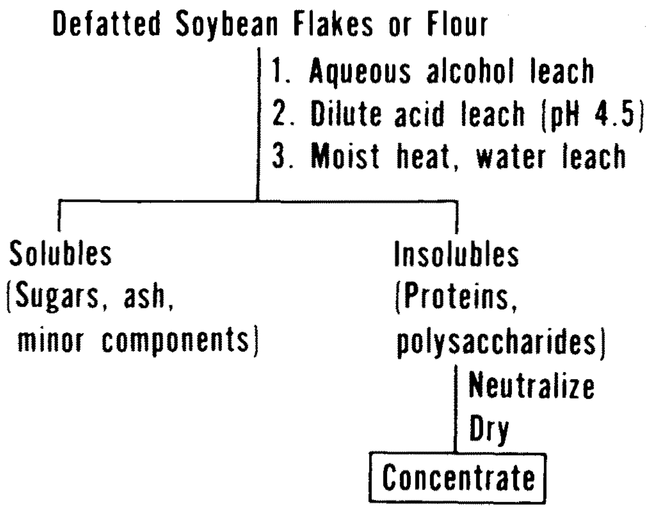

FIG. 5. Preparation of soy protein concentrate.

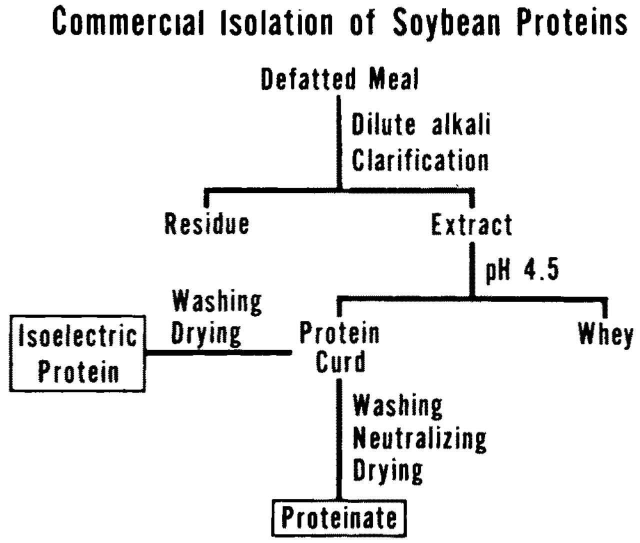

FIG. 6. Process for the preparation of isolates soybean protein.

meal is at least as valuable as the oil and in recent years has tended to be even more so (Table V).

SOYBEAN PROTEIN

In considering the soybean as a supplier of protein, simple arithmetic shows that if the yearly world production of 1.7 billion bushels soybeans were consumed directly as human food, there would be enough to satisfy the protein requirements of 800 million human beings, based upon per capita daily diet of 65 g protein/day. Of course, it is realized that the soybean, through processing, has been developed to supply soybean oil principally for a variety of food uses and soybean meal for animal feeds. To keep the proper perspective, it is important to understand that, of the 16-17 million tons of soybean meal produced annually, only 400-500 thousand tons, or ca. 3%, are used directly in human foods. In short, no rational argument can be made for the complete elimination of animal protein by vegetable protein, such as that from the soybean.

The objective of soybean processing is to remove the oil from the protein in the most efficient manner. Ca. 66% of the U.S. crop is processed into oil and meal, and ca. 95% of this processing is accomplished by the continuous solvent extraction with hexane.

The soybean seed is made up of a seedcoat (hull) and an embryo, the latter being composed of a hypocotyl and the cotyledons. The cotyledons, which account for most of the bulk and wt of the seed, contain nearly all the oil and

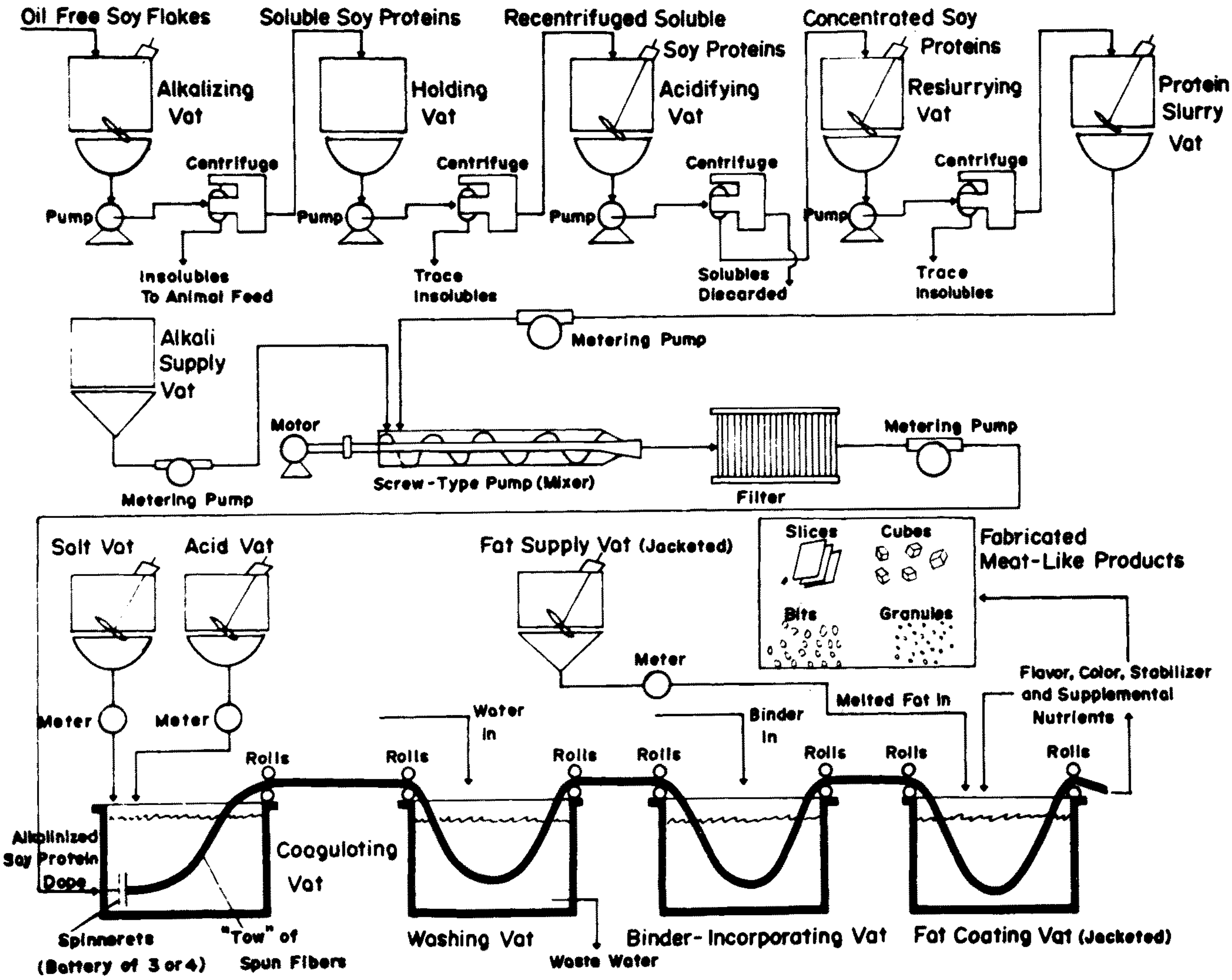

FIG. 7. Soy protein spinning process.

protein found in the soybean. The seedcoat carries a small seed scar, known as the hilum.

The chemical composition of soybeans varies somewhat with different varieties, geographical locations, and climatic conditions. On an average, however, the protein content is ca. 40% and is ca. twice that of the fat (Table VI).

The N-free extract + fiber consists of the seedcoat (hulls) and both soluble and insoluble carbohydrates (Table VII).

Ca. 75% soybeans grown in the U.S. come from the five corn belt states–Illinois, Iowa, Indiana, Ohio, and Missouri –plus Arkansas and Minnesota (Table VIII).

For years the number one producing state has been Illinois. Even though there are at least 50 different soybean varieties used by farmers in different areas of the U.S., Illinois grows only a few, of which Wayne is the most prominent (Table IX).

Soybeans selected for food operations normally conform to grades one and two of the Official Standards, which permit up to 3% damaged seed, 2% foreign material, and 14% moisture.

The basic steps involved in making soy protein products for human foods include the following: cleaning, cracking, dehulling, tempering, flaking, and extracting with hexane (Fig. 1). The yields are shown in Figure 2.

The manner in which the residual hexane is removed from the defatted flakes determines the degree of denaturation of the protein present and ultimately controls later specific functional properties in the soy protein product. In practice this denaturation is measured empirically by a determination of nitrogen solubility or dispersibility, resulting in numerical values referred to as nitrogen solubility index (NSI) or protein dispersible index (PDI). The PDI value is normally larger than the NSI, due primarily to the fact that the former method involves a more rapid stirring operation in dispersing the material in water (Fig. 3). In either method the value is a ratio of amount of nitrogen dispersed to the total nitrogen in the material.

The nutritional quality of soy protein products conveniently is characterized by means of PDI values (Table X) and can be regulated by controlling the variables of temperature, time, and moisture during the removal of hexane from the defatted flakes.

The wet defatted flakes, containing ca. 30% hexane, are conveyed to the desolventizing and drying operations, of which there are at least four general types (8). The system employed for the production of edible soy protein products containing a wide range of PDI values commonly is known as a desolventizer-deodorizer-toaster (Fig. 4).

Ca. 99% solvent is removed in the desolventizer by recycling superheated hexane, and the PDI of the protein flakes is ca. 90%. To obtain products with lower PDI values, water or steam is added under controlled conditions at the deodorizer step which brings about denaturation of the protein. The flakes then are cooled and ground into grits and flours.

One method of producing commercial full-fat soy flours is to subject dehulled cracked beans to heat treatment and, after cooling, grind the material so that most of it passes

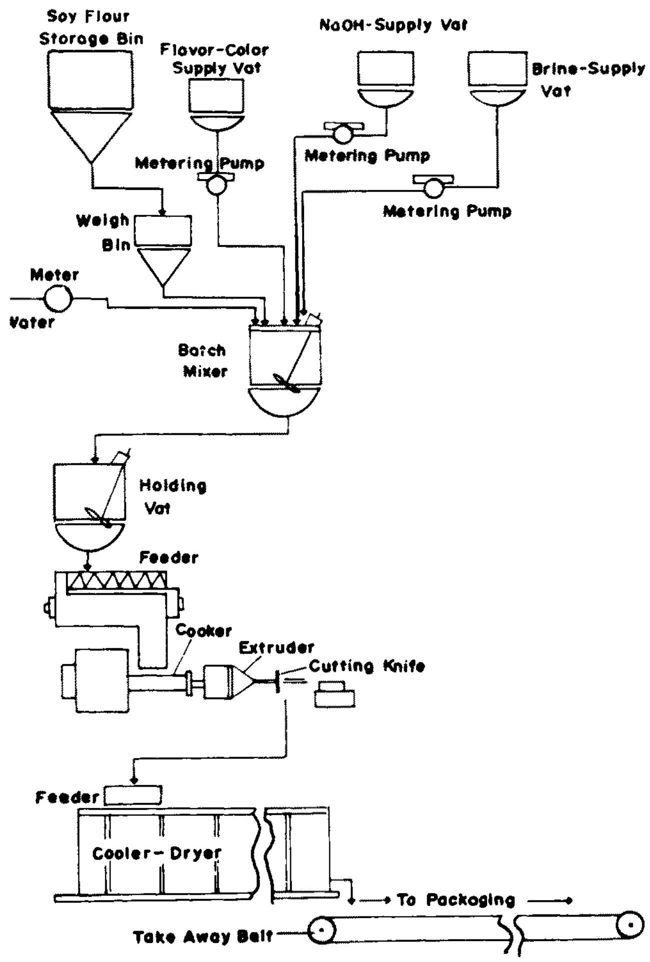

FIG. 8. Thermoplastic extrusion process. Cooking extrusion is a technique for texturizing soy flours. Technique is similar to that employed for manufacturing cereal based snack foods.

through a no. 100 screen.

The undenatured, 50% protein, defatted flakes may be upgraded to form concentrates by leaching out soluble materials with either aqueous alcohol or under acidic (isoelectric point) conditions; commercial yields are ca. 60% or ca. 80% protein. Soy protein isolates are made commercially by treating the 50% protein flakes with an alkaline solution to dissolve the protein and then coagulating the protein into a curd at the isoelectric point (pH 4.5); commercial yields are ca. 33%, corresponding to ca. 60% recovery of the protein. Both the concentrates and the isolates may exist as water-insoluble products or as soluble proteinates. Simplified schemes of production are given in Figures 5 and 6 (9), and proximate compositions of the soy flours, concentrates, and isolates are summarized in Table XI.

TEXTURED SOY PROTEIN

Transforming a powdery protein material (a flour) into one which has texture, described as "chewiness," and a fibrous character, adds attractiveness to it as a food. The most significant development in this area in recent years is that of textured soy protein products, which are finding applications primarily in food systems based upon meat. Basically, two processes, fiber spinning and thermoplastic extrusion, are used.

The Spinning Process

In the process used today, isolated soy protein is solubilized in an alkaline medium and passed through a spinneret to form fibers which are coagulated in an acidic bath and then stretched by means of a series of rolls revolving at increasing speeds. Bundles of fibers are held together with edible binders and treated with other ingredients such as colors, flavors, seasonings, and supplementary nutrients to give fabricated slices, cubes, bits or granules which may simulate many animal type products, such as beef, bacon, ham, fish, and chicken.

The versatility of this process points out clearly that the spinning technology makes it possible to manufacture truly engineered foods. Depending upon the choice of ingredients other than the spun soy fibrils, there is literally a limitless number of ways in which a protein food can be fabricated for a specific use.

It is important to understand that the soy fibers themselves do not constitute a finished meat-like product. On a dry basis such a product might consist of 40% fibers, 10% binder, 20% fat, and 30% supplementary ingredients (wheat gluten, soy flour, sugar, flavorings, coloring).

Owing to the many processing steps (11) involved in the spinning of protein fibers and their fabrication into a finished product, it is understandable that a product of the spun-fiber type is relatively costly. Therefore, it is necessary for it to compete in a higher priced market, i.e. as a meat analogue replacing meat completely (Fig. 7).

The Thermoplastic Extrusion Process

The essential characteristic of this process (11) is that soy flours (50% protein) are used as the starting material. This fact gives this process an inherent cost advantage over the spinning process. A cooker-extruder is used to cause the thermoplastic protein material to be forced through a die, which controls the size and shape of the texturized material (Fig. 8). After drying the unflavored product consists of 50% protein and has excellent storage stability. When used it is hydrated with two parts water.

These types of extruded products (12) have had probably the greatest impact in bringing low-cost textured vegetable products into commercialization.

For proper perspective it might be well to point out that even though there are ca. 125 soybean processing plants in the U.S., only ca. a dozen of these are involved in manufacturing the specialty products of edible soy flours, concentrates, isolates, and the most recent textured products. A list of the principal U.S. companies involved, with the specialties, is given in Table XII.

Some of the countries outside the U.S., having one or more plants to produce edible soy protein products are listed in Table XIII.

This discussion was designed to demonstrate that the soybean has been on a long voyage. It began as a staple food item in the eastern world, then became probably the most important protein, supplying animal feed throughout the world. Now through modern technological innovations, it is emerging as one of the most exciting ingredients in human foods. The soybean is now in the spotlight of the world. The speed of the voyage is accelerating, and all those connected with this voyage realize that it indeed can be prosperous. To make the most of the opportunities at hand it might be well to reflect again on the last few lines of Goethe's poem, *A Prosperous Voyage:*

> The skipper gets busy.
> Make haste, make haste!
> The waves now are parted,
> The distance comes nearer;
> Now I behold land!

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