Whole Seed Processing by Extrusion Cooking

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ABSTRACT

Extrusion cooking of full fat soy eliminates heat labile growth inhibitors and beany bitterness in soy. The basic principles, advantages, and limitations of this process are explained. A typical processing line for the production of full fat soy for man and animal is reviewed.

INTRODUCTION

Extrusion cooking techniques are used in the processing of a wide range of products for both human and animal consumption. Oilseed proteins and vegetable oils have an important place in this process for their nutritional and functional properties. High protein snacks and breakfast cereals, pet foods, and fish foods produced from mixtures of cereals, vegetable proteins, and other ingredients are typical examples (Fig. 1). Several of the oilseed proteins are used as ingredients, with the limitation that they do not contain other antinutritive factors than those which can be destroyed by moist heat.

APPLICATIONS

Extrusion cooking is capable of effectively and economically cooking, texturizing, and shaping certain food and feedstuff mixtures in a continuous operation. There are several characteristics of this process which make it a suitable tool to both upgrade the nutrients and to destroy or control heat labile antinutritive constituents in foods or feedstuffs. This capability is used in the processing of certain pulses and beans and in the processing of full fat soybeans for both human and animal consumption.

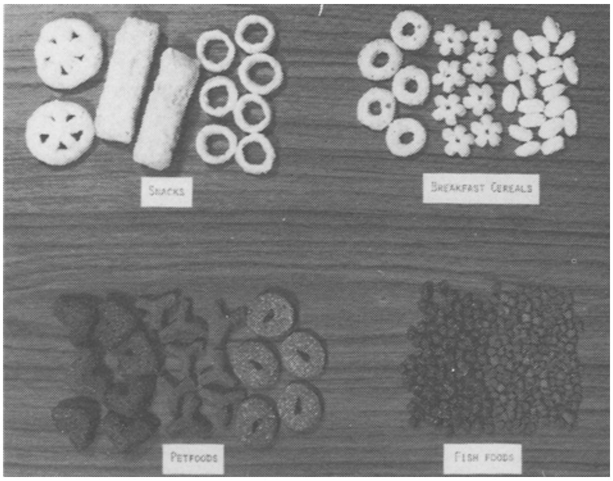

FIG. 1. Examples of products containing oilseed proteins.

Soy is the best suitable oilseed to be processed whole without having the fat removed. Most of the other oilseeds contain, compared to soy, relatively high levels of oil and relatively low levels of protein, and processing the whole seed for a food or feedstuff is not economically feasible (Table I). The value of a vegetable oil is usually a multiple of the value of the protein meal, wt for wt. If the oil content is relatively high and the protein content relatively low, oil extraction will be the more economical utilization of the oilseed. The protein content would also be disproportionally low compared to the energy content of such a feed or food ingredient.

When oilseeds contain antinutritive factors which are not heat labile, these must be removed or destroyed by other means. Extensive work is being done in breeding new plant strains which are free of toxic constituents and in the removal of toxic constituents in processing. The latter usually is coupled to a concentration or isolation of the protein. Vegetable protein concentrates and isolates of this type indeed are important raw materials for use in the extrusion cooking process; e.g., defatted soy flakes or flours and soy concentrates are the basic ingredients for meat extenders and analogs produced by extrusion cooking (Fig. 2) (1). However, it is now possible to substitute at least a large part of the soy with some of the other vegetable protein concentrates or isolates. This contributes much to the ability to balance the amino acids for increased protein efficiency. Peanut and rapeseed proteins as well as wheat gluten have been utilized successfully in levels up to 50%.

The subject of this presentation is whole seed processing. Most of the work done on whole seed processing has been concentrated on soy. This oilseed has a protein:fat ratio which makes it an economically feasible proposition. All the important antinutritive factors can be controlled efficiently by correct heat treatment, and both the protein and the oil are of excellent nutritive quality. The general

TABLE I

Protein and Fat Content of Some Major Oilseeds

	World production[a] 1973 (million tons)	Decorticated seed[b]	
		Protein (%)	Oil (%)
Soybeans	44.2	44	20
Cottonseed	24.1	32	32
Groundnut	18.8	27	50
Sunflower	12.2	22	48
Rapeseed	7.1	21	40
Coconut (as copra)	3.9	8	60
Sesame	1.9	28	51

[a]With seed hull / as normally marketed (Production Yearbook FAO, 1973).
[b]Moisture-free basis, indicative, variations possible.

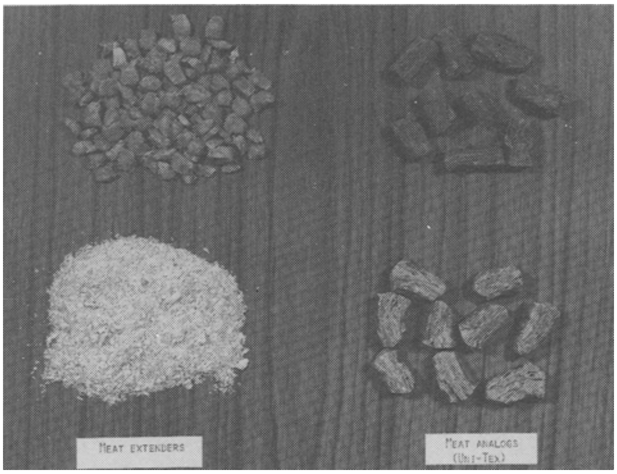

FIG. 2. Examples of textured vegetable proteins.

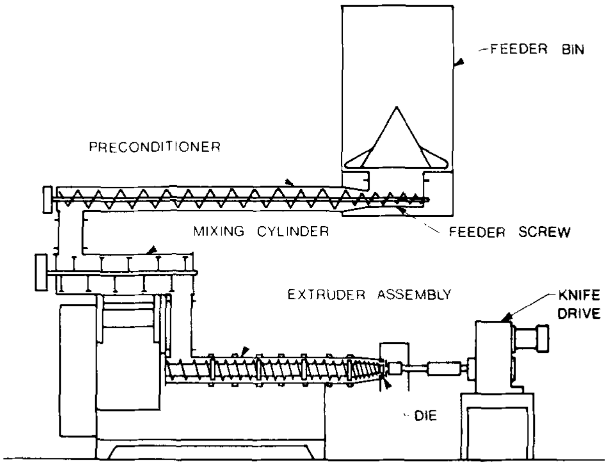

FIG. 3. Main components of multipurpose extrusion cooker.

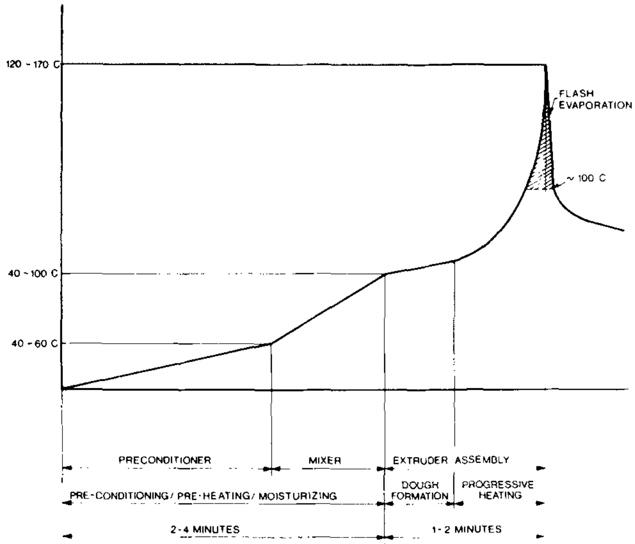

FIG. 4. Time/temperature relationship in extrusion cooking process.

methodology described will be applicable to the processing of full fat soy as well as the extrusion cooking of other products.

METHODOLOGY

Extrusion cooking, as the name implies, is basically a cooking process. However, the cooking process proper and some of the steps associated with cooking take place in a manner on a single unit during a relatively short time. The extrusion cooking process can, for practical purposes, be divided into several steps (Fig. 3):

1. *Feeding:* Uninterrupted, controllable, and even feed rate of the dry, granular, or floury material or mixtures of different flours must be provided.
2. *Preconditioning:* This serves to premoisten and heat the product evenly while still in floury or granular form. Some processing materials require or benefit by preconditioning with atmospheric steaming at moderate temperatures.
3. *Mixing:* Moisture or ingredients in the form of pumpable slurries can be added and efficiently mixed with the dry, in some cases preconditioned, material. Temperature and moisture of the mixture can also be increased by direct steam injection at this stage.
4. *Extrusion cooking:* Several steps take place during the passage of the product through the extruder configuration.

   a. The moistened, but generally free flowing, granular or floury, amorphous processing material is worked into a colloidal dough.
   b. The temperature of the dough is raised at an increasing rate. The highest temperatures are first reached in the last coned nose section of the extruder assembly.
   c. Simultaneously, the pressure within the extruder configuration is augmented as the increasingly viscous partially cooked processing material progresses forward. These pressures are higher than the vapor pressure of the moisture so that the moisture remains in a liquid state.
   d. The cooked and now normally highly viscous mass is forced through one or several die openings into a lower pressure, usually the surrounding atmospheric pressure. The sudden drop of pressure results in an instantaneous flash evaporation of part of the entrained moisture, with rapid cooling as a result. Considerable amount of volatile constituents will be driven off at this point (Fig. 4).

   The required heat for thermal processing in an extrusion cooker can be created in various ways. In the described Short Time/High Temperature unit, most of the required heat is produced by the conversion of mechanical energy to thermal energy through friction between product and the screw, product and the tube, and viscous shear within the product itself. This limits or avoids the use of heat transfer surfaces which usually are the limiting factor in heat processing equipment. However, the sectional extruder tube and sometimes the screw can be heated or cooled by external means to adjust process conditions.

   Different products require different dwell times during dough development and require different rates of thermal input. Viscosity characteristics can also vary considerably from one product formula to another. Versatility is obtained by the ability to change the length of the extruder configuration and the ability to change the screws, heads, and other configuration components at any point to obtain appropriate transport, shear, and pressure creating characteristics.
5. *Texturizing and shaping:* If the properly processed product has plastic and gas entraining properties when reaching the die, the product will be expanded. The partial drying and evaporative cooling will result in a partial hardening of the expanded matrix. Textures can be varied by altering processing conditions within the limits of the characteristics of the processed material. The expanded product can either be given the final cross-sectional shape by the extruder die or reshaped by,

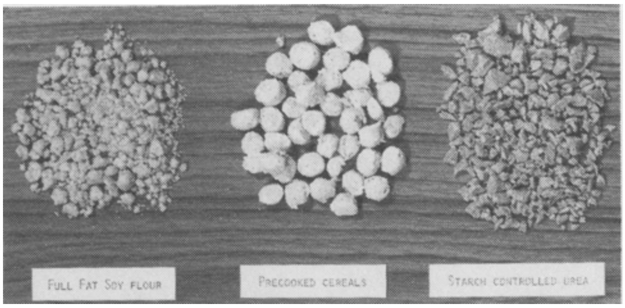

FIG. 5. Examples of extrusion cooked products where shape l/or texture are of secondary importance.

for example, rolling or by forming extrusion. Similarly, the expanded product can be cut at the extruder die or after a reshaping operation. Shape and/or textural characteristics can be of secondary importance in some applications. However, a change in texture, histology, and product density always will be the result of the process (Fig. 5).

EFFECT ON NUTRITIVE AND ANTINUTRITIVE CONSTITUENTS

Extrusion cooking is thus a process which performs eral functions in a continuous operation. It might be ful to look at the effect of this process upon some of the ferent constituents of the processed material.

›teins

The effect of moist heat on proteins improves the nutri- ; value. This improvement is not necessarily due to an ›rovement of the major proteins; on the contrary, even derate heat when prolonged can reduce their nutritional ue (2). Some of the antinutritive factors in proteins have :n identified as being proteins which can be destroyed or ctivated by heat as well. The advantage is that the anti- tritive proteins usually are destroyed first (3). The time/ nperature relation and the ability to control these is an portant prerequisite in this compromise.

ırches

The advantages of applying heat and moisture to rches for increasing their nutritive value are well estab- ıed. The degree of gelatinization required is very much pendent upon the species and the age of the animal for ıich it is intended, as well as the source of the starch.

Mature oilseeds are devoid of, or very low in, starches. ıce this subject is outside of the scope of this paper, it ffices to define the gelatinization of starches as the ıpture of starch granule, brought about by a combination moisture, heat, pressure, and (in some instances) :chanical shear" (4). Extrusion cooking is an efficient :thod for the gelatinization of starches in cereals.

ts

The effect of moderate heat on fats normally neither :reases nor decreases their nutritional value. Excessive nperatures in the presence of oxygen can result in oxida- ›n with the formation of toxic substances. Extrusion oking temperatures of such magnitudes are normally not ilized. On the contrary, it has been found that extrusion oked products containing lipids have excellent shelf life, fat splitting enzymes are essentially deactivated. Another ›ssibility might be the cause for the sometimes un- pected shelf life. It has been shown that high energy xing on a dough in absence of air results in a marked :rease in lipid binding in the dough (5). The extrusion oking process cannot be equated with anaerobic proc- ;ing; but, at the stage where the granular material is ırked into a dough, little, if any, air is present.

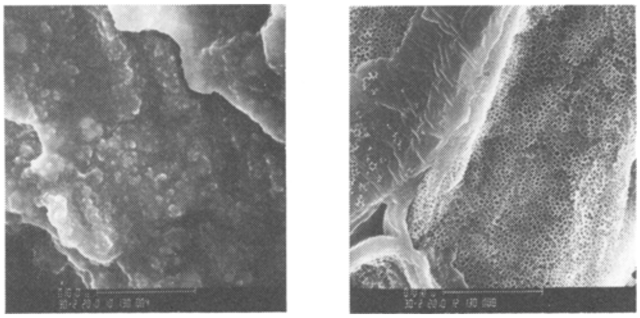

FIG. 6. Split soybean cotyledon. Left: before fat extraction. Right: after fat extraction.

Micronutrients

In the extrusion cooking process, micronutrients will be effectively distributed throughout the product and physically bonded throughout the extrudate. It has been shown that the heat treatment in this process results in comparatively little destruction of vitamins compared with other heat treatment processes (6). Certain vitamins are lost excessively and should be applied externally after extrusion cooking and after possible drying. Several of the vitamins available in a microencapsulated form have increased stability in the extrusion cooking process.

Toxic Constituents

Toxic constituents which can be destroyed by moist heat are being controlled efficiently by extrusion cooking. By toxic constituents are understood those substances found in foods which produce a deleterious effect when ingested by men or animals (7). In soybeans the most important is the trypsine inhibitor. Among other heat labile toxic constituents are hemagglutinins, a goiterogenic factor. Several other heat labile and heat stable toxic constituents in soy have been identified, but their relative importance has not been well defined (6,8).

Bacteriological and Mycological Status

The Short Time/High Temperature process in extrusion cooking has been equated with a pasteurizing process (9). The bacteriological status encountered in properly extrusion cooked products is very low, with no pathogens known to survive (6).

Taste and Flavor

This process, with the described atmospheric steaming and subsequent flash-off at the die, causes loss of considerable taste and flavor components. In some applications this is considered a negative aspect. However, in the processing, for example, of full fat soy, this is an advantage. A multitude of flavor components have been identified or estimated in soybean products (10). Most of these are either destroyed or volatilized in the process. Extrusion cooked full fat soy is devoid of the beany bitterness and has only a slight, nut-like flavor.

HISTOLOGICAL CHANGES

Scanning electron microscopy[1] is a useful tool for probing the subcellular structures and the changes which take place during the extrusion cooking of full fat soy.

Figure 6 shows the greater part of one elongated cell of a cotyledon of a raw soybean split with a razor blade before and after the fat has been removed with ether. Fat spherozomes can be seen to be imbedded in the cut surface. When the fat is removed, the indentations in the cytoplasmic intercellular material show the places where fat spherozomes were imbedded. Note the cut (bottom left) and

[1]Through the cooperation of Dr. Paul A. Seib, Department of Grain Science, Kansas State University, Manhattan, Kansas.

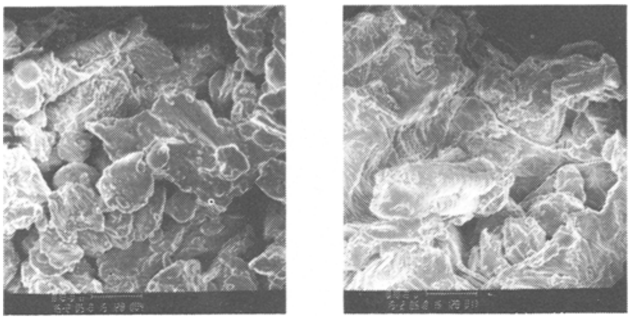

FIG. 7. Ground soy (as is).

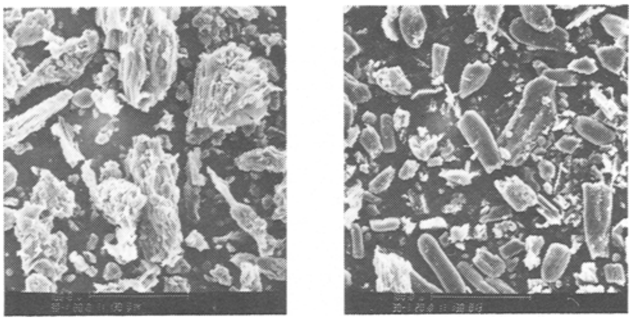

FIG. 8. Ground soy (fat removed). Left: raw soybean. Right: extrusion cooked.

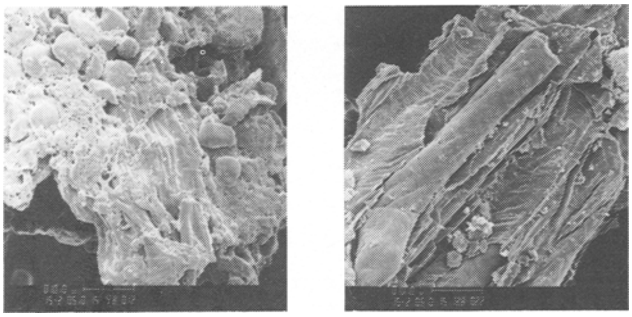

FIG. 9. Ground soy (fat removed). Left: raw soybean. Right: extrusion cooked.

cleaved (top left) cell wall. The cell would normally be tightly packed with protein bodies of 1-20 μ (11). These were washed away when the fat was removed together with some cytoplasmic material.

Figure 7 shows ground, raw soybean and the extrusion cooked product. In the raw product, some protein bodies can be seen as smooth, round particles between the larger cell wall pieces which have jagged edges. Fat spherozomes can be seen on the surface of both protein bodies and on cell surfaces. The surfaces of the extrusion cooked product seem to have been "painted," which might be caused by the fat. No fat spherozomes can be seen in this case.

Figure 8 shows ground, raw soybean and the extrusion cooked product where the fat has been removed. Some free protein bodies and some partially imbedded protein bodies can be seen in the raw sample. In the extrusion cooked counterpart, larger, fused protein bodies are visible. It should be noted that these pictures give a slight indication of what happens in the production of meat extenders and analogs by extrusion cooking: the fusion together of several protein bodies. Here they have been prevented from forming larger strands or plates due to the lubrication and shortening effect of the fat.

Figure 9 shows ground, raw soybean and the extrusion cooked equivalent. Separate protein bodies, cell wall material, and the somewhat deformed cytoplasmic network is seen. In the extrusion cooked product the larger, fused

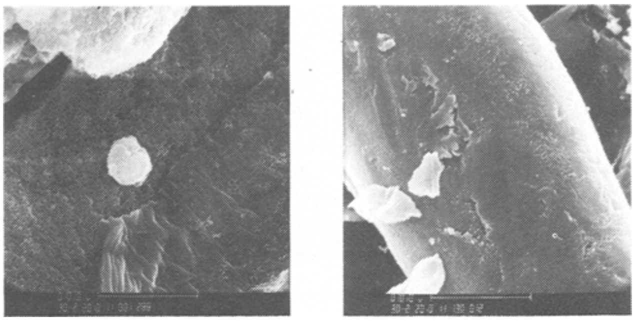

FIG. 10. Soy protein (fat removed). Left soybean. Right: extrusion cooked.

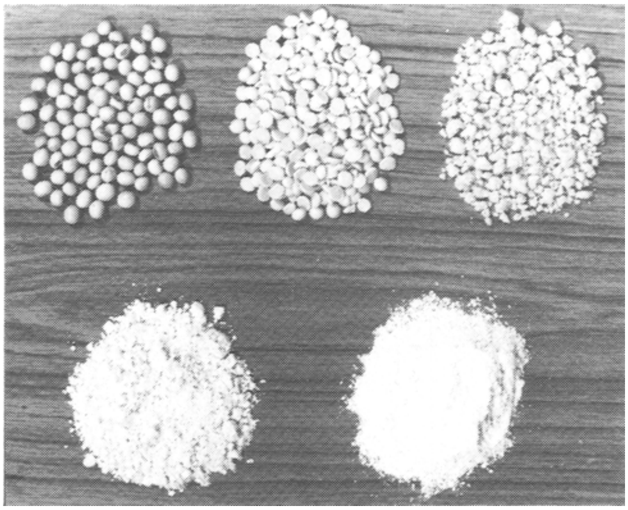

FIG. 11. Dehulled full fat soy production. Clockwise: whole beans, dehulled/split beans, extrusion cooked agglomerates, ground soybean, impact milled extrusion cooked flour.

protein body is clearly visible imbedded in the deformed cell structure. Very little material is seen which could have been cytoplasmic material. This material might have been washed away in the fat removal process.

Figure 10 shows two defatted protein bodies in the raw, defatted cell. Note the latticed cell structure of the protein body where fat spherozomes apparently have been imbedded in the protein just as seen in the cytoplasmic material. On the extrusion cooked, fused protein body only a few indentations where fat spherozomes were located can be noted. Notice that the relative size of the rather large (ca. 17 μ) raw protein body and the fused product on the right indicates that many protein bodies must have been fused together.

TYPICAL PRODUCTION LINE

The production of extrusion cooked full fat soy can best be demonstrated by showing the steps involved (Fig. 11):

1. The beans are cleaned of foreign particles by conventional means.
2. The dehulling operation is optional and need only be applied if the fiber content should be low or if the end product is to be milled to a flour. Soybeans can be extrusion cooked with the hulls.
3. The whole or dehulled beans are ground in a hammermill and transported to the feeding system of the extrusion cooker.
4. The ground product is extrusion cooked as described earlier.
5. The extrusion cooked product is dried. The residual moisture of the product (after flash-off) is between 14 and 18%. By cooling the product further in ambient air,

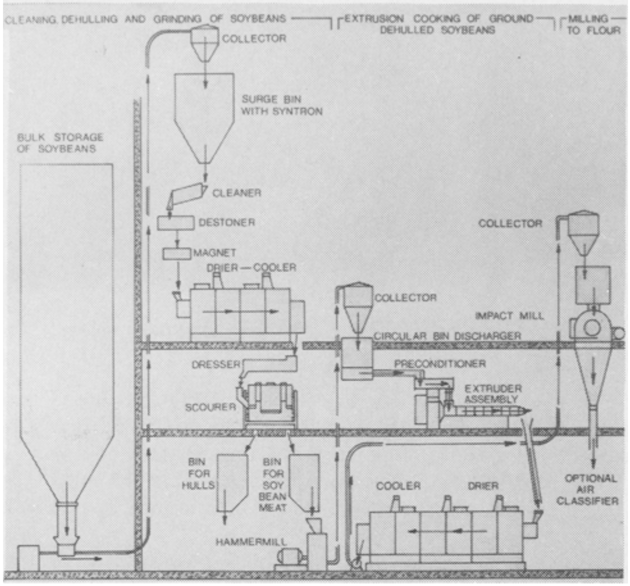

FIG. 12. Extrusion cooked full fat soy production line.

the residual moisture content will be lowered to ca. 12% by evaporative cooling. Where prolongued stability of the product, or the grinding of flour, is required, the product should be dried to ca. 4% moisture at moderate temperatures.

6. The dried product can now be ground on an impact type mill to a flour, if required. Particle sizes in the range of 300-100 μ are most common, depending on the end use. Air classifying can also be applied, which will remove part of the fiber.

A typical production line with a capacity of 2,500 kg/hr is shown in Figure 12. The dehulling method utilizes a traveling bed drier/cooler combination. The heating and cooling will loosen the hull from the meats. The beans are then passed through a high speed dresser-blender which will split the beans and loosen the hulls, which subsequently are removed through an aspirating scourer. Utilizing this method, fiber content in the finished product will normally be below 3%.

UTILIZATION

It is not within the scope of this presentation to review the advantages and limitations of extrusion cooked full fat soy.

Shortly mentioned should be that several producers of milk replacers for calves are using Wenger extrusion cooked full fat soy as a partial replacement for milk proteins in their formulas. The feeding of poultry with extrusion cooked full fat soy is especially successful. Millions of broilers and layers receive a high percentage of their protein and fat from this source.

In the field of human nutrition, extrusion cooked full fat soy is used extensively in malnutrition foods, for protein enrichment of dietary beverages and in soybean milk, in bread and cake, and as a meat extender and sausage binder.

One of the advantages of the system is its versatility. It is possible to make provisions in the system enabling the production of breakfast cereals one day and the changeover to snacks, textured soy protein, or full fat soy the next day. Similarly, it is possible in the case of animal feeds to produce pregelatinized cereals one day and to change over to full fat soy or pet foods the next day.

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