Extrusion Cooking Systems And Textured Vegetable Proteins

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INTRODUCTION

Many fabricated foods are cooked industrially and are given desired textures, shapes, density and rehydration characteristics by an extrusioncooking process. This relatively new process is used in the preparation of «engineered» convenience foods: textured vegetable proteins, breakfast cereals, snacks, infant foods, dry soup mixes, breadings, poultry stuffings, croutons, pasta products, beverage powders, hot breakfast gruels, and in the gelatinization of starch or the starchy component of foods.

First developed as an economical method of gelatinizing starches, extrusioncookers have been modified during the recent years to process an ever - widening group of food, industrial and animal feed products, at ever increasing capacities, and with production costs per pound which have steadily decreased, as contrasted to other industrial methods of cooking.

Modifications were made in the extrusion cooker which enable it to destroy the growth inhibitors present in soy proteins and in certain pulse proteins (Jiminez **et al.** 1963, Mustakas **et al. 1964,** and DeMaeyer 1965). This let to the protein fortification of extrusion-cooked cereal based foods, although it took a decade of evaluation of biological performance to learn what could be done, and what must not be done in thermal processing of cereals with proteins, vitamins, and amino acids, all of which can be harmed in biological feeding value by improper thermal treatments. Protein enriched breakfast cereals, snacks, infant foods, and instantized beverage powders are quickly developing. A method was developed to make full fat soy flours from extrusioncooked soybeans.

Extrusion - cooked textured soy protein is produced from defatted soy flour or soy concentrates, with or without pH modification of the protsin. Used principally as a meat extender, such products are additionally used as an ingredient in a new range of fabricated protein foods which, (for lack of a better name) will be referred to here as the third generation of textured plant protein foods. This chronology would consider the meat analogues prepared from spun protein isolates as the first generation of textured plant protein foods, and extrusion - cooked meat extenders prepared from defatted soy flours or concentrates as the second generation of such textured plant protein foods. This third generation of textured plant protein foods utilizes textured soy protein extenders, (extrusion - cooked from defatted soy flours) plus isolated soy proteins, unsaturated vegetable oils, egg albumens, and a bit of cereal flour to create this new third generation of textured products in the form of breakfast sausages, slices, patties, steaks, roulades, shrimps, etc.

Extrusion - cooking has the capability of controlling product textures and mouthfeel to a surprising extent through a wide range of product densities and rehydration characteristics. It also acts as a product pasteurizer, producing end products of excellent bacteriological status and shelflife, without any appreciable contribution to ecological problems.

Extrusion - cooking may be defined as «the process by which moistened, expansile, starchy and/or proteinaceous material (s) are plasticized in a tube by a combination of pressure, heat and mechanical shear. This results in elevated product temperatures within the tube, gelatinization of starchy components, denaturation of proteins, the stretching or restructuring of tractile components, the shaping of the end product, and the exothermic expansion of the extrudate.

Extrusion - cooked foods are foods engineered to meet a specific need or group needs. These include :

1. The need for convenience foods «engineered» to meet specific food requirements.
2. The need for nutritional balance, and to up grade the biological utilization of foods.
3. The need to pasteurize foods for improved shelf - life.
4. The need to reduce nutrient losses often encountered in thermal processing of foods.
5. A need to lower production costs.
6. A need for specific textures or functional characteristic (s) of foods or ingredients used in the preparation of foods.
7. A need for versatility in line of products to be produced.

This paper will attempt to explain the capabilities and the limitations of extrusion - cooking to meet these needs. Additionally it will outline some of the methods which have been followed to meet specific processing objectives, to tell something about methods developed to control of effect rheological properties of the foods produced, and some of the things we believe can be produced by extrusion - cooking in the future.

PRINCIPLES OF THE EXTRUSION PROCESS (HT/ST)

wtrusion - cookers include a method of steam preconditioning at modest and carefully controlled temperatures (65°to 100°C) at atmospheric pressures; a method of uniform application of moisture; an extruder assembly designed to work the moisturized oilseed or cereal into a dough at modest temperatures (85° to 110°C); a means of elevating the temperature of the dough in the extruder in a coned nose section of extruder to a desired higher temperature (115° to 175°C) during a very short period of time (12 to 20 seconds); the forming of the dough into the desired shape by use of a final die, and a means of cutting the expanding dough into segments of desired length. (See Figures 1, 2)

Certain extrusion - cooked products (textured soy proteins or breadings for example) are run through a wet milling device after extrusion - cooking but before drying and cooling. (See Figure 3.)

Flaked breakfast cereals are made by cutting an extrusion - cooked and cooled extrudate into pea sized balls which are flaked in a water jacketed roller mill while the extrudate is still moist and pliable, before drying. (See Figure 4.)

After extrusion processing, all products are passed through a tunnel type drier and cooler, sometimes followed by a flavor application reel with which liquid flavors or dry powdery flavors are applied externally to the extrudate from a suitable flavor feeding device. Flavors in liquid form (solution or emulsion) are sometimes suspended in a vegetable oil carrier. Alternate techniques have been developed to sugar coat breakfast cereals or snacks.

Most extrusion - cooked products may be reduced to a precooked flour or granule by impact milling or roller milling of the dried extrudate.

Extrusion - cookers are built in several configurations - as steam pressure cookers which discharge into a forming extruder, or as a simpler long barreled extruder which gradually builds pressured and temperatures while feed materials are advanced through the barrel and into which barrel steam is injected. The high temperature/short time (HT/ST) extrusion - cooker shown in Figure 2 is the one which this paper will comment on.

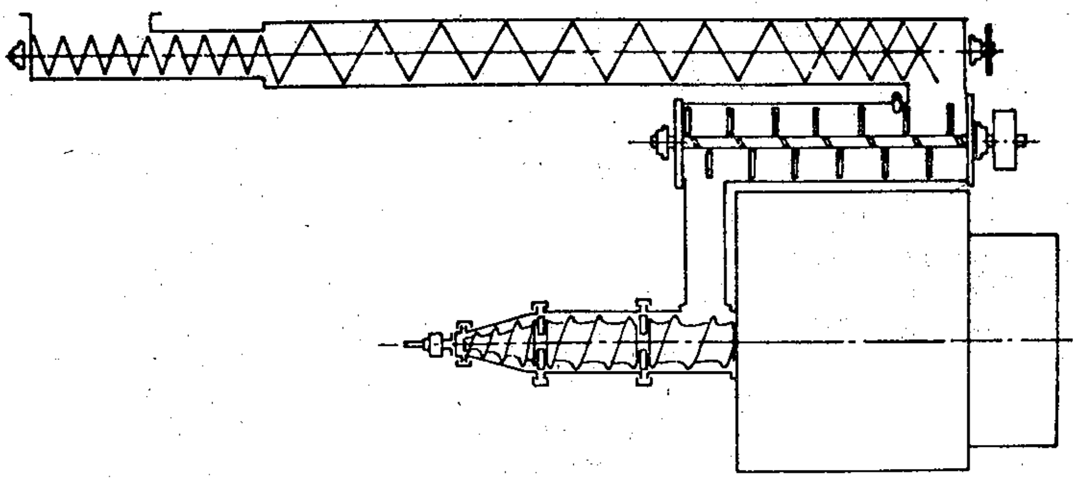
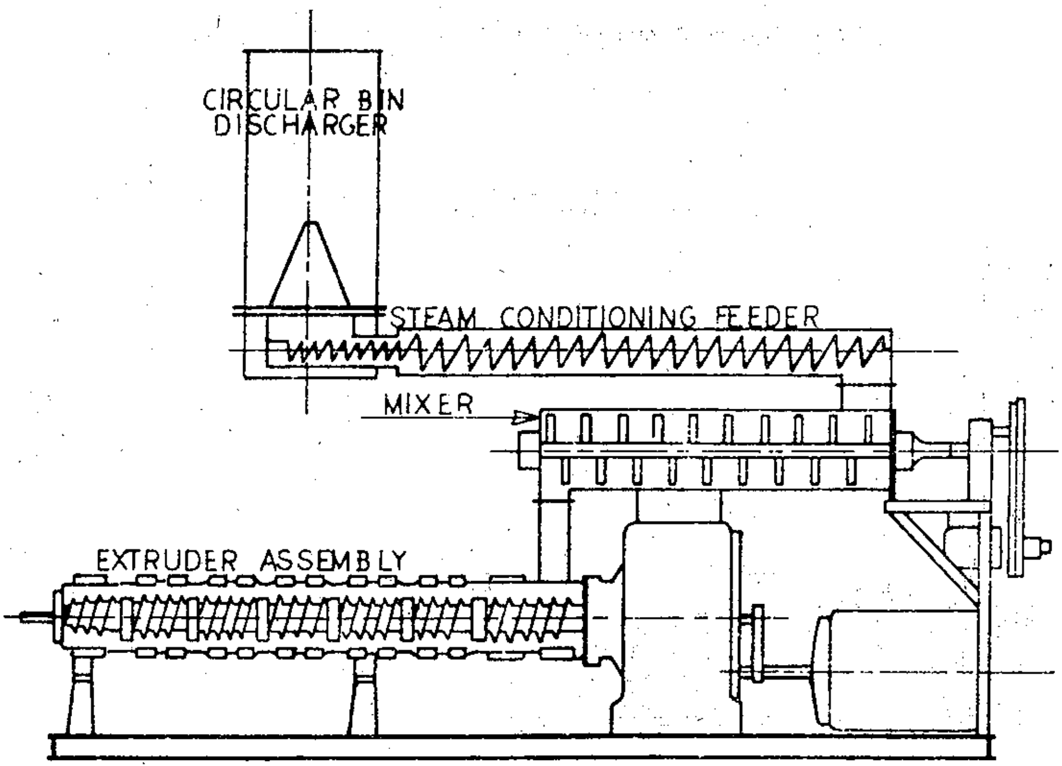


Fig. 1. High Temperature/Short Time Extrisior Cooker, Including Preconditioner



CUTAWAY VIEW OF LARGE CAPACITY EXTRUSION COOKER

Fig 2. Typical Arrangement Of Live Bin Feeder, Precon Ditioner, And Extrusion Cooker

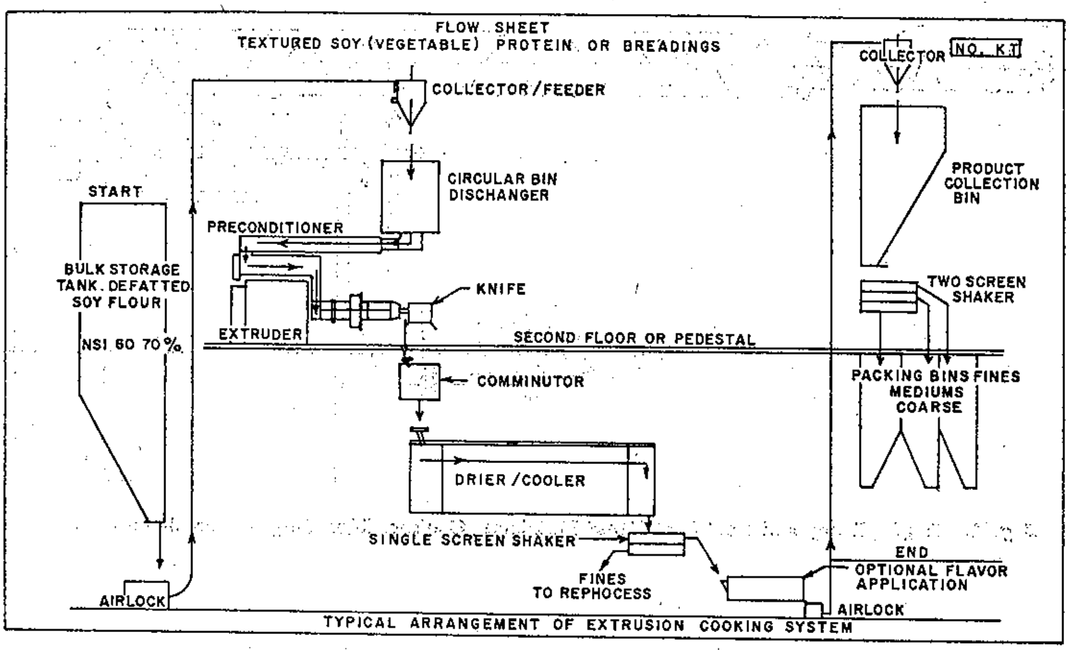


FIG. 3

Fig 3. Typrical Arrangement Of Extrusion Cooking System

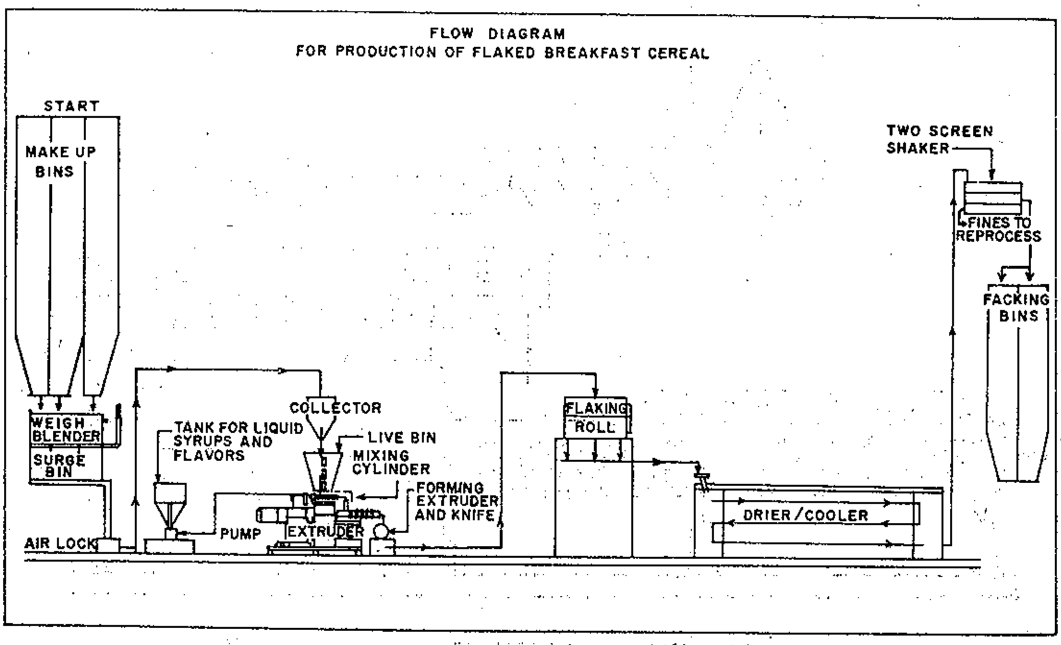


FIG. 4

Fig 4. Flow Diagram For Production of Flaked Breakfast Cereal

Preconditioning with steam is desirable for some, but not for all extrusion - cooked products. Hence, extrusion - cookers are produced with or without steam preconditioners, dependent upon product line.

Such extrusion - cookers are efficient converters of electrical energy to thermal energy and are thermodynamically efficient. They have the ability to entrain moisture and heat. make doughs; gelatinize starches; denature and debitter proteins; control heat labile growth inhibitors; histologically restructure process materials; and retexture, shape, expand, size, and partially dry the expanded products themselves.

Senaturation of proteins is the thermal processing of proteins which lowers protein solubility, renders the protein digestible, and destroys the biological activity of enzymes and of toxic proteins.

Growth inhibitors may be defined as any substance in foods which exert a deleterious physiological effect on man or animals as revealed by growth or metabolic studies.

Gelatinization may be defined as «the complete rupture of the starch granule, brought about by a combination of moisture, heat, pressure and (in some instances) mechanical shear.»

More precise terminology and measurement tools are needed for starch conversion however, as gelatinization as defined above covers only the basic rupture of the starch granule. In point of fact starch conversions are much more complex, and occupy several plateaus between the basic rupture of the starch granule and the dextrinization of starches. Precise industry definitions and rapid methods of measurement are needed for each level of starch conversion.

CAPACITY OF EXTRUSION - COOKERS

Processing can be done of dry expanded petfoods, for example, at capacities to 20,000 pounds per hour, or of textured soy protein at 3000 to 4000 pounds per hour. Snacks are produced in somewhat smaller machines at capacities of 700 pounds per hour, and breakfast cereals weighing only 3 pounds per cubic food can now be produced on a single machine at upwards of 2800 pounds per hour. Breakfast cereal flakes can be prepared at capacities of up to 4000 pounds per hour.

ADVANTAGES OF EXTRUSION - COOKING

1. Gelatinization of cereals or starches results in great uptake of water for improved digestibility and caloric availability. Additionally, gelatinized starches have improved functional characteristics - better extensibility, gas holding properties, pasting characteristics, and evidence some gluten development during processing. Starches gelatinized by extrusion - cooking bond added proteins and microingredients (vitamins, minerals, food colors, flavors, etc.) uniformly and irreversibly throughout the extrudate. This then assures that a reasonably even distribution of such additives will reach the consumer in every mouthful of food, no matter what the particle size may be. Additionally, the solubility and textural characteristics of an extrusion - cooked carbohydrate can be adjusted over a wide range, so that it may be produced as soluble as a drum dried infant food or as chewy as the most dense breakfast cereal, or may be given on intermediate density or textural characteristic. It is practical also to extrusion - cook cereal flours or starches which have been modified in pH (within reasonable limits) for desired textural change.

2. The inactivation of growth inhibitors and the thermal elimination of anti - palatability factors in important in processing soybeans or other pulse proteins. The temperature required to destroy growth inhibitors found in uncooked soy proteins and in certain other pulse proteins is uniquely high, but the shorter the period at that temperature peak, the better. The brevity of the cooking period at high temperatures is the major reason for the excellent biological performance of HT/ST extrusion - cooked foods. It is practical to extrusion - cook concomitantly for control of heat labile growth inhibitors and to gelatinize cereal flours and to provide desired textural properties to the precooked protein enriched food thus produced. (See Table 1.)

3. Labor costs and processing costs per ton are lower in extrusion - cooking systems than in any other industrial cooking method known. Processing costs per ton have steadily declined with increasing capacity per horse-power and per man hour. Investment costs per ton of production capacity are lower for the large capacity HT/ST extrusion - cookers than investment costs per ton of production capacity in other cooking methods.

4. Extrusion - cookers and driers and coolers built as part of the system are designed to be quickly and easily disassembled for clean out. Total bacterial plate counts are very low, and no insects, larvae, pathogens or salmonella have been known to survive the process, where recommended sanitation procedures have been followed.

Table 1. Protein Utilization Of Typical Extrusion Cooked Mixtures Of Cereals And Oilseed Proteins

Reference No:	Ingredients	Per Vaues Mixtures	Casein	Net Protein Utilization
(1)	Degerminated Corn- Full Fat Soy- Sugar- Ca_3 PO_4	2.40	2.50	74
(4)	Full Fat Soy - Full Fat Feanut - Rice Flour	2.32	2.50	60
(14)	Full Fat Soy - Full Fat Cottenseed Corn	2.30	3.00	63
(2)	Wheat Flour - Peanut Flour - Milk	1.68	2.50	54
(12)	Rice - Full Fat Soy - Defatted Soy	2.49	3.00	65
(14)	Full Fat Soy Alone	2.44	3.00	66
(1)	Degerminated Corn - Full Fat Soy Milk - Sugar	2.51	3.00	58
(3)	Casava Flour - Full Fat Soy	2.51	3.00	57
(14)	Expeller Cottonseed - Defatted Soy - Sugar - Corn	2.19	3.00	58

5. Shelf - life of extrusion - cooked products seems extraordinarily good without refrigeration, if reasonable sanitation procedures have been followed. Fat splitting enzymes are essentially deactivated during the extrusion - cooking process, improving the oxidative stability of the lipids in the process. While the pasteurizing effect of the extrusion - cooker is important indeed, and while the inactivation of lipase during the process will improve shelf - life of extrusion - cooked products, one additional possibility seems reasonable cause for the unexpectedly good shelf - life. British workers (Daniels **et al.** 1970) showed that high energy mixing of a dough in the absence of air results in a marked increase in lipid binding in the dough. It was found that when such doughs were freeze - dried and powdered, they showed no sign of rancidity in storage, unlike airmixed doughs, which released the greater part of their lipid in the free form and quickly developed rancid offodors. Daniels **et al** (1970) have shown that bound lipids are protective against peroxidation, and have shown that lipid peroxides were formed exclusively in the **free** lipids of the doughs. They demonstrated that aerobic mixing of doughs results in the release of lipids which have been bound in the early stages of hydration of the doughs. They found that «lipid release was found to be suiprisingly sensitive to small quantities of air admitted to the dough and preceded the formation of appreciable amounts of lipid peroxides in the dough.» They found also that aerobic mixing of the dough, under various work levels, while increasing the amount of air available to the dough, led to a decrease in the lipid binding after mixing. Moreover, as the work load increased, the effect of air on lipid binding became more pronounced.

By anaerobic mixing, on the other hand, Daniels and his colleagues were able greatly to increase the work level, while actually increasing the percentage of bound lipids. The aerobic mixing work was performed in the presence of normal amounts of air, while the anaerobic mixing of doughs was performed under nitrogen or under vacuum.

Extrusion - cooking cannot be considered as anarerobie mixing. Nonetheless, the conversion of moistened granular meterials to a colloidal dough occurs in HT/ST extrusion - cookers inside the extruder harrel itself, at which point there is a starving effect, as far as air is concerned.

6. Extrusion - cookers are very versatile. The same HT/ST extrusion - cooker can produce any one or a whole range of normal or protein - enriched food products.

The basic equipment is designed in extruder configuration to produce the specific food or foods which are desired at the outset. However, should some other extrusion - cooked product be desired at a later date, interchangeable extruder components are produced (to such extent that it is necessary to exhange an existing extruder screw or head or die for enother) to produce the new product or products. It is also possible to lengthen or shorten the extruder assembly where needed to produce some new product. Flexibility of product line is perhaps the most important capability of modern extrusion - cookers.

7 They require only a small amount of labor and a small amount of floor space per ton of production capacity. Careful positioning of system components will further reduce labor requirements.

8. Extrusion - cookers can produce a wide range of product shapes, textures, sizes, densities, rehydration ratios, and rehydration characteristics. Individual ingredients or mixtures may be cooked. They can gelatinize starches while simultaneously cooking for control of growth inhibitors.

9. HT/ST extrusion - cookers can cook vegetable proteins with practically no harm to protein quality and with only minimal drop in vitamin content, when microencapsulated vitamins are used.

10. They histologically modify and restructure all foods processed by them. It is possible to control the texture of the cooked oduct within reasonable limits.

11. They can cook a wide range of ingredients - all the cereal flours, oilseed and pulse proteins, wet milled starches, dehydrated flours of root carbohydrates, defatted vegetable proteins (soy, peanut, linseed, copra, etc.). Egg proteins, fish proteins, or meat proteins can be blended into any of the above, in dry or slurry form, prior to extrusion - cooking. Synthetic amino acids blended into cereals show only modest losses (Howe **et al.** 1965) during HT/ST extrusion - cooking of the mixture. Milk proteins can be blanded into such mixtures, but special precautions need be exercised when cooking mixtures which include milk proteins. Many flavors are sufficiently stable to stand HT/ST extrusion - cooking, but others are so volatile that they need to be appplied after extrusion and after drying, perhaps in an oil emulsion.

12. Engineered convenience foods have been the fastest developing foods of industrialized societies.

13. Extrusion - cookers produce almost no effluent or other ecological hazard.

14. HT/ST extrusion - cookers consume less total energy per ton of production capacity than any other cooking method known and are thermodynamically efficient.

Hawthorn (1973) has reported that the world needs to examine the production of foodstuffs from the standpoint of energy consumed in all aspects of getting that food on the table. Generally, manufacturers of foods examine processing costs per ton, but Slesser (1973) had previously suggested that we look much further - to the energy input in producing fertilizer and pesticides plus the energy subsidy and the labor needed in preparing the soil, fertilizing, irrigating, cultivating, harvestng, processing, drying, particle sizing, packaging, storage, rafrigeration, shipment, distribution, preparation in the home, and (presumably) the treatment and disposition of effluents. He points out that «energy utilization to power the human race is just as subject to the laws of thermodynamics as is the energy utilization to power an internal combustion engine.» Berry (1972) has shown that thermodynamic analysis is a realistic way to assess the ultimate value of an economic process because it does so in terms of the only commodity in the world in ultimate limitation - thermodynamic potential.

When we examine food costs in the light of total energy subsidy plus the total labor costs, and relate those costs to 100 grams of utilizable protein, or to 100 calories of metabolizable energy, we may find that many of our food patterns should indeed be changed.

15. Extrusion - cookers have the ability to modify greatly the texture, mouthfeel, and utility of every product which is extrusion-cooked, be it breakfast cereal, snacks, breadings, or textured soy protein. The latter is probably as good an illustration as can be found to explain the steps through which desired textural changes are produced. The raw material normally used in the production of textured vegetable protein is defatted soy flour (min. 50 % protein; max 3 % fiber; maw 1 % fat, and preferred NSI of 50 to 70). Soy protein concentrates or other vegetable proteins high in protein content also may be used in the preparation of such chewy protein gels. The nitrogen solubility of (NSI) **unprocessed** vegetable proteins is quite high. However, during extrusion - cooking the proteins are denatured, the mojor evidence of which is a great reduction in protein solubility. As defatted vegetable proteins are denatured, the protein strands are rendered stretchable and bacome good encapsulators of gases, yet retain the characteristics of rapid firming of the cell structure after extrusion through the final die plate. The reduction in solubility of the proteins, plus their characteristic of becoming stretchable, act concomitantly to make these denatured proteins capable of reorientation into certain desired structures. In this way, defatted soy flours or concentrates are made into chewy textured soy proteins by an extrusion - cooking process which accomplishes all of the following steps:

a. Moistening and heating of the protein flour; pH adjustment for changed textural characteristics is possible, but is not necessary;

b. Effective detruction of residual growth inhibitors;

c. Denaturation of protein which makes the protein stretchable;

d. Rupture of the cellulose sac which surrounds each protein body;

e. The joining of these liberated protein bodies into fibers of protein, which subsequently are twisted together into protein strands; and

f. The stretching and twisting of these protein strands and the uniform, systematic layering of these strands one over another produces a structure quite similar to the structure of muscle tissue. This gives textured soy protein its chewy, meatlike characteristic and its laminar structure.

Textured soy proteins produced from defatted soy flours or concentrates are the most important meat extenders available today - a boon not only to household budgets in these days of high meat prices, but also for their high protein content, and for making no known contribution to serum cholesterol levels. Used widely in institutional feeding programs (school lunch feeding programs, etc.), textured soys are also being incorporated into suitably labeled prepacked hamburged and food flavoring ocndiments sold in superkarkets. Textured plant proteins would also seem to have important potential markets in foods for the military, for field workers, and in allergy diets, etc. Usage of moisturized textured soy as meat extenders includes the preparation of hamburger, meatloaf, chilli, soups, stews, salads, pizza, dry soup mixes, sausages, pot pies, tacos, qravies, curries, enchiladas, seasonings, tamales, pasta casseroles, meat and spaghetti sauces, frozen dinners, canned foods lnd meat and spaghetti sauces, frozen dinners, canned foods and in vegetarian diets.

Density, chewiness, and rehydration characteristics of the textured plant proteins may be controlled over a considerable range by selective configuration of extruder components. Further textural madifications can be made bycareful adjustment of pH, before extrusion - cooking in most cases. However, pH adjustments can also be made after extrusion - cooking.

DISADVANTAGES OF EXTRUSION - COOKING

1. Extrusion - cookers process only floury or granular materials. Whole grains or whole oilseeds may be put through an extrusion - cooker, but in that event the extruder has to be designed in part as a grinder, with high shear forces, and thus loses cooking efficiency, capacity, and flexibility in textural versatility. It also loses some of the advantages found in biological performance of processed proteins.

2. Mixtures containin milk proteins must be cooked in the lower third of the available range of extrusion temperatures - say from 100° to 135°C for optimum biological utilization of the protein (Smith 1969). A Maillard reaction can occur at higher temperatures, although this may be acceptable in certain foods for its contribution to flavor.

3. It has not yet been possible consistently to bind or destroy the growth inhibitor «gossypol» found in cottonseed.

4. Several of the **microencapsulated** vitamins can be premixed with cereals prior to HT/ST extrusion - cooking and length show little loss in vitamin stability, probably due to the period at high temperatures (12 to 20 seconds) in an HT/ST system. Hower, certain vitamins, particularly Vitamin C, show excessive loss in processing, and should be applied externally after extrusion - cooking and after drying.

CONTROL OF PROCESS VARIABLES TO AFFECT TEXTURAL PROPERTIES

The textures which can be achieved by extrusion - cooking are many. Experience has shown that there are six major means available to modify textures in extrusion - cooked foods:

1. Control of product moisture levels and selection of the points of moisture application and selection of the form in which maisture in applied (as water, as steam, or as mixtures of both, or as syrup).
2. Control of product temperatures at each point in the system.
3. Selection of ingredients or mixtures of several ingredients for desired functional characteristics.
4. Control of pH of ingredients or mixture (s).
5. Selection of extruder components to provide the dwell time and the product temperatures desired in each section of the extruder. Interchangeable extruder components are designed to produce low, medium, or high temperatures of product within each section of the extruder. Extruder assemblies can be arranged to utilize only a short extruder (as needed for producing snacks) or a much extended extruder as needed for other products. Extruder heads are Jacketed so steam, cold water, or brine may be circulated as needed.
6. Final dies are selected primarily to shape the extrudate as needed, but die selection can also have an effect on the textural characteristics of the final product.

No capability of modern extrusion - cookers is more important than their ability to control product temperatures at each point within the system and quickly to alter that temperature should product temperatures vary form that temperature preselected for any point. An automatic temperature control system has been developed for use where product uniformity is particularly important, such as breakfast cereals or textured soy proteins, for example. Manual control of product temperature is still in widespread use, however, particularly where a bit of irregularity in product is acceptable.

THE TEXTURING OF EXTRUSION - COOKED PRODUCTS

It has been indicated earlier that whenever any cereal and/or protein is extrusion-cooked, the extrudate is texturally and histologically restructured. Before this takes place, however, several steps occur during the cooking process and these steps themselves often affect the texture of the final product:

1. The materials are uniformly moistened sometimes with steam, sometimes only with water or sometimes with a combination of both.
2. The moistened (and sometimes heated) raw materials of mixtures are worked into a dough, followed by modification of the amorphous structure of an opaque, stretchable colloidal structure.
3. Proteins are denatured and rendered tractile, chewy, and capable of being stranded. Heat labile growth inhibitors are destroyed during the extrusion process.
4. Gelatinization of starchy components occurs during this process, foolowed by a great uptake of moisture and substantial increases in dough viscosity.
5. During propulsion through the final coned section of the extruder the dough is elevated rapidly in temperature to a point at which its moisture content is well above the boiling point. However, since the area through which the dough is propelled (in the final coned section of the extruder) is being reduced, it is obvious that the moisture being converted to steam has no chance to expand. Hence the final coned section of the extruder itself becomes a small superheater. Since the dough has been rendered stretchable by being gelatinized or denatured, and since the moisture content is in superheated form at the instant of extrusion, the cell structure of the extrudate expands rapidly at the moment it is expelled from the extruder. The degree of expansion for any single ingredient or mixture will normally be directly proportional to the temperature of extrusion. Hence it is possible to control the degree of expansion within reasonable ranges by control of the extrusion temperature and moisture content.
6. Thermosetting follows normally within a few seconds of final extrusion. Most extrudates have a breadlike cell structure, and lose their plasticity rapidly after extrusion.

The texturing of extrusion - cooked foods is a process about which much has been learned, and it is now possible, within reasonable limits, to provide certain characteristics of chewiness or tenderness, brittleness or plasticity, crunchiness or crumbliness. Much still has to be learned about this field, and about the employment of additives, about the functional selection of ingredients, and about the affect of pH changes. Experience is being gained about the affects of and the selection of shortenings, emulsifiers, bleaching agents, humectants, glutens, and starches on rheological properties of extrusion - cooked foods. Much more has been learned about the control and utilization of process variables and modifications in component configurations to achieve desired product forms, chapes, densities, and textures within the desing limitations of the system.

FLATULENCE IN FABRICATED PLANT PROTEIN FOODS

The cuses of flatulence are several, but most recent research seems to agree that fermentative degradation of carbohydrates of low nolecular weight by the microflora in the ileum and colon are the primary causes (Steggerda **et al.** 1966, and Calloway 1966). Of these, stachyose and raffinose appear to be the most likely culprits. Calloway (1966) showed that the human ileal and colonic microflara utilize stachyose to produce gas. Rackis **et al.** (1967) showed that raffinose and stachyose hydrolyzed with yeast invertase and acid produced large amounts of gas. Rackis **et al.** (1967) also showed that defatted cottonseed or peanut produced flatulent activity in dogs comparable to the flatulence of soy. Rakis **et al.** (1970) reported that oligosaccharides in defatted soybean meal total about 15 % of the weight of the meal. Kawamura **et al.** (1963) showed that this total is made up of 6 to 8 % sucrose, 4 to 5 % stachyose, 1 to 2 % raffinose, plus a trace of verbacose. Steggerda **et al.** (1966) reported flatus volume of several soy protein products in man, and found there are considerable differences between individuals in flatus volume when each individual in the group was fed on a specific soy diet.

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