

Full-Fat and Defatted Soy Flours for Human Nutrition¹

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ABSTRACT

Full-fat and defatted soy flours represent basic forms of soy protein that can be produced by simple, uncomplicated and low cost processes, and properly processed soy flours have excellent nutritional value as demonstrated in biological feeding tests with humans and small animals. New, simple production methods for full-fat soy flours, including an extrusion process for use in urban communities and a simple hand process for use in villages where skilled labor, machines and steam power are unavailable, have been developed. Severe heat treatment during processing reduces the availability of amino acids, impairs oxidative stability, reduces vitamin content and develops poor flavor characteristics in the product. Lipoxigenase inactivation before the toasting treatment is important to obtain a stable, high fat product. Good flavor in soy flours can be achieved to make them acceptable to the consumer as constituents in a wide range of processed foods.

During the past 35 years or so workers in the field of animal nutrition have shown, that the protein of soybeans when properly processed is an economical source of feed protein for the efficient production of livestock and poultry. The protein in soy flours can also perform the same function in the diet of human beings and is today one of the most economical sources of concentrated food-grade vegetable protein.

Soy flour is used in a variety of food products. The most common uses (1) include: fully-cooked flour (baby cereals, meat processing, bakery goods, animal milk replacers, pharmaceuticals); medium-cooked flour (meat processing,

hydrolyzed vegetable protein, bakery goods, animal milk replacers, baby cereals, beverages); lightly-cooked flour (bakery mix, doughnut mix, beverages, hydrolyzed vegetable protein, baby cereals); uncooked flour (bleaching agent in white bread).

Soybean flour, particularly the full-fat type, has been receiving attention in research at the Northern Laboratory. Emphasis is being placed on full-fat flour because of the importance of both calories and protein in feeding hungry people around the world. This paper will review general technological aspects of soy flours and will emphasize research information developed at the Northern Laboratory under support from the U.S. Agency for International Development (AID) and in an earlier cooperative program with UNICEF.

PROCESSING

The production of flours from soybeans involves the removal of hulls to produce a full-fat soy flour or removal of both hull and oil fractions to produce a defatted flour. Steps in the manufacture of both full-fat and defatted soy flours by equipment conventionally used in oil extraction plants are shown in Figure 1.

Study of the production of full-fat soy flour by extrusion cooking (2,3) was undertaken in 1965 at the Northern Laboratory in cooperation with AID. Extruders are being used industrially to produce many foods such as snack-type cereal foods, but extrusion for heat processing of soybeans to produce a flour was new to oilseed processors.

Conventional toasting in atmospheric pressure stack cookers or jacketed conveyors takes from 30-45 min. In contrast the same effect can be accomplished in a matter of seconds or minutes by extrusion cooking the meals under pressure at high temperatures.

A second phase of our research program was to develop a simple hand process (4) for making full-fat soy flour in overseas villages. Since skilled labor, electric power and steam are nonexistent in these remote areas, we devised a simple process by which unskilled laborers using hand-operated equipment could produce flour meeting rigid specifications with respect to nutritional quality, sanitation, flavor acceptability and stability.

Equipment for the Village Process is exceedingly simple. The total assembly is estimated to cost under \$250. With this equipment six men can produce 300 lb. of soy flour in an 8-hr day. These 300 lb. will supply half the daily requirement of protein for more than 1600 adults.

The experimental flours were tested in many basic food formulas and food combinations (5) in cooperation with the Human Nutrition Research Division, ARS, USDA, at

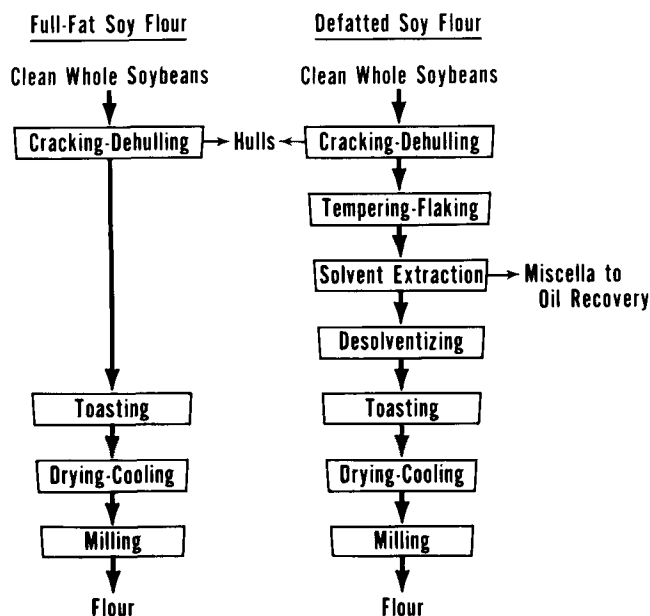


FIG. 1. Production of both full-fat and defatted soy flours by conventional processes.

TABLE I

Relative Nutritional Values of Commercial Types of Defatted Soy Flours

| Type | Protein dispersibility index, % | Relative protein efficiency, ^a % |
|-----------------|---------------------------------|---|
| Negligible heat | 90-95 | 40-50 |
| Light heat | 70-80 | 50-60 |
| Moderate heat | 35-45 | 75-80 |
| Toasted | 8-20 | 85-90 |

^aDried skim milk equals 100%.

TABLE II

Comparison of Bromothymol Blue (BTB) Absorption with Other Tests Normally Used for Evaluating the Steam Heat Treatment of Soybeans

| | Steaming period, hr | Mg BTB absorbed/g flakes | NSI ^a , % | Urease activity, pH increase | Trypsin inhibitor destroyed, % |
|-------------|---------------------|--------------------------|----------------------|------------------------------|--------------------------------|
| Undercooked | 0 | 2.58 | 89 | 2.30 | 0 |
| | 0.5 | 3.68 | 16 | 0.10 | 100 |
| | 1.0 | 3.98 | 10 | 0.08 | 100 |
| | 1.5 | 4.28 | 7.0 | 0 | |
| | 2.0 | 4.40 | 6 | 0 | |
| | 2.5 | 4.58 | 6 | 0 | |
| | 3.0 | 4.62 | 6 | 0 | |
| | 3.5 | 4.78 | 5 | 0 | |
| | 4.0 | 4.80 | 5.0 | 0 | |
| | 4.5 | 4.84 | 5.0 | 0 | |
| Overcooked | 5.0 | 4.88 | 5.0 | 0 | |

^aNSI = nitrogen solubility index.

Beltsville, Md. Types of foods prepared included soy beverages for young children, yeast breads, main dishes, cereal products and baked desserts. Objectives in these preparations were to use the optimum amount of soy flour to gain a nutritious product and to provide palatable food resembling those indigenous to various developing countries.

COMPOSITION OF FLOURS

Typical analyses (1) of full-fat and defatted soy flours are as follows:

| | Defatted, % | Full-fat, % |
|-----------------------|-------------|-------------|
| Protein (N x 6.25) | 50.5 | 41.0 |
| Fat | 1.5 | 20.5 |
| Fiber | 3.2 | 2.8 |
| Ash (minerals) | 5.8 | 5.3 |
| Carbohydrates (total) | 34.2 | 25.2 |

Moisture generally varies between 5% and 10% depending on atmospheric conditions. The flours contain approximately 0.2% calcium and 0.6% phosphorus. Values for these nutritionally essential elements are considerably higher than those found in most cereals commonly used for human food, such as corn, wheat and rice. Sodium, potassium, magnesium and the trace minerals (iron, copper, cobalt, zinc, etc.) are also present in the soy flours in various but appreciable amounts. In comparison with cereal grains, soy flours are fairly good sources of B-Complex vitamins (6). Unheated soybeans contain a high level of

thiamine (vitamin B₁). Even though this amount is reduced by some forms of heat processing, the level remaining is still greater than in most cereals. Other water soluble vitamins contained in varying amounts include riboflavin, pyridoxine, pantothenic acid, folic acid and niacin. Inositol and choline are present as components of the lecithin fraction (5). Other fat soluble vitamins or provitamins are also present, such as carotene and tocopherols.

There is approximately 30% carbohydrate present; a recent study of soybean sugars (7) shows that defatted soy flours average about 8.2% sucrose, 1.2% raffinose and 5.5% stachyose. These sugars contribute to the toasted flavor when soybean flours are heated in the presence of moisture.

Food energy values of soy flours are high and compare favorably with values for all-purpose wheat flours and corn flour being in terms of calories per gram: 3.6 for wheat flour, 3.7 for corn flour, 3.3 for defatted soy flour and 4.2 for full-fat soy flour. Full-fat soy flours exceed the values for defatted flours due to the high caloric value for the oil component.

HEAT TREATMENT AND NUTRITIONAL VALUE

Although soy protein has a high content of essential amino acids, raw soybeans contain trypsin inhibitors and other antigrowth factors that require cooking to make the bean edible and more nutritious for humans (8). In addition cooking improves the soy product in other ways. It improves flavor, provides good shelf life and influences certain other functional properties such as water absorption and dispersibility in water.

As early as 1917, Osborne and Mendel (9) showed that heating soybeans improved their nutritive quality. Since then numerous other investigators have improved methods for heat treating soybeans. When properly heated, soy protein has excellent nutritional value with the limiting amino acid being methionine. However heating must be controlled to prevent adverse effects upon nutritive value and dispersibility. Even though it is well established that both overheated and underheated soy protein are of inferior nutritive value (8), not too much is known of the fundamental nature of the changes brought about as a

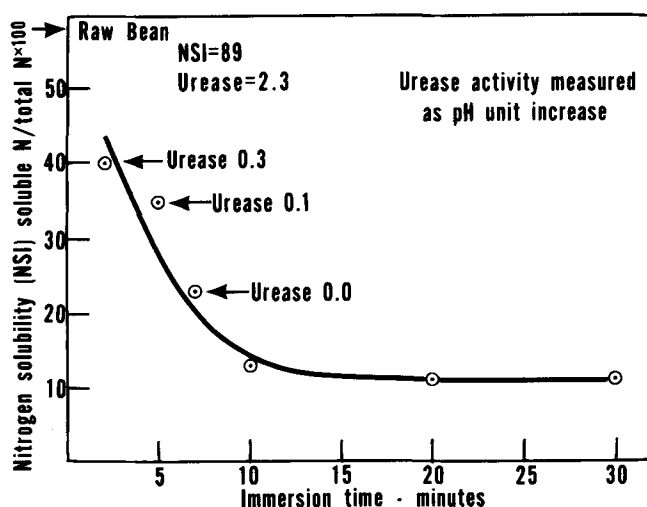


FIG. 2. Nitrogen solubility index (NSI) and urease activity of immersion-cooked, presoaked whole soybeans (60-65% moisture).

TABLE III

| Vitamin Analysis of Extruded Full-Fat Soy Flours | | | |
|--|--------------------------|-----------------------------|-------------------------|
| Soybean fractions | Thiamin, $\mu\text{g/g}$ | Riboflavin, $\mu\text{g/g}$ | Niacin, $\mu\text{g/g}$ |
| Original flakes | 9 | 2.9 | 50 |
| Extruded full-fat flours | | | |
| Test A | 10 | 3.1 | 63 |
| Test H | 9 | 2.9 | 47 |

TABLE IV
Biological Values of Extruded Full-Fat Soy Flours by Rat Bioassay

| Sample lot designation | Protein efficiency ratio 4 weeks, 10% protein level | | Net protein utilization (NPU) ^a | | |
|------------------------|---|-----------------------|--|-------------------|-------|
| | Gyorgy ^b | Morrison ^c | Maintenance level Platt ^d | 10% protein level | |
| | | | | TNO ^e | Platt |
| A | 2.36 | 2.39 | 62 | 60 | 57 |
| H | 2.29 | 2.44 | 62 | 64 | 57 |
| Casein control | --- | 3.09 | --- | 74 | --- |
| Dry skim milk control | 3.00 | --- | --- | --- | --- |

^aNPU by carcass analysis at the protein level required for both maintenance and at protein level in the diet fed (namely, 10 g protein/100 g diet).

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result of the heating process.

Tests in common use today for measuring the proper degree of heat treatment in toasting are protein dispersibility index (PDI) or nitrogen solubility index (NSI) and urease activity (10).

The data (1) in Table I show that the PDI test can be an effective guide in achieving a good relative protein efficiency. Both PDI and urease activity are good indices for judging the degree of undercooking but are less reliable for testing the overcooking of flours.

Urease activity is a widely used criterion for indicating the destruction of antibiological factors. A defatted soy flour showing an increase in pH over 0.3 should be suspected of receiving insufficient heating for good nutrition. A product with an increase of 0.02 or less should be suspected of being overheated (11).

Indeed the urease test and NSI were useful assay procedures for guiding the cooking studies in our development of the Village Process. Early studies showed that initial moisture content of the whole beans had a highly significant effect on urease deactivation during cooking. Beans soaked overnight reached moisture contents of 62-68% and could then be cooked with rapid reduction of urease.

Figure 2 shows the NSI and urease activity of presoaked whole soybeans when immersion-cooked for various periods. Of the several cooking methods tried, water immersion looked the best for rapid, simple control and yielded a nutritious product.

Currently we are investigating a new dye binding test (12) for evaluating toasting, using bromothymol blue (BTB). We believe that this test may evaluate the degree of

heat treatment more accurately and that the dye may indicate whether the soy protein is overcooked or undercooked. Table II compares BTB absorption values with those for other tests commonly used in evaluating the degree of soybean cooking. It can be seen that BTB values continue to increase with steaming time past the points where the other tests either terminate (urease activity, trypsin inhibitor) or reach a plateau or constant level (NSI) which does not change as the overcooked range is reached. Additional studies are contemplated to correlate these chemical results with biological feeding tests.

Under conditions of heat and moisture the free epsilon amino group of lysine in proteins can undergo reactions with reducing sugars and other compounds that decrease the physiological availability of the lysine. The available lysine in fully cooked full-fat soy flours made by the extrusion process ranged from 6.2-6.4% of total protein. For the Village Process flours, this range was 6.0-6.5%. These ranges show a high availability of the total lysine which was equal to about 6.5% before heat treatment.

In some commercial processes heat treatment of soybeans reduces concentrations of thiamine to low levels. Amounts of thiamine, niacin and riboflavin before and after extruder cooking in the full-fat soy flour process are compared for two samples in Table III. Data demonstrate that heat treatment in the extruder process destroys little of the original vitamin content. Biological testing of extruded full-fat flours by rat and chick feeding (2), and in clinical testing with infants up to 12 months of age, showed that the product had good nutritional quality (13).

Results (2) of both protein efficiency ratio (PER) and net protein utilization (NPU) obtained in rat feeding (Table

TABLE V
Weight Gains and Feed Conversions of Chicks Fed Diluted Diets Containing Soybean Proteins Processed Differently^a

| Soybean source | Average 2-week gain, g (2-4 weeks) | | Feed/gain (2-4 weeks) | |
|---|------------------------------------|--------------|-----------------------|--------------|
| | No supplementation | + Methionine | No supplementation | + Methionine |
| Control dehulled soybean oil meal + soybean oil | 262 | 312 | 2.48 | 2.15 |
| Commercial full-fat soy flour | 244 | 306 | 2.60 | 2.22 |
| Extruded full-fat soy product | 278 ^b | 315 | 2.45 | 2.19 |

^aDiluted diet calculated to contain 12.7% protein, 0.19% methionine, 0.195% cystine, 0.7% lysine, and 1.601 kcal of metabolizable energy/lb.

^bBetter than value obtained with commercial full-fat flour but not better than control meal at a 95% level of significance.

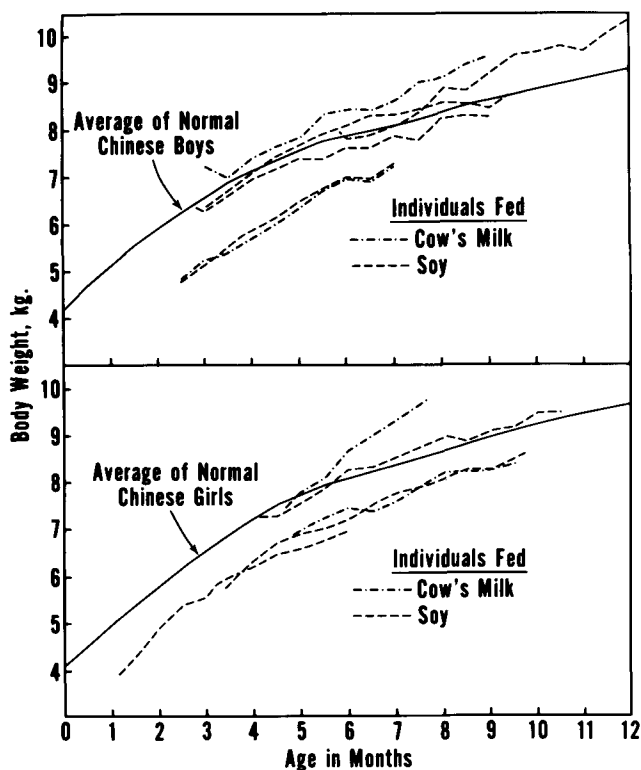


FIG. 3. Weight gain curves of extruded full-fat soy flour as compared with curve for cow's milk group and normal Chinese children.

IV) indicate that samples in Table IV had good biological value. In other words these properly processed, experimental, extruded products had about the same biological value as commercially prepared full-fat and defatted soy flours.

Controlled feeding tests with broiler chicks (2) demonstrated that both commercial and extruded soy flours promoted good growth and feed conversion efficiency. Table V lists weight gains and feed conversion of 240 chicks fed to 4 weeks in a completed battery trial. One group was fed a dehulled toasted soybean meal plus soybean oil (control). Another was fed a commercial toasted full-fat soy flour, and a third extruded soybean meal. Addition of methionine to the diets not only improved the feeding value in all groups, but also brought the results with the

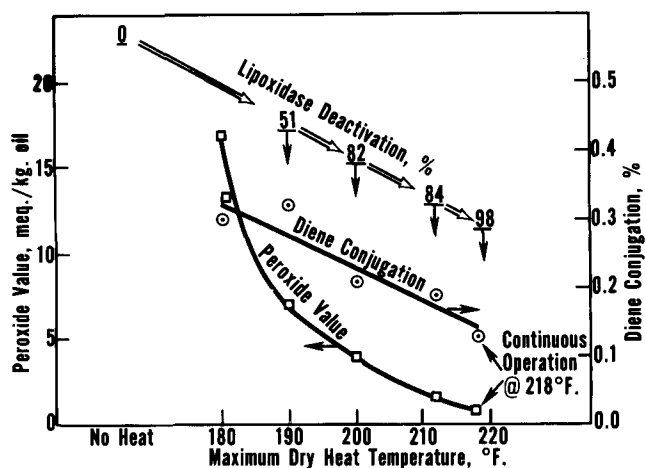


FIG. 4. Effect of dry heat treatment on lipoxigenase deactivation, peroxide value and diene conjugation of full-fat soy flours. All samples wetted to 25% for 2 hr at room temperature and dried.

commercial flour to essentially the same level as the other two.

In 1964, experimental full-fat flours produced by the extrusion process were sent to the University of Taiwan by UNICEF where they were evaluated in infant feeding (13). Rice flour, sugar and vitamins were added to the soy flour, and the formulation was fed for 6 months to children from 1-6 months of age. No proteins from animal origin were included in their diets. Growth curves for several of the boys and girls participating (Fig. 3) show that soy flour supported excellent growth and development and that these gains were comparable to those observed in babies fed cow's milk.

FLAVOR EVALUATION AND OXIDATIVE STABILITY

In conjunction with our extrusion studies, full-fat soy flours were evaluated by a taste panel to assess flavor characteristics. In this study the flours were tasted as a beverage for which the flour was diluted in a 1:8 flour-water ratio. Scoring was based on a 10-point scale with 10 indicating a bland product. The panel reported that the strong bitter beany flavor characteristic of soybeans was replaced by a mild nutty flavor. Table VI gives the flavor score for flours prepared under various experimental conditions.

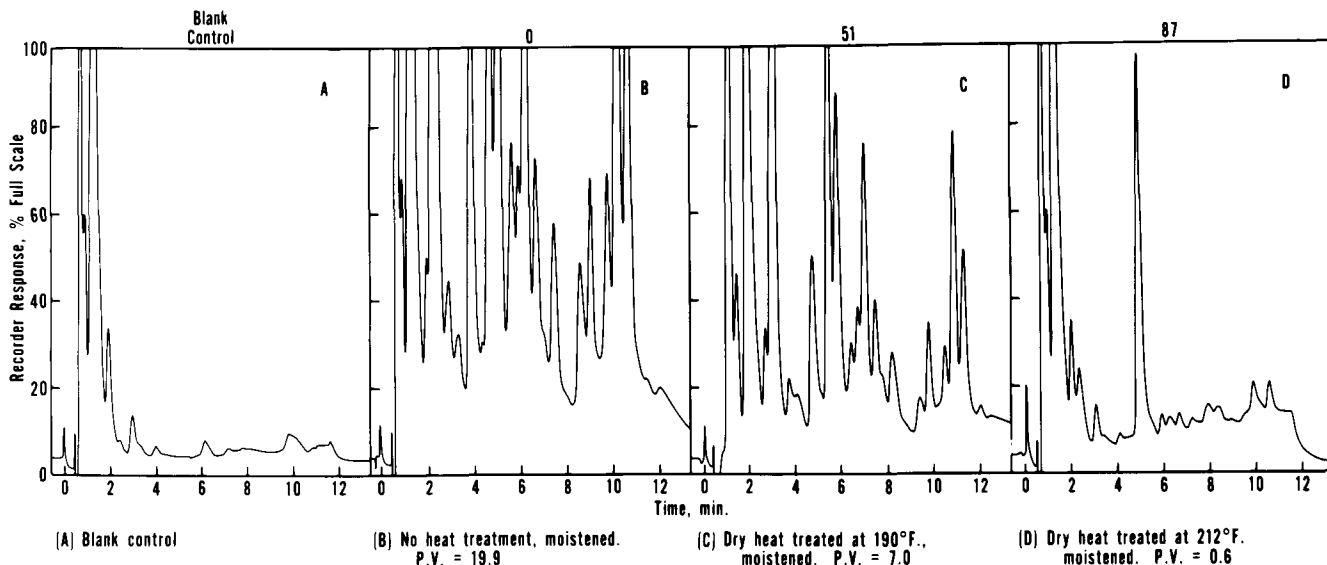


FIG. 5. Chromatogram showing effects of enzyme deactivation.

TABLE VI
Mean Flavor Scores at 0 and 12 Months' Storage Times

| Moisture, % | Retention time, min | Flavor rating ^{a,b} | | | | | |
|-------------|---------------------|------------------------------|-----------|-------|-----------|-------|-----------|
| | | 250 F | | 275 F | | 300 F | |
| | | 0 | 12 months | 0 | 12 months | 0 | 12 months |
| 15 | 0.50 | 7.8 | 7.3 | 7.2 | 6.9 | 8.2 | 7.5 |
| | 1.25 | 8.5 | 7.4 | 8.0 | 7.2 | 8.0 | 7.0 |
| | 2.00 | 8.2 | 7.3 | 8.0 | 7.7 | 7.8 | 6.9 |
| 20 | 0.50 | 8.3 | 7.6 | 8.5 | 7.1 | 7.8 | 7.6 |
| | 1.25 | 8.2 | 7.8 | 7.3 | --- | 6.8 | 2.1 |
| | 2.00 | 7.3 | 7.2 | 8.2 | --- | 7.0 | 4.3 |
| 25 | 1.25 | 8.3 | 7.0 | 7.5 | 7.2 | 6.7 | 1.8 |
| 30 | 2.0 | 8.2 | 7.5 | 7.7 | 3.3 | 6.3 | 2.0 |

^aValues have 95% limits given by ± 0.95 . At zero time, each mean is based on six flavor scores and at 12 months based on 12 flavor scores by a trained panel of six tasters.

^bScoring—strong undesirable flavor (0) → bland (10); (Minimum acceptable flavor = 6).

Temperature attained during cooking was a significant factor in developing good flavor, and its effect depended on the retention time-moisture combination. At the shortest time the effect of temperature was greater than at the longest.

The prevention of off flavors and odors which result from fat deterioration in full-fat soy flours is of critical importance in consumer acceptance of these products. In our studies good stability of extrusion-cooked full-fat soy flours depended on two basic factors: (1) deactivation of lipoxygenase E.C. 1.13.1.13 (lipoxidase) as a pretreatment in the process and (2) control of process variables during heat treatment in the extruder.

Studies of lipoxygenase effects (14) showed that lipids in cracked, dehulled, whole soybeans were rapidly oxidized after the lipoxygenase system was activated by increasing moisture content to 20%. These studies demonstrated further that preliminary heat treatment was effective in inactivating lipoxygenase and thus yielding a full-fat soy flour free of rancid odor and flavors. Dry heat to 212 F, steaming, or both, deactivated lipoxygenase to give flours that had low values of peroxide, conjugated diene and free fatty acid (Fig. 4). The flours had good flavors after 2 years' storage. Gas liquid chromatograph studies (Fig. 5) also gave evidence that the rapid formation of volatiles in full-fat flours was catalyzed by an enzyme system. In the chromatograms enzyme-deactivated sample D showed a low profile (comparable to a reference blank control sample A) in comparison with nondeactivated samples B and C. A 10-member taste panel was able to detect significant flavor and odor differences between oxidized and nonoxidized samples.

Stability of full-fat flours was also enhanced by operating the extruder at optimum levels of retention time, temperature and moisture (3). This preserved natural antioxidants which can become ineffective through excessive heat treatment.

The stabilizing effect of natural antioxidants present in full-fat soy flours was demonstrated by a storage test evaluation in which an extruded full-fat soy flour and hexane-defatted soy flour with added fat (soybean oil) were stored for 56 days at 120 F. Apparently there is an indigenous antioxidant factor in full-fat flour that is removed upon defatting soybeans, as data in Table VII for the accelerated test demonstrate that full-fat flour retained good stability, whereas the defatted flour plus added fat

TABLE VII
Accelerated Storage Test of Soy Flours

| Soy flour | Peroxide value, meq/kg, 120 F storage, days | | |
|---|--|-----|------------------|
| | 0 | 28 | 56 |
| Commercial defatted plus added soybean oil, 22.9% fat | 2.5 | 1.6 | 101 ^a |
| Extruded full fat, ^c 22% fat | 1.6 | 1.6 | 2.9 ^b |

^aFlavor rating = 3.7; maximum blandness = 10.0.

^bFlavor rating = 7.8; maximum blandness = 10.0.

^cExtrusion conditions: 2 min retention, 275 F exit temperature, 15% moisture.

became highly rancid as indicated by both peroxide value and flavor test.

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