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FULL-FAT AND DEFATTED SOY FLOURS FOR HUMAN NUTRITION[1/]

by

G. C. Mustakas
United States Department of Agriculture, Agricultural Research Service
Northern Regional Research Laboratory
Peoria, Illinois
United States of America

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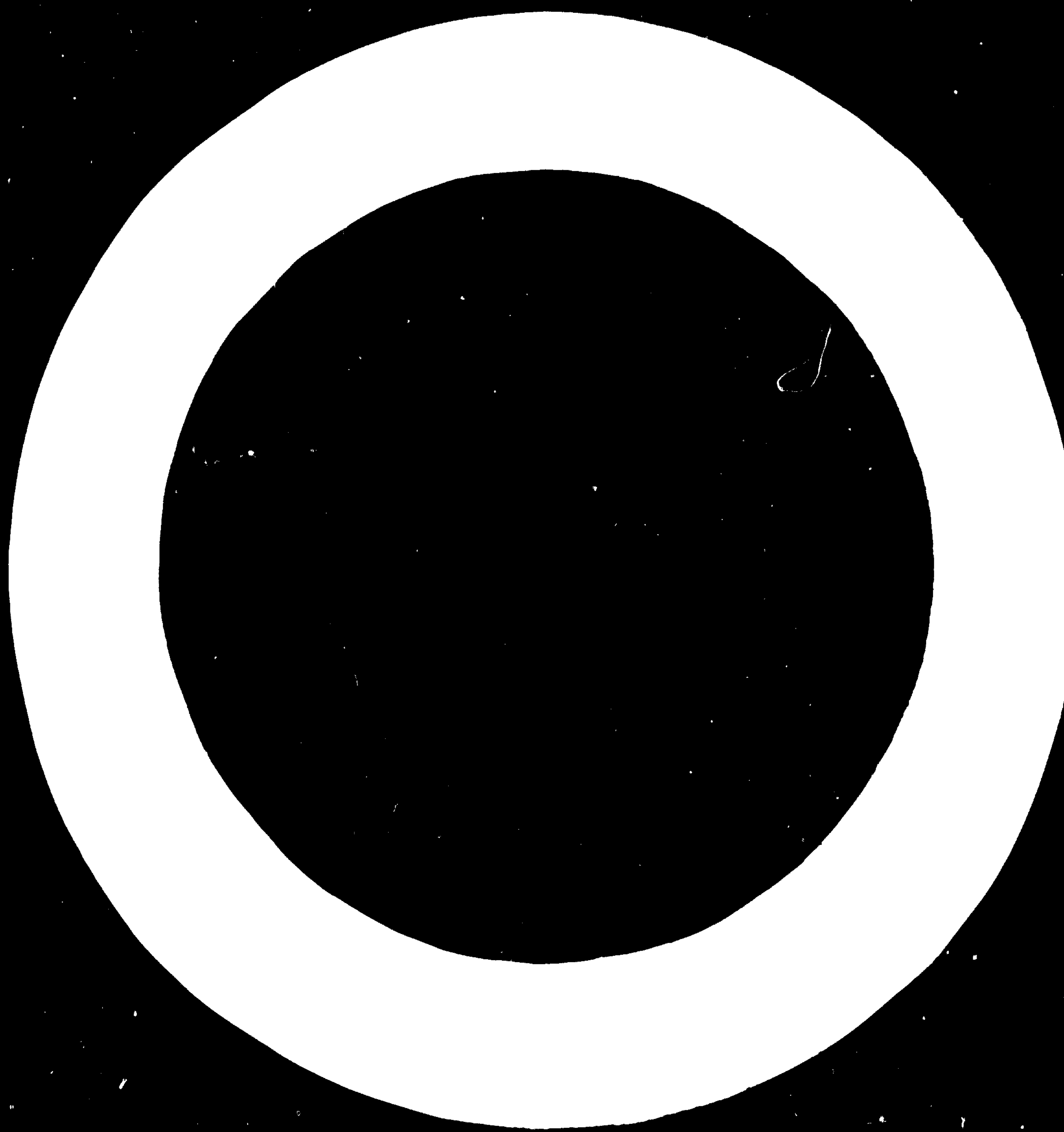

Over the past 35 years or so, workers in the field of animal nutrition have shown that the protein of the soybean, when properly processed, is an economic source of feed protein for the efficient production of livestock and poultry.

The protein in soy flours can also perform the same function in the diet of human beings and is, today, the most economical source of 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 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. The quantitative yield of each flour from a bushel of soybeans is diagrammed in Figure 1.

Fig. 1

Steps in the manufacture of both full-fat and defatted soy flours by conventional processes are shown in Figure 2.

Fig. 2

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 to 45 minutes. 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. Our experimental extruder unit is photographed in Figure 3 and a

Fig. 3

flow sheet of this process is given in Figure 4.

Fig. 4

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 had to devise equipment that could be hand operated and a process that could be easily learned by unskilled laborers--but yet such a process must meet rigid specifications with respect to nutritional quality, sanitation, flavor acceptability, and stability.

Figure 5 represents a flow sheet of the process that was developed.

Fig. 5

The experimental flours were tested in many basic food formulas and food combinations in cooperation by the Human Nutrition Research Division, ARS, USDA, at Beltsville, Maryland. 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.

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 pounds of soy flour in an 8-hour day. These 300 pounds will supply half the daily requirement of protein for more than sixteen hundred adults.

Composition of Flours. Typical or average analyses (1) of full-fat and defatted soy flours are shown in Table 1.

Table 1.--Composition of Soy Flours

Constituent	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 content generally varies between 5% to as much as 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 a fairly good source of B complex vitamins (5). Unheated soybeans contain a high level of thiamine (vitamin B_1). Even though this amount is reduced by some forms of heat processing, the level remaining is still a few times 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, but comparatively little is known about its composition or its use as a source of energy in the body. A recent study of soybean sugars (6) shows that defatted soy flours average about [illegible] sucrose, [illegible] 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 (Figure 6) with values for all-purpose wheat flours and corn flour.

Fig. 6

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 (7). In addition, cooking improves the soy product in other ways. It improves flavor, provides good shelf-life, and controls certain other functional properties such as water absorption and dispersibility.

As early as 1917, Osborne and Mendel (8) showed that heating soybeans improved their nutritive quality. Numerous other investigators since then have improved methods for heat-treating soybeans. When properly heated, soy protein has excellent nutritional value with the limiting amino acid being methionine. But, heating must be stopped short of 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 (7), comparatively little is known of the fundamental nature of the changes brought about as a 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.

The data (1) in Table 2 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.

Table 2.--Relative Nutritional Values of Commercial Types of Defatted Soy Flours

Type	Protein Dispersibility Index	Relative Protein Efficiency[1]
Negligible heat	90-95	40-50
Light heat	70-80	50-60
Moderate heat	35-45	75-80
Toasted	8-20	85-90

[1] Dried skim milk equals 100%.

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 would 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 (9).

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 7 shows the NSI and urease activity of presoaked whole

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Fig 7

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soybeans when immersion-cooked for various periods. Of the several cooking methods tried, water immersion looked the best for rapid, simple cooking, and yielded a nutritive product.

Currently we are investigating a new dye-binding test (10) for evaluating toasting, using bromthymol blue (BTB). We feel that this test may evaluate the degree of heat treatment more accurately and that the dye may determine whether the soy protein is overcooked or undercooked. Table 3 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.

Table 3.--Comparison of Bromothymol Blue Absorption with Other Tests Normally Used for Evaluating the Steam Heat Treatment of Soybeans

Steaming Period, Hr	Mg BTB[1] Absorbed/ g Flakes	NSI,[2] %	Urease Activity, pH Increase	Trypsin Inhibitor Destroyed, %	
0	2.38	89	2.30	0	Undercooked
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		
5.0	4.88	5.0	0		↓ Overcooked

1 BTB = bromothymol blue.

2 NSI = nitrogen solubility index.

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 lower the physiological availability of the lysine. The available lysine in fully cooked full-fat soy flours made by the extruder process ranged from [illegible] to 6.4% of total protein. For the village process flours, this range was 6.0 to 6.5%. These ranges show a high availability of the total lysine, which was equal to about [illegible] before heat treatment.

In commercial processing, heat treatment of soybeans generally reduces concentrations of such vitamins as thiamine, niacin, and riboflavin to low levels. Amounts of these vitamins before and after extruder cooking in the full-fat soy flour process are compared for two samples in Table 4. Data demonstrate that heat treatment in the extruder process destroys little of the original vitamin content. Biological testing of extruded full-fat soy flours by rat and poultry feeding, and in clinical testing with infants up to 12 months of age, showed that the product has good nutritional quality.

Table 4.--Vitamin Analysis of Extruded Full-Fat Soy Flours

Soybean Fractions	Thiamin, µg/g	Riboflavin, µg/g	Niacin, µg/g
Original flakes	9	2.9	50
Extruded full-fat flours			
Test A	10	3.1	63
Test B	9	2.9	47

Results (2) of both protein efficiency ratio (PER) and net protein utilization (NPU) obtained in rat feeding (Table 5) indicate that the samples in Table 4 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.

Table 5.--Biological Values of Extruded Full-Fat Soy Flours by Rat Bioassay

Sample Lot Designation	Protein Efficiency Ratio (PER) 4 Weeks, 10% Protein Level		Net Protein Utilization (NPU)[1] Maintenance Level	10% Protein Level	
	Gyorgy[2]	Morrison[3]	Platt[4]	TNO[5]	Platt
A	2.36	2.39	62	60	57
B	2.29	2.44	62	64	57
Casein control	...	3.09	...	74	...
Dry skim milk control	3.00	...	...	...	...

[1] NPU 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).

[2] P. Gyorgy, Philadelphia General Hospital, Philadelphia, Pa.

[3] A. B. Morrison, Vitamins and Nutrition Section, National Health and Welfare, Food and Drug Laboratories, Ottawa, Canada.

[4] B. Platt, National Institute for Medical Research, London, England.

[5] Central Institute for Nutrition and Food Research, Utrecht, The Netherlands.

Controlled feeding tests with broiler chicks (2) demonstrated that both commercial and extruded soy flours promoted good growth and feed conversion efficiency.

Table 6 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 commercial flour to essentially the same level as the other two.

Table 6.--Weight Gains and Feed Conversions of Chicks Fed Diluted Diets Containing Soybean Proteins Processed Differently[1]

Soybean Source	Average 2-Week Gain, g (2-4 Weeks) No Supplementation	Average 2-Week Gain, g (2-4 Weeks) + Methionine	Feed/Gain (2-4 Weeks) No Supplementation	Feed/Gain (2-4 Weeks) + 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[2]	315	2.45	2.19

[1] Diluted diet calculated to contain 12.7% protein, 0.19% methionine, 0.195% cystine, 0.[illegible]% lysine, and 1,[illegible] kcal of metabolizable energy/lb.

[2] Better than value obtained with commercial full-fat flour but not better than control meal at a 95% level of significance.

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 (31). Rice flour, sugar, and vitamins were added to the soy flour, and the formulation was fed for 6 months to children from 1 to 6 months of age. No proteins from animal origin were included in their diets. Growth curves for several of the boys and girls participating (Figure 8) show that

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Fig. 8

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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 7 gives the flavor score for flours prepared under various experimental conditions.

Table 7.--Mean Scores Based on Flavor Ratings of Experimental Flours, Extruder Cooked

Treatment Retention Time, min.	Moisture, %	Flavor Rating[1] 250° F.	275° F.	300° F.
0.5	15	8.2	7.3	6.8
0.5	20	8.3	8.5	7.8
1.0	25	8.2	7.7	6.3
1.25	15	7.3	8.2	7.0
1.25	20	8.3	7.5	6.7
2.0	15	7.8	7.2	8.2
2.0	20	8.5	8.0	8.0
2.0	30	8.2	6.0	7.8

[1] Values have 95% limits given by ± 0.05.

Temperature was a significant factor in developing food 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:

(a) deactivation of lipoxygenase E.C. 1.13.1.13 (lipoxidase) as a pretreatment in the process and (b) process control of variables during heat treatment in the extruder.

Studies of lipoxygenase effects (1[illegible]) 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 flavor. 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 (Figure 9). These flours had good flavors after 2 years'

Fig. 9

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storage. Gas liquid chromatograph studies (Figure 10) also gave

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Fig. 10

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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 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. 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 a 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.

The data in Table 8 for the accelerated test demonstrate that full-fat flour retained good stability, whereas the defatted flour plus added fat became highly rancid as indicated by both peroxide value and flavor test.

Table 8.--Accelerated Storage Test for Soy Flours

Soy Flour	Peroxide Value, meq/kg, 120° F. Storage 0 Days	28 Days	56 Days
Commercial defatted plus added soybean oil (22.9% fat)	2.5	1.6	101[1]
Extruded full fat (22% fat)	1.6	1.6	2.9[2]

[1] Flavor rating = 3.7; maximum blandness = 10.0.

[2] Flavor rating = 7.8; maximum blandness = 10.0.

SUMMARY

Full-fat and defatted soy flours represent simple and basic forms of soy protein that can be produced by simple uncomplicated and low-cost processes. Cooperative research between USDA and AID has developed new, simple, production methods for full-fat soy flours. These include an extrusion process for use in urban communities and a simple hand process for use in villages of developing foreign countries where skilled labor, machines, and steam power are unavailable. When properly processed, soy flours have excellent nutritional value as demonstrated in biological feeding tests with humans and small animals. Severe heat treatment during processing can reduce the availability of amino acids, impair oxidative stability, reduce vitamin content, and develop poor flavor characteristics in the product. Lipoxygenase inactivation applied before the toasting treatment is also important to obtain a stable high-fat product. Good flavors in soy flours can thus be achieved to make them acceptable to the consumer as constituents in a wide range of processed foods.

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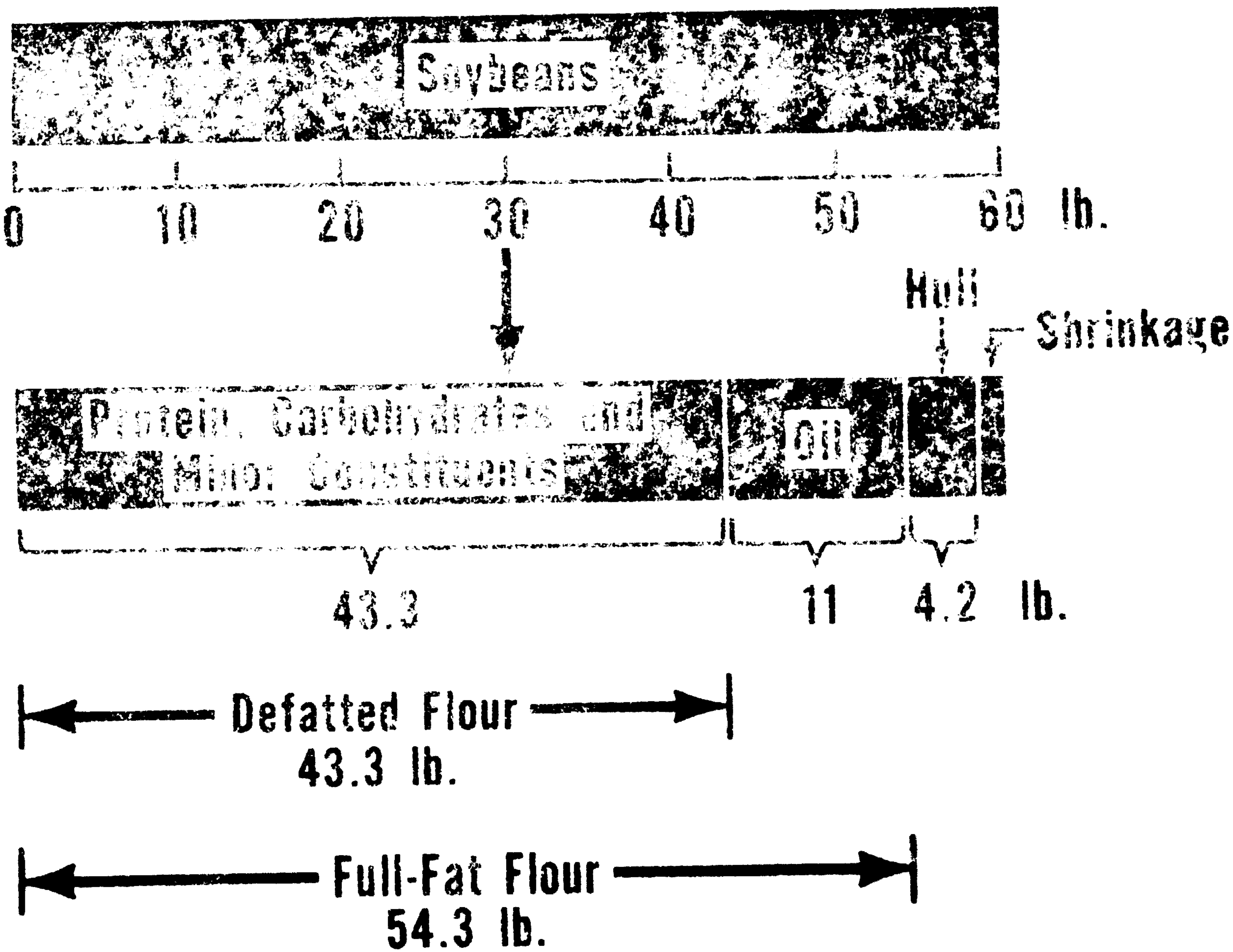
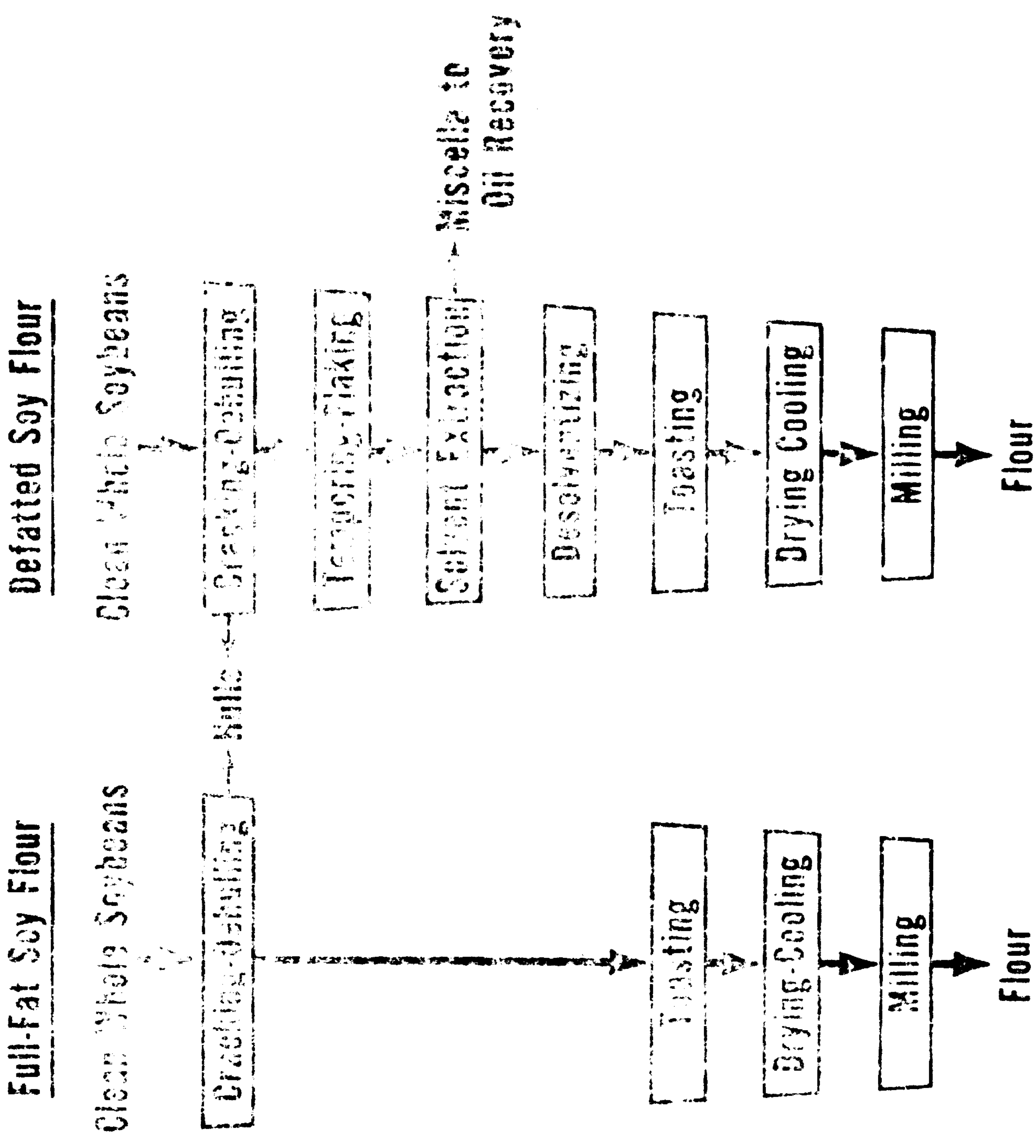

Soybeans
0
10
20
30
40
50
60 lb.
Hull
Shrinkage
Protein, Carbohydrates and
Minor Constituents
Oil
43.3
11
4.2 lb.
Defatted Flour
43.3 lb.
Full-Fat Flour
54.3 lb.

Fig. 2 Production of both full-fat and defatted soy flour by conventional processes.



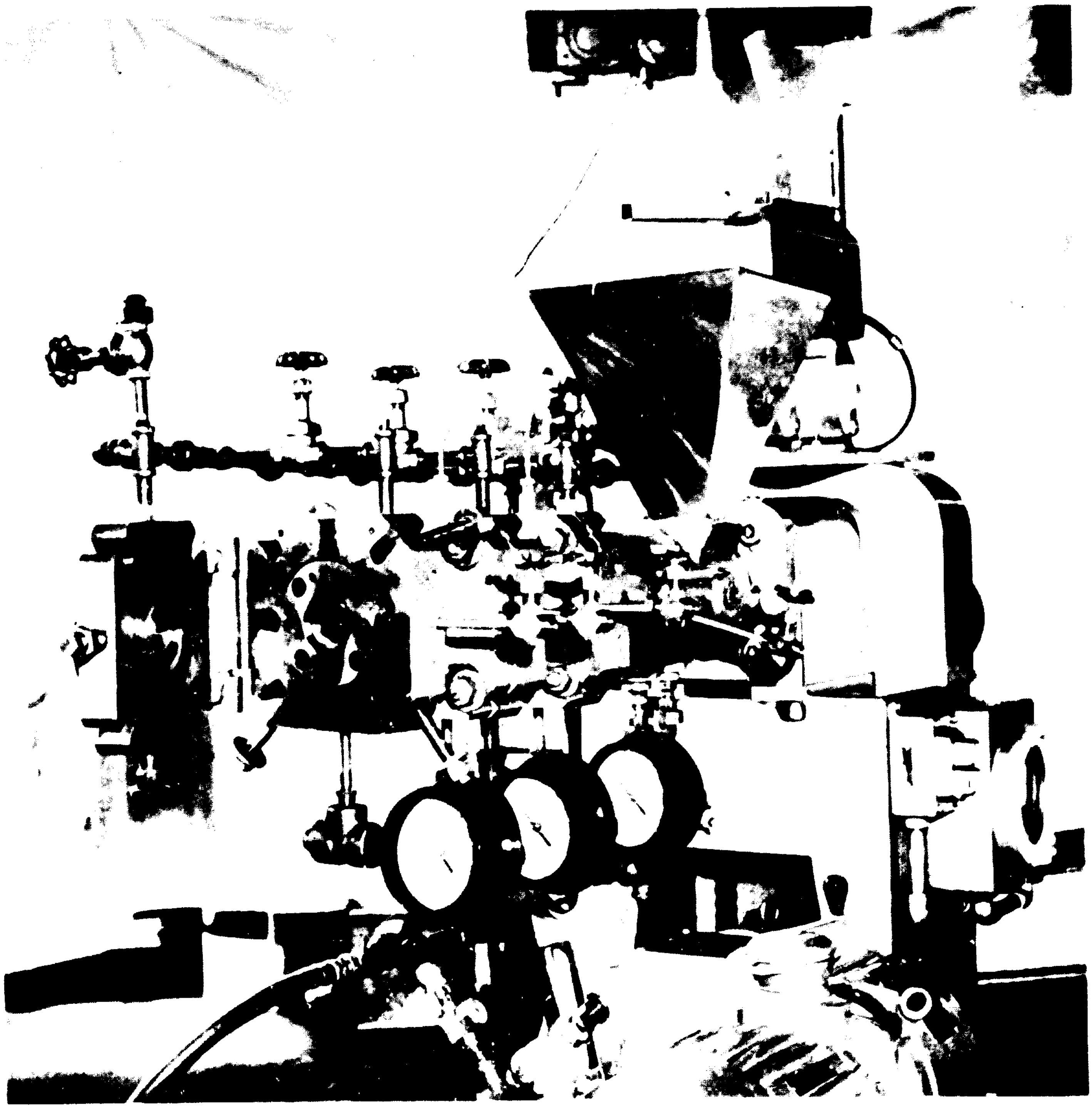


Fig. 3 Extruder-cooker used in the pilot plant of the Northern Regional Research Laboratory to process soyabeans.

Fig. 4

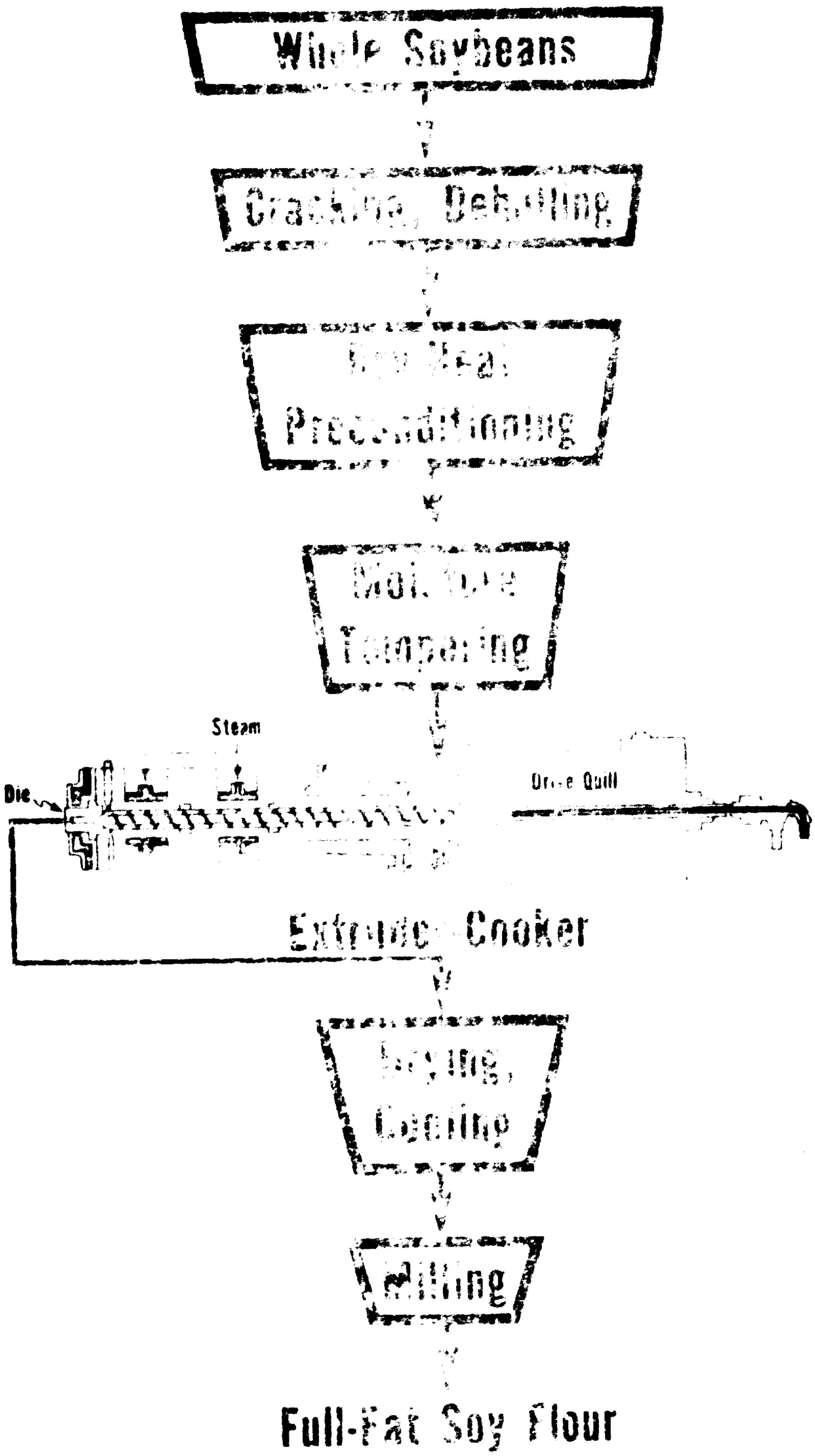
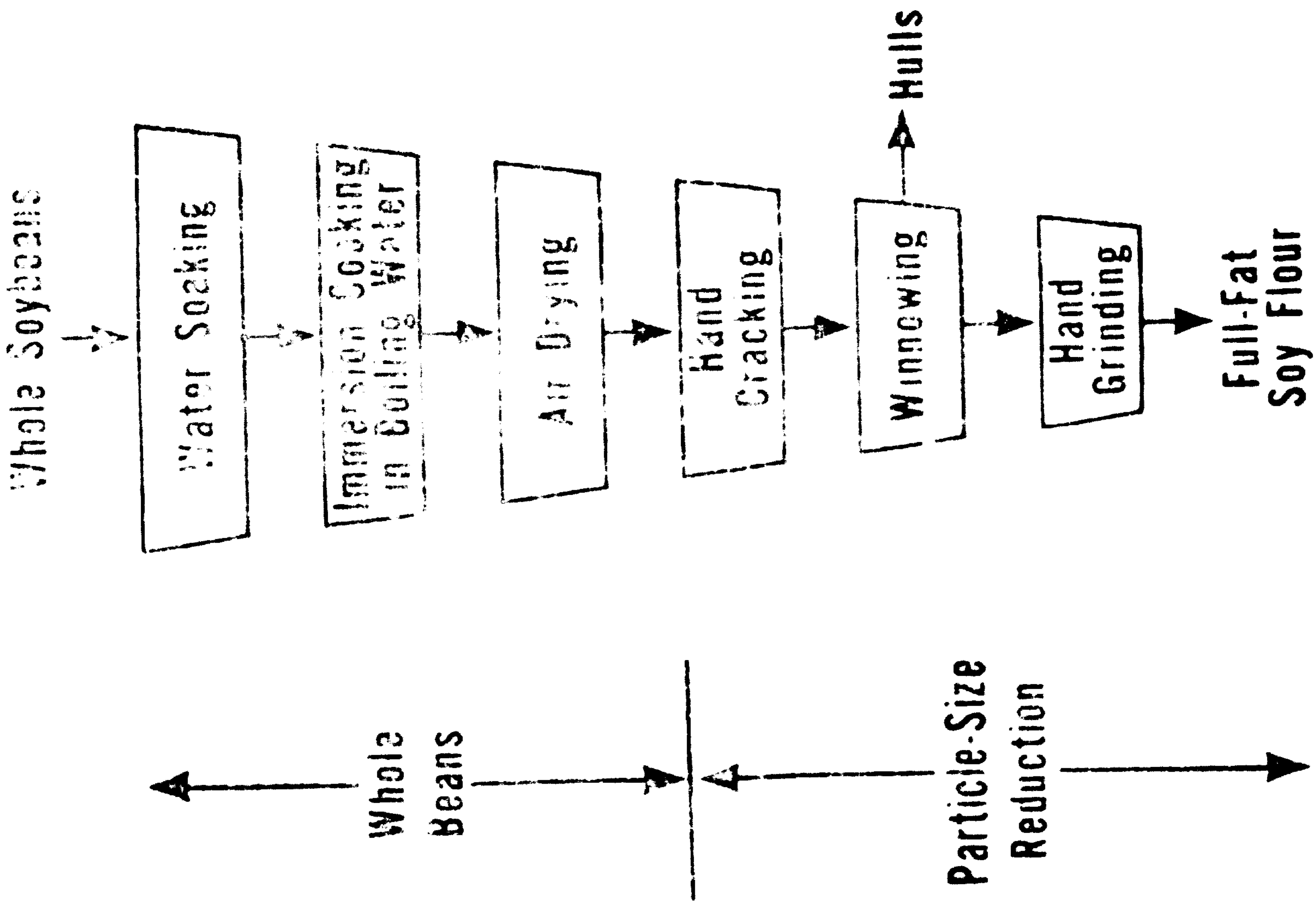
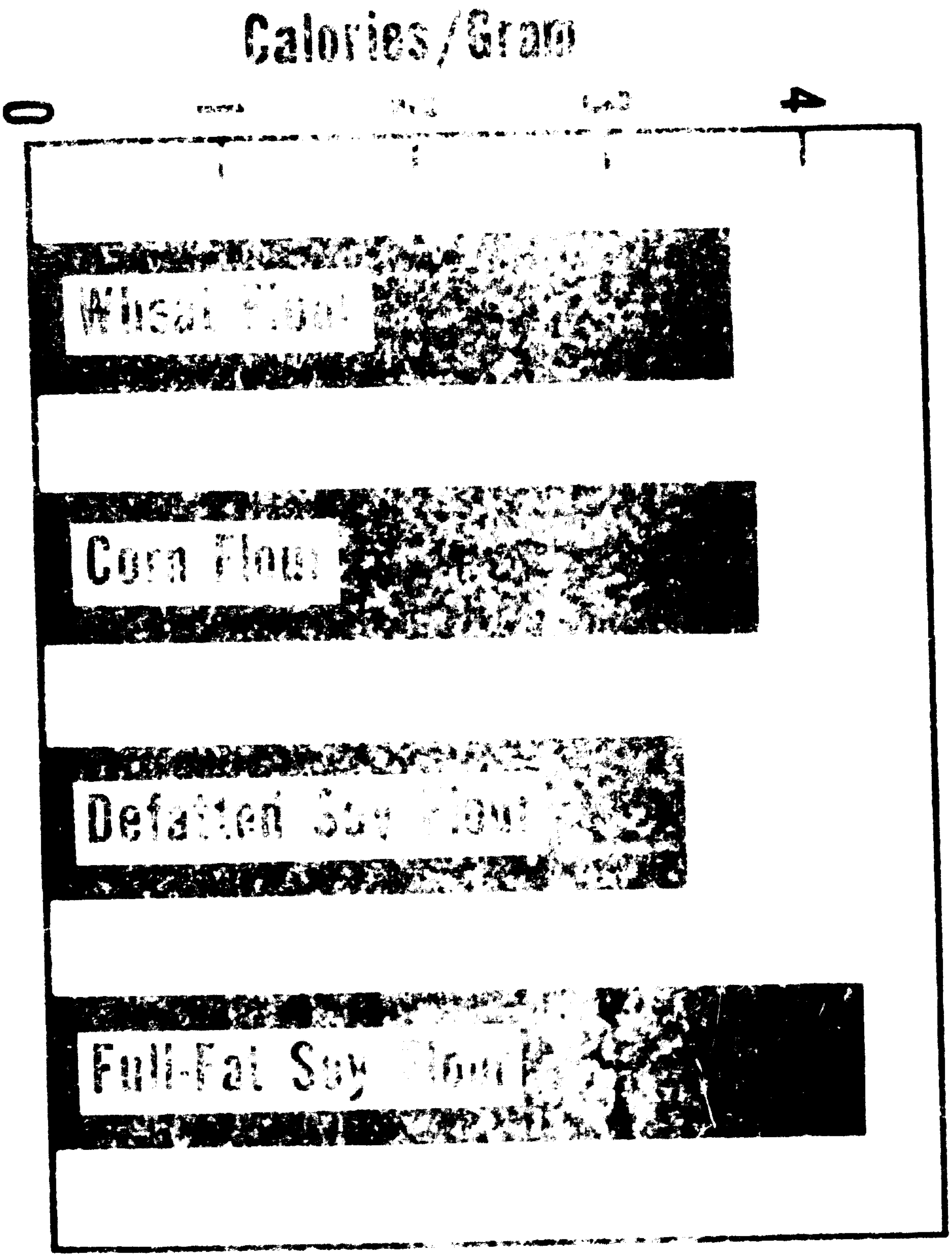
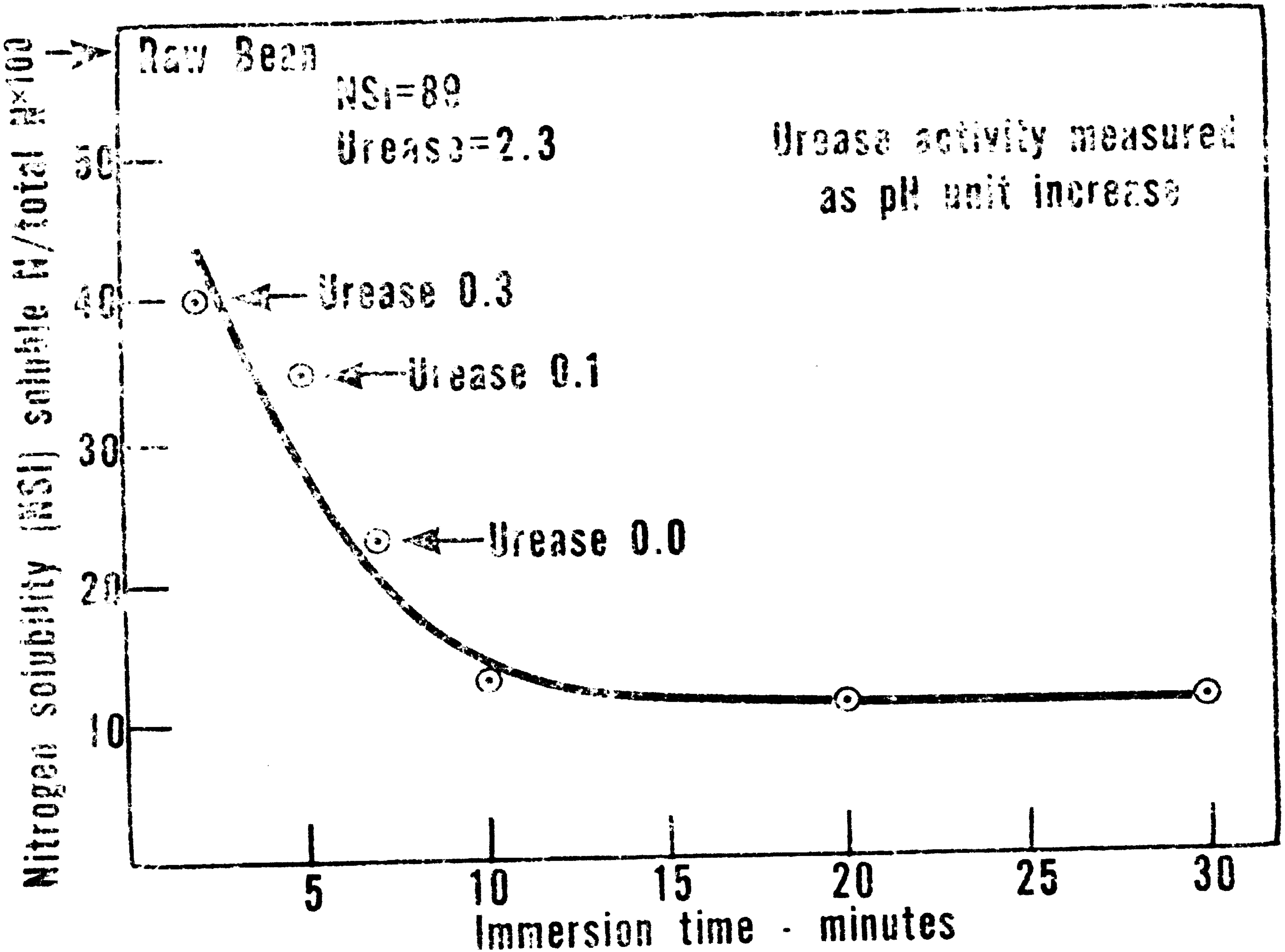
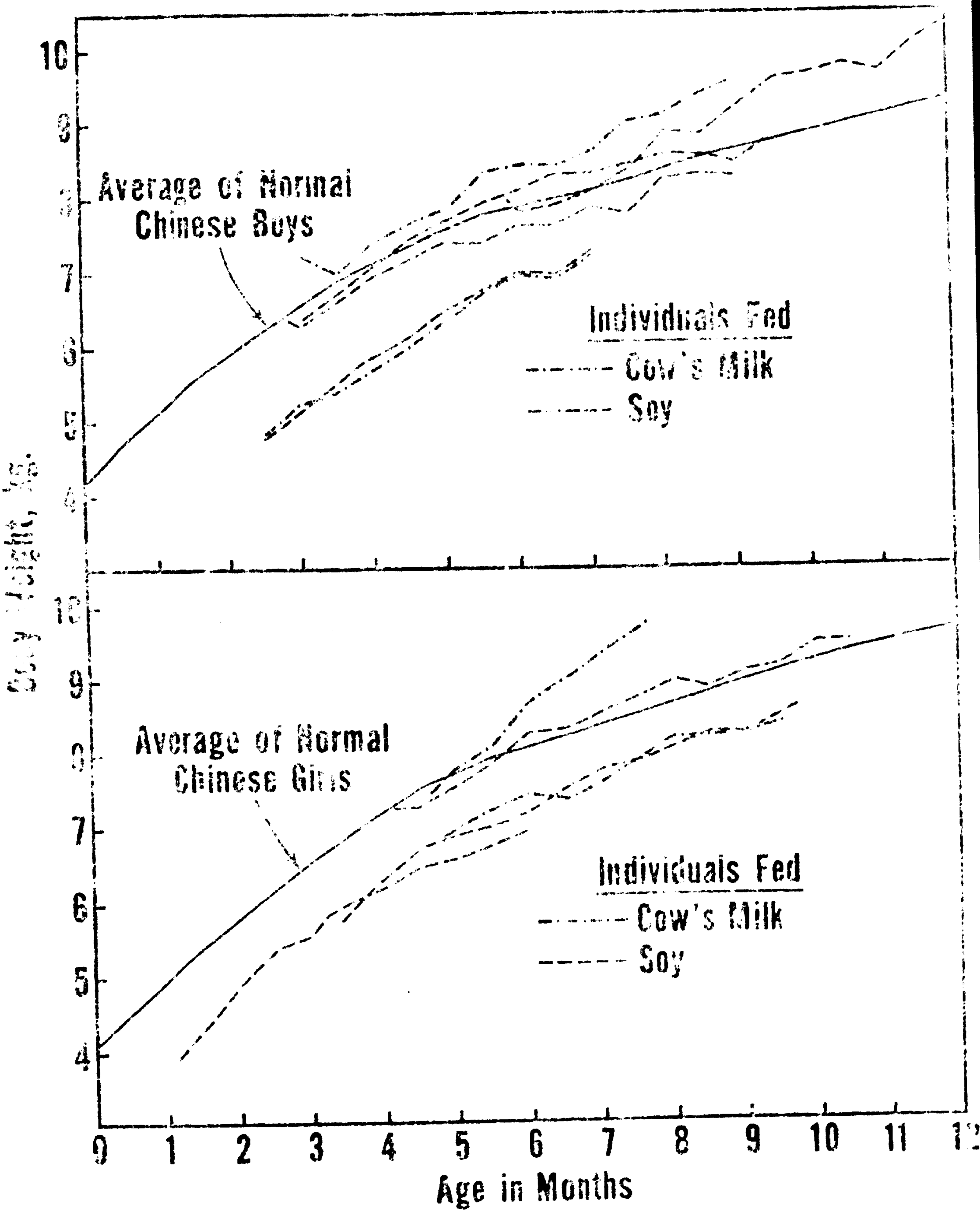

Whole Soybeans
Cracking, Dehulling
Preconditioning
Tempering
Steam
Die
Drive Quill
Extruder Cooker
Milling
Full-Fat Soy Flour

Fig. 5   Whole bean process for making full-fat soy flour.

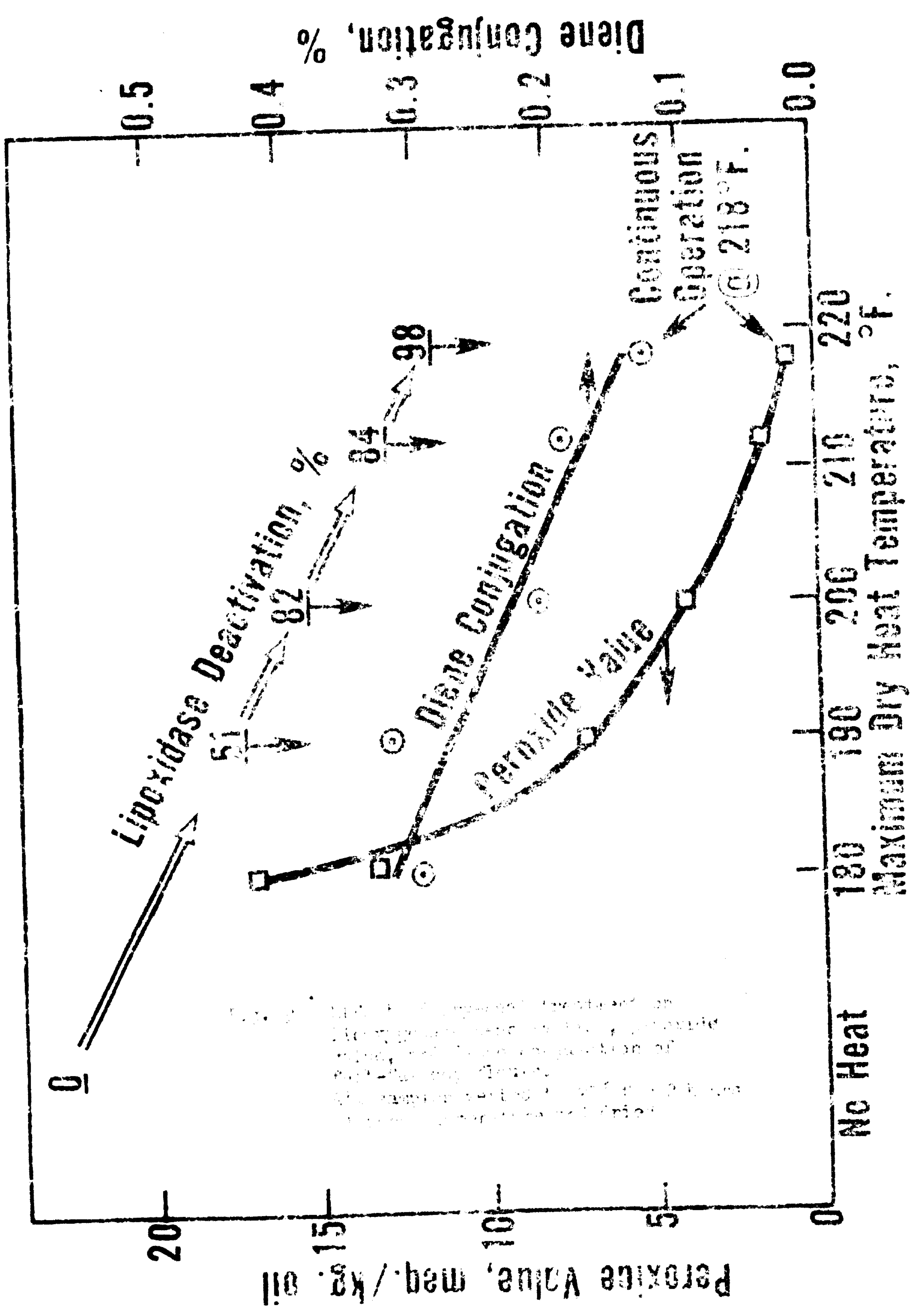



Calories / Gram
0
4
Wheat Flour
Corn Flour
Defatted Soy Flour
Full-Fat Soy Flour


Nitrogen solubility (NSI) soluble N/total N×100
50
40
30
20
10
Raw Bean
NSI=89
Urease=2.3
Urease activity measured
as pH unit increase
Urease 0.3
Urease 0.1
Urease 0.0
5
10
15
20
25
30
Immersion time - minutes



Average of Normal Chinese Boys
Individuals Fed
Cow's Milk
Soy
Average of Normal
Individuals Fed
Cow's Milk
Soy
Age in Months


Diene Conjugation, %
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0.4
0.3
0.2
0.1
0.0
Lipoxidase Deactivation, %
0
51
82
84
98
Diene Conjugation
Peroxide Value
Continuous Operation @ 218°F.
No Heat
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190
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210
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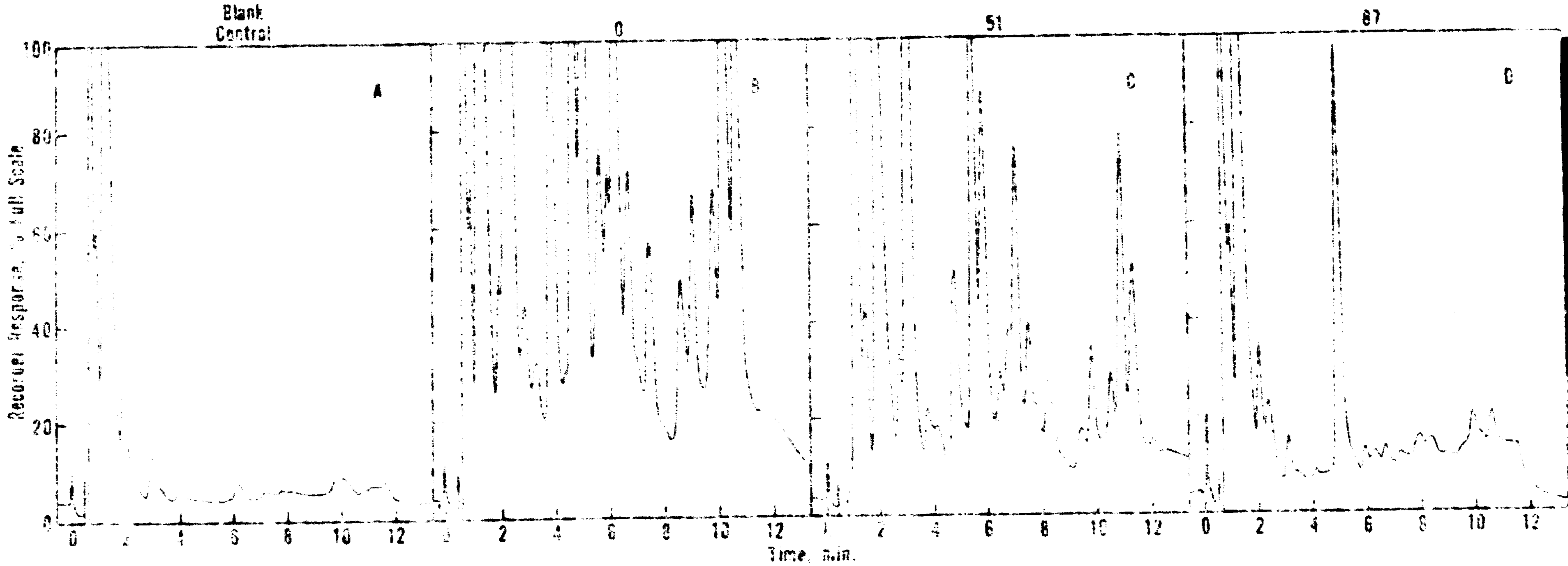
Maximum Dry Heat Temperature, °F.
Peroxide Value, meq./kg. oil
20
15
10
5
0



(A) Blank control

(B) No heat treatment, moistened. P.V. = 19.9

(C) Dry heat treated at 190°F, moistened. P.V. = 7.0

(D) Dry heat treated at 212°F, moistened. P.V. = 6.6

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