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ANNUAL REPORT

EVALUATION OF LOW-COST EXTRUSION COOKERS FOR USE IN LDC'S

Departments of Agricultural and Chemical Engineering
and Food Science and Nutrition
Colorado State University
Fort Collins, Colorado 80523

July, 1978

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Evaluation of Low-cost Extrusion Cookers for Use in LDC's

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ANNUAL REPORT

Evaluation of Low-cost Extrusion Cookers for Use in LDC's

1.0 INTRODUCTION

1.1 Background

Lack of a well balanced and nutritious diet is a problem that exists in many parts of the world. The use of legumes in combination with cereal grains has been one method of supplementing diets. It is necessary to cook the legumes in order to denature their naturally occurring antigrowth factors and enzymes. These cooked combinations can be used as food fortifiers, weaning foods, new food items, etc.

The USDA[1] initially evaluated the possibility of using low-cost extrusion cookers (LEC's) as a means of cooking cereal/legume combinations for supplementing the diets of LDC's (less developed countries). The extruder cookers that are in consideration for use in LDC's have been developed in the United States primarily for preparing feed rations for livestock and specifically to cook soybeans. In order to understand the operating possibilities of these extruders, USDA contracted the Agricultural and Chemical Engineering and Food Science and Nutrition Departments at Colorado State University to study these extruders and determine their operating parameters and characteristics and their utility in producing nutritious foods. This report represents the second annual report summarizing the results of the testing, evaluation

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[1] P. R. Crowley, "Evaluation of a Low-cost Extrusion Cooker for use in Less Developed Countries." Report to TA/N, AID, Washington, D. C., 1973.

and demonstration program on LEC's and a related roasting technology. The first annual report, published in April 1977, is available through CSU.

In order for extrusion cookers to be effectively applied to the food and nutrition problems of the LDC's, they must have the following characteristics.

1. Low cost - processing system cost less than $82,700/metric ton/hr capacity. To achieve these costs the extruder needs to cost less than $22,000/metric ton/hr capacity.
2. Moderate production rate - Production rate ranging between 225 and 900 kg/hr.
3. Simple operation - Requires little sophisticated technical capability to operate.
4. Minimal auxiliary equipment - To the greatest possible extent the system should not require auxiliary boilers, dryers or pre- or post-process conditioning equipment that will increase cost and can lead to production contamination.
5. Versatile - Process should handle a wide variety of cereals in combination with protein-rich legumes or oil seeds.
6. Maintenance - System should be easily maintained and should utilize locally available parts and equipment to the greatest possible extent.
7. Sanitary - Equipment must be cleanable and suitable for human food products.

Work has been under way at Colorado State University since October 1974 to evaluate low-cost extrusion cookers. To date, the following extruders have been examined extensively:

1. Brady Crop Cooker
   Koehring Farm Division
   P. O. Box 1279
   Appleton, Wisconsin 54911

2. Insta-Pro Extruder (#500)
   Triple "F," Inc.
   Urbandale, Iowa 50322

These two extrusion machines meet the criteria listed above. A multifaceted testing, evaluation and operational program has been undertaken to determine their operating parameters and the extent that they can be used to extrude cereal grains with or without the presence of oil seed or legumes to produce nutritious food for LDC's.

1.2 Objectives

The objectives of the testing and evaluation program at CSU are as follows:

1. Set up a test facility to determine the capabilities and limitations of LEC's.
2. Evaluate the nutritional and physical characteristics of extruded materials.
3. Develop nutritional specifications of new products.
4. Provide technical backstopping for existing test programs and others interested in extrusion.
5. Assist in the application and implementation of LEC technology.
6. Evaluate alternate low-cost technologies such as roasting.

2.0 EXTRUDED PRODUCTS EVALUATION

2.1 Cottonseed Blends

Cottonseed protein is the second largest plant protein source, after soybeans. Its relative availability in many LDC's makes it a

valuable commodity for food fortification, or to use as a protein source in conjunction with cereals. The presence of a toxic compound, gossypol, has made cottonseed protein utilization difficult for many years. Although gossypol-free cottonseed varieties have been developed, production of these varieties has been rather low, largely due to findings that oil content in cottonseed increases with gossypol. The economic importance of cottonseed oil means glandless cottonseed production has been only in the background. In the past few years, however, some processing methods have been found to be effective in binding gossypol to below-toxic levels.

Two LEC's, the Brady #206 Crop Cooker and Insta-Pro Model 500 extruder, have been very effective in deactivating trypsin inhibitor and heama glutens in soybeans. Following the success in this aspect and production of high quality CSB-like blends, these machines have been evaluated with the following objectives for cottonseed blends.

1. Determine the LEC's capability in processing cottonseed/cereal blends to make nutritious blended foods.
2. Determine the ingredient composition and the processing required to make CSB-like blends using cottonseed.
3. Determine the effect of processing on the deactivation of gossypol.

2.1.1 Design of Experiments for Operational Variables

The experimental work used to define operating parameters of extrusion equipment and products included the following variables.

Operational Variables--

1. Processing temperature
2. Cone/race clearance or steam lock combinations

Formulation Variables--

1. Cottonseed: glandless cottonseed; glanded cottonseed
2. Cereals: whole corn; whole sorghum

The effects of these independent variables on:

1. Power/energy input
2. Product characteristics - physical characteristics: viscosity, consistency, WAI, WSI, bulk density, NSI, storage properties; nutritional properties: gossypol deactivation, proximate analysis and PER.

2 1.2 Operating Variables and Formulations

Four combinations and three blends of each combination were selected for extrusion. Each blend was processed at three extrusion temperatures where possible. The selection of these blends was based on proximate analysis of the raw material and the intended goal of providing 15-20% protein in the extruded products. Processing temperatures were selected based on previous experience with the machines.

Operational data are summarized in Table 1. Mixtures of 30% and 20% glandless or glanded cottonseed with corn extruded easily through both extruders. No water addition was required for the Brady Crop Cooker. Up to 6.6% water was added to maintain a temperature of 138°C with 80% corn and 20% glandless cottonseed on the Insta-Pro extruder. The extrusion of 40% glandless or glanded cottonseed/corn mixtures, however, was possible at 150°C for glandless and 160°C for glanded cottonseed mixtures. High back pressures resulted when the 60/40 corn/glandless cottonseed blend was extruded at 160°C and with the 60/40 corn/glanded cottonseed blend at 170°C. No definite reason can be

Table 1. Extrusion conditions for cottonseed (glanded and glandless) blends with corn or sorghum.

Sample description	Extruder	Feed auger setting	Orifice clearance mm	Water added % (WB)	Throughput kg/hr	Processing temp., °C	Power consumption kW	Specific energy kWh/kg
60% corn /40% glandless cottonseed	Brady	2.0	1.42	0	216	152	20.6	0.095
70% corn /30% glandless cottonseed	Brady	2.0	1.42	0	292	150	28.5	0.097
70% corn /30% glandless cottonseed	Brady	2.0	1.27	0	294	163	32.8	0.112
70% corn /30% glandless cottonseed	Brady	2.0	1.02	0	312	171	38.7	0.124
80% corn /20% glandless cottonseed	Brady	2.0	2.03	0	258	151	25.9	0.100
80% corn /20% glandless cottonseed	Brady	2.0	1.52	0	246	160	27.8	0.113
80% corn /20% glandless cottonseed	Brady	2.0	1.78	0	252	171	32.6	0.129
60% corn /40% glanded cottonseed	Brady	2.0	1.52	0	228	149	19.4	0.085
60% corn /40% glanded cottonseed	Brady	2.0	1.27	0	234	163	25.3	0.108
70% corn /30% glanded cottonseed	Brady	2.0	1.52	0	300	149	27.5	0.092
70% corn /30% glanded cottonseed	Brady	2.0	1.08	0	288	163	31.7	0.110
70% corn /30% glanded cottonseed	Brady	2.0	1.02	0	270	169	32.4	0.120
80% corn /20% glanded cottonseed	Brady	2.0	1.52	0	288	151	28.1	0.098
80% corn /20% glanded cottonseed	Brady	2.0	1.52	0	276	163	31.6	0.114
80% corn /20% glanded cottonseed	Brady	2.0	1.40	0	270	171	35.7	0.132
60% sorghum/40% glandless cottonseed	Brady	2.0	0.57	0	243	149	21.6	0.089
60% sorghum/40% glandless cottonseed	Brady	2.0	0.56	0	234	161	22.7	0.097
60% sorghum/40% glandless cottonseed	Brady	2.0	0.36	0	252	170	28.6	0.113
70% sorghum/30% glandless cottonseed	Brady	2.0	0.95	0	255	148	24.0	0.094
70% sorghum/30% glandless cottonseed	Brady	2.0	0.76	0	252	163	27.5	0.109
70% sorghum/30% glandless cottonseed	Brady	2.0	0.44	0	244	170	28.7	0.118
80% sorghum/20% glandless cottonseed	Brady	2.0	1.02	0	234	148	22.4	0.096
80% sorghum/20% glandless cottonseed	Brady	2.0	0.76	0	240	163	28.5	0.119
80% sorghum/20% glandless cottonseed	Brady	2.0	0.51	3.5	276	171	36.2	0.131
60% sorghum/40% glanded cottonseed	Brady	2.0	1.02	0	240	149	23.6	0.098
60% sorghum/40% glanded cottonseed	Brady	2.0	0.64	0	240	163	25.3	0.105
60% sorghum/40% glanded cottonseed	Brady	2.0	0.51	0	243	170	26.9	0.111
70% sorghum/30% glanded cottonseed	Brady	2.0	1.02	0	255	149	25.8	0.101
70% sorghum/30% glanded cottonseed	Brady	2.0	0.61	0	242	163	27.2	0.113
70% sorghum/30% glanded cottonseed	Brady	2.0	1.27	0.5	294	171	35.9	0.125
80% sorghum/20% glanded cottonseed	Brady	2.0	1.02	0	243	149	26.3	0.108
80% sorghum/20% glanded cottonseed	Brady	2.0	0.085	0	240	163	29.3	0.122
80% sorghum/20% glanded cottonseed	Brady	2.0	0.68	3.8	255	171	33.0	0.130

Table 1. Extrusion conditions for cottonseed (glanded and glandless) blends with corn or sorghum (continued).

Sample description	Extruder	Steam locks	Die size mm	Water added % (WB)	Throughput kg/hr	Processing temp., °C	Power consumption kW	Specific energy kWh/kg
60% corn /40% glandless cottonseed	Insta-Pro	10- 8-5	8	0	168	135	9.05	0.054
60% corn /40% glandless cottonseed	Insta-Pro	10- 8-5	8	0	192	147	11.2	0.058
70% corn /30% glandless cottonseed	Insta-Pro	10- 8-5	8	0.8	150	138	10.2	0.068
70% corn /30% glandless cottonseed	Insta-Pro	10- 8-5	8	0	144	149	11.3	0.079
80% corn /20% glandless cottonseed	Insta-Pro	10-10-8-8	5*	6.6	162	138	11.6	0.072
80% corn /20% glandless cottonseed	Insta-Pro	10-10-8-8	5*	4.2	150	151	15.6	0.104
60% corn /40% glanded cottonseed	Insta-Pro	10- 8-5	8	0	198	138	13.0	0.066
60% corn /40% glanded cottonseed	Insta-Pro	10- 8-5	8	0	168	149	11.1	0.066
70% corn /30% glanded cottonseed	Insta-Pro	10- 8-5	8	0	174	138	11.2	0.064
70% corn /30% glanded cottonseed	Insta-Pro	10- 8-5	8	0	162	143	14.4	0.088
80% corn /20% glanded cottonseed	Insta-Pro	10-10-8-8	5*	4.7	174	141	13.7	0.079
80% corn /20% glanded cottonseed	Insta-Pro	10-10-8-8	5*	3.8	144	146	13.7	0.095
60% sorghum/40% glandless cottonseed	Insta-Pro	10- 8-5	8	0	168	141	8.0	0.048
60% sorghum/40% glandless cottonseed	Insta-Pro	10- 8-5	8	0	162	146	11.2	0.069
70% sorghum/30% glandless cottonseed	Insta-Pro	10- 8-5	8	0	168	141	8.9	0.053
70% sorghum/30% glandless cottonseed	Insta-Pro	10- 8-5	8	0	168	149	11.2	0.067
80% sorghum/20% glandless cottonseed	Insta-Pro	10-10-8-8	5*	1.5	198	135	14.7	0.074
80% sorghum/20% glandless cottonseed	Insta-Pro	10-10-8-8	5*	0	---	---	---	---
60% sorghum/40% glanded cottonseed	Insta-Pro	10- 8-5	8	0	192	138	12.1	0.063
60% sorghum/40% glanded cottonseed	Insta-Pro	10- 8-5	8	0	174	149	13.1	0.076
70% sorghum/30% glanded cottonseed	Insta-Pro	10- 8-5	8	0	174	138	12.6	0.073
70% sorghum/30% glanded cottonseed	Insta-Pro	10- 8-5	8	0	168	147	13.2	0.079
80% sorghum/20% glanded cottonseed	Insta-Pro	10-10-8-8	5*	5.6	192	141	14.8	0.077
80% sorghum/20% glanded cottonseed	Insta-Pro	10-10-8-8	5*	5.0	180	149	14.8	0.082

*Multiple orifice (6) die, each orifice having a 5 mm diameter.

determined for this anomaly, but the low feed rates employed could be a probable cause.

Sorghum blends extruded easily through the range of temperatures. However, 3.5% to 3.8% water was added to the 80/20 mixtures for the 171°C processing temperature on the Brady with both glandless and glanded cottonseed blends. For the 171°C processing temperature, 0.5% water was added to the 70/30 sorghum/glanded cottonseed blend. Up to 5% water was required to maintain the required temperatures in the Insta-Pro.

No specific differences between operational characteristics of glanded cottonseed blends and glandless cottonseed blends were observed. It appears that gossypol content in glanded cottonseed does not affect the extruder operation with cottonseed blends and cereals.

The 20% and 30% cottonseed blends were well expanded. Grinding the output of the extruders through a Fitz hammer mill showed that the extrudates could be easily ground using U.S. screen No. 20 (0.85 mm nominal sieve opening) without serious clogging of the screen. Grinding of 40% cottonseed blends, however, was difficult even when U.S. screen No. 10 (2 mm nominal sieve opening) was used. The screens were co consistently clogged due to the high oil content.

For both glanded and glandless cottonseed mixtures, specific energies measured ranged from 0.085 to 0.13 kWh/kg with the Brady Crop Cooker and 0.05 to 0.08 kWh/kg with the Insta-Pro extruder. The water addition to the Insta-Pro extruder which reduced the extrusion temperature contributed to the lower specific energy inputs. Further, the design of these extruders achieved sufficient processing at much lower temperatures than with the Brady Crop Cooker. With both extruders, specific energy increased with higher processing temperature. A

slight increase in specific energy with decrease in cottonseed or increase in cereal composition was noticeable.

Reaching an equilibrium processing temperature was easier and faster with the Brady Crop Cooker. This was possibly due to the operational controls on the machine that allowed adjustments during operation. The controlling factor is the cone-race clearance. The Insta-Pro, however, achieves processing temperatures by controlling the feed rates, moisture content and steam lock configuration. Both of these are more difficult to vary independently and it takes longer to equilibrate at the required temperatures. Further observations showed that 70% corn and 30% glandless cottonseed can easily be processed on both extruders through the entire range of temperatures, 150-170°C. However, 70/30 sorghum/cottonseed mixtures may require extensive water addition at temperatures above 170°C. At temperatures to 160°C, 80/20 cereal/cottonseed mixtures are easily extruded, but higher energy inputs are required at 170°C and extensive water addition may be needed. Although the 60/40 mixtures can be extruded at 150°C and 160°C, these blends caused problems at 170°C in some cases, where reductions in feed rate were required. With the exception of sorghum/glanded cottonseed, these mixtures could only be processed at 170°C.

The Insta-Pro extruder showed easy operation at temperatures between 135°C and 150°C. Achievement of temperatures above this range was cumbersome and time consuming and often difficult to maintain. In the case of the higher oil content mixtures, the maintaining of 150°C may even be more difficult.

2.1.3 Functional Properties

An extensive series of experiments was carried out on cereal/cottonseed mixtures extruded on both the Brady and Insta-Pro extruders. Corn, sorghum and wheat were used in combination with both glanded and glandless dehulled cottonseeds. The functional properties and gossypol levels are summarized in Tables 2-8.

The effects of extrusion, using a Brady extruder, on gossypol levels in full-fat cottonseed flour and several cottonseed/cereal blends are listed in Table 2. Extrusion reduced free gossypol 70% in cottonseed flour, but the final level of 0.209% is still considerably higher than the maximum of 0.06% specified by the PAG for human food use. The free gossypol levels of the corn or sorghum blends with glanded cottonseed were all below 0.06%. However, since cottonseed represents only 30% of the mixture, the free gossypol level should be below 0.02% in these blends. It is known that iron salts are able to bind free gossypol. It is possible that addition of an iron salt, in equimolar amounts with gossypol, prior to extrusion will result in acceptable levels of free gossypol in the extruded product. This will be examined in a subsequent experiment.

In Table 3, proximate analysis data, nitrogen solubility index (NSI), free gossypol and water absorption data are listed for an extensive series of cereal blends with glanded or glandless cottonseed. An advantage cottonseed has over soy is the increased fat content in the blend. For example, mixtures of cottonseed with corn (70/30) contain 13% fat compared to about 8% in a similar blend made with soy.

Free gossypol levels in these particular blends were generally at or below 0.02%. The NSI's for the blends ranged from 6-9% and did not

Table 2. Free and total gossypol content of cottonseed and cottonseed blends extruded on the Brady extruder.

FSN Code #	Description	Total[1] Gossypol %	Free[2] Gossypol %
2-15-13	Glanded cottonseed, extruded, 138°C	0.831	0.209
2-15-14	Glanded cottonseed, not extruded	0.863	0.653
2-15-15	Glandless cottonseed, not extruded	0.088	0.032
2-13- 1	70% corn /30% glanded cottonseed 141°C	0.258	0.053
2-13- 2	70% corn /30% glanded cottonseed 160°C	0.264	0.034
2-13- 3	70% corn /30% glanded cottonseed 169°C	0.262	0.024
2-13- 4	70% sorghum/30% glandless cottonseed 169°C	0.005	0.004
2-13- 5	70% sorghum/30% glandless cottonseed 163°C	0.003	0.003
2-13- 6	70% sorghum/30% glandless cottonseed 142°C	0.001[3]	0.007[3]

[1]Analyzed according to AOCS Official Method Ba8-55 (corrected 1964, reapproved 1973).

[2]Analyzed according to AOCS Official Method Ba7-58 (revised 1968, reapproved 1973).

[3]Here, total gossypol was determined to be less than free gossypol, which indicates that, due to the spectrophotometer's slight drift from zero absorbance during readings and the very, very small amounts of gossypol present, these amounts should be designated as "negligible." These readings would seem to be slightly out of the range of the spectrophotometer, and should perhaps be defined as "less than 0.01%."

Table 3. Cereal/Cottonseed samples extruded on the Brady extruder.

FSK Code #	Description	Extrusion temp., °C	% Moisture	% Fat	% Total Nitrogen	% Water Sol. N	NSI	% Free Gossypol	% Water Absorption
2-33-12	60% corn /40% glandless cottonseed	152	3.68	18.08	3.56				
2-33-11	60% corn /40% glandless cottonseed	152	3.69	17.82	3.46				
2-33-18	60% corn /40% glandless cottonseed	152	3.54	17.34	3.07				
2-33-13	70% corn /30% glandless cottonseed	150	4.03						
2-33-21	70% corn /30% glandless cottonseed	150	4.19						
2-33-17	70% corn /30% glandless cottonseed	150	3.98						
2-33-14	70% corn /30% glandless cottonseed	163	3.80	14.26	3.19				
2-33-15	70% corn /30% glandless cottonseed	163	3.73	14.20	3.20				
2-33-20	70% corn /30% glandless cottonseed	163	4.11	13.40	2.86				
2-33-19	70% corn /30% glandless cottonseed	170	3.31						
2-33-10	70% corn /30% glandless cottonseed	170	2.99						
2-33-16	70% corn /30% glandless cottonseed	170	3.06						
2-33- 9	80% corn /20% glandless cottonseed	159	4.24	11.24	2.68				
2-33- 4	80% corn /20% glandless cottonseed	159	3.96	10.85	2.59				
2-33- 6	80% corn /20% glandless cottonseed	159	3.96	9.31	2.33				
2-33- 2	80% corn /20% glandless cottonseed	150	4.34						
2-33- 5	80% corn /20% glandless cottonseed	150	4.29						
2-33- 7	80% corn /20% glandless cottonseed	150	4.34						
2-33- 8	80% corn /20% glandless cottonseed	171	3.37						
2-33- 1	80% corn /20% glandless cottonseed	171	3.61						
2-33- 3	80% corn /20% glandless cottonseed	171	3.21						
2-35-10	60% corn /40% glanded cottonseed	149	3.68		3.51	0.31	8.83		
2-35- 3	60% corn /40% glanded cottonseed	149	3.94		3.34	0.28	8.38		168
2-35- 7	60% corn /40% glanded cottonseed	149	3.35		3.04	0.18	5.92		
2-35- 5	60% corn /40% glanded cottonseed	163	3.03	16.10	3.63			0.0239	
2-35-17	60% corn /40% glanded cottonseed	163	3.38	15.82	3.30			0.0217	264
2-35-24	60% corn /40% glanded cottonseed	163	2.85	15.18	3.11			0.0180	
2-35-21	70% corn /30% glanded cottonseed	149	3.55		2.99	0.24	8.03		
2-35- 4	70% corn /30% glanded cottonseed	149	4.05		2.81	0.23	8.19		
2-35- 6	70% corn /30% glanded cottonseed	149	3.66		2.53	0.22	8.70		
2-35-22	70% corn /30% glanded cottonseed	163	3.58	12.98	3.09	0.20	6.47	0.0175	293
2-35-16	70% corn /30% glanded cottonseed	163	3.78	12.95	2.89	0.17	5.88	0.0162	291
2-35-13	70% corn /30% glanded cottonseed	163	3.58	12.26	2.67	0.20	7.49	0.0133	229
2-35-23	70% corn /30% glanded cottonseed	169	3.20		3.38	0.23	6.80	0.0186	
2-35- 2	70% corn /30% glanded cottonseed	169	3.70		2.93	0.20	6.83	0.0160	254
2-35- 8	70% corn /30% glanded cottonseed	169	3.19		2.88	0.19	6.60	0.0143	

Table 3. Cereal/Cottonseed samples extruded on the Brady extruder (continued).

FSN Code #	Description	Extrusion temp., °C	% Moisture	% Fat	% Total Nitrogen	% Water Sol. N	NSI	% Free Gossypol	% Water Absorption
2-35-12	80% corn /20% glanded cottonseed	171	3.21					0.0086	
2-35-19	80% corn /20% glanded cottonseed	171	3.45					0.0071	
2-35-11	80% corn /20% glanded cottonseed	171	3.14					0.0087	
2-35-14	80% corn /20% glanded cottonseed	160	3.91	9.83	2.73			0.0115	
2-35- 9	80% corn /20% glanded cottonseed	160	3.72	9.06	2.45			0.0093	297
2-35- 1	80% corn /20% glanded cottonseed	160	3.54	8.63	2.27			0.0071	
2-35-18	80% corn /20% glanded cottonseed	150	4.06		2.40	0.17	7.08		
2-35-15	80% corn /20% glanded cottonseed	150	4.15		2.30	0.20	8.70		
2-35-20	80% corn /20% glanded cottonseed	150	3.64		2.27	0.17	7.49		
2-31-35	60% wheat /40% glandless cottonseed	149	4.26	17.12	4.52				
2-31-19	60% wheat /40% glandless cottonseed	149	3.15	17.07	4.21				
2-31-16	60% wheat /40% glandless cottonseed	149	2.81	15.75	4.11				
2-31- 7	70% wheat /30% glandless cottonseed	152	2.52						
2-31- 8	70% wheat /30% glandless cottonseed	152	3.55						
2-31- 9	70% wheat /30% glandless cottonseed	152	3.59						
2-31- 6	70% wheat /30% glandless cottonseed	159	3.51	12.79	3.74				
2-31- 5	70% wheat /30% glandless cottonseed	159	3.22	12.90	3.76				
2-31- 4	70% wheat /30% glandless cottonseed	159	3.18	12.[illegible]	3.67				
2-31-13	60% sorghum/40% glandless cottonseed	160	2.14	17.29	3.34				
2-31-34	60% sorghum/40% glandless cottonseed	160	3.66	17.71	3.61				
*	60% sorghum/40% glandless cottonseed	160							
2-31-10	60% sorghum/40% glandless cottonseed	170	2.36						
2-31-11	60% sorghum/40% glandless cottonseed	170	1.83						
2-31-12	60% sorghum/40% glandless cottonseed	170	2.43						
2-31- 2	60% sorghum/40% glandless cottonseed	149	2.53						
2-31- 3	60% sorghum/40% glandless cottonseed	149	2.63						
2-31- 1	60% sorghum/40% glandless cottonseed	149	2.79						
2-31-33	70% sorghum/30% glandless cottonseed	148	3.81						
2-31-30	70% sorghum/30% glandless cottonseed	148	3.93						
2-31-29	70% sorghum/30% glandless cottonseed	148	3.18						
2-31-32	70% sorghum/30% glandless cottonseed	163	3.23	14.28	2.95				
2-31-25	70% sorghum/30% glandless cottonseed	163	2.84	13.74	2.83				
2-31-26	70% sorghum/30% glandless cottonseed	163	2.35	13.08	2.83				
2-31-31	70% sorghum/30% glandless cottonseed	171	3.08						
2-31-28	70% sorghum/30% glandless cottonseed	171	2.33						
2-31-27	70% sorghum/30% glandless cottonseed	171	2.31						
2-31-14	80% sorghum/20% glandless cottonseed	149	3.49						
2-31-21	80% sorghum/20% glandless cottonseed	149	3.82						
2-31-15	80% sorghum/20% glandless cottonseed	149	3.71						

Table 3. Cereal/Cottonseed samples extruded on the Brady extruder (continued).

FSN Code #	Description	Extrusion temp., °C	% Moisture	% Fat	% Total Nitrogen	% Water Sol. N	NSI	% Free Gossypol	% Water Absorption
2-31-17	80% sorghum/20% glandless cottonseed	160	3.13	12.39	2.63				
2-31-18	80% sorghum/20% glandless cottonseed	160	3.42	11.10	2.52				
2-31-20	80% sorghum/20% glandless cottonseed	160	2.76	10.69	2.48				
2-31-23	80% sorghum/20% glandless cottonseed	170	3.12						
2-31-22	80% sorghum/20% glandless cottonseed	170	3.31						
2-31-24	80% sorghum/20% glandless cottonseed	170	2.96						
2-47- 1	60% sorghum/40% glanded cottonseed	Raw	5.85						
2-47-10	60% sorghum/40% glanded cottonseed	149	3.70						
2-47-25	60% sorghum/40% glanded cottonseed	149	2.99						144
2-47-29	60% sorghum/40% glanded cottonseed	149	2.74						
2-47-14	60% sorghum/40% glanded cottonseed	163	3.65	16.00	3.32	0.31	9.34	0.0210	
2-47-23	60% sorghum/40% glanded cottonseed	163	2.95	15.89	3.17	0.26	8.20	0.0223	164
2-47-15	60% sorghum/40% glanded cottonseed	163	3.70	14.63	3.16	0.25	7.91	0.0188	
2-47- 5	60% sorghum/40% glanded cottonseed	171	3.83						
2-47-24	60% sorghum/40% glanded cottonseed	171	2.52						216
2-47- 9	60% sorghum/40% glanded cottonseed	171	3.40						
2-47- 6	70% sorghum/30% glanded cottonseed	Raw	7.50						
2-47-22	70% sorghum/30% glanded cottonseed	149	2.68		3.03	0.27	8.91	0.0177	
2-47-17	70% sorghum/30% glanded cottonseed	149	4.18		2.76	0.24	8.70	0.0174	138
2-47-13	70% sorghum/30% glanded cottonseed	149	4.62		2.75	0.22	8.00	0.0164	
2-47-18	70% sorghum/30% glanded cottonseed	163	3.77	12.84	2.85	0.23	8.07	0.0120	205
2-47- 4	70% sorghum/30% glanded cottonseed	163	3.70	12.26	2.90	0.23	7.93	0.0119	210
2-47- 8	70% sorghum/30% glanded cottonseed	163	3.85	11.62	2.69	0.18	6.69	0.0085	166
2-47- 2	80% sorghum/20% glanded cottonseed	Raw	7.25						
2-47-21	80% sorghum/20% glanded cottonseed	149	3.66						
2-47-12	80% sorghum/20% glanded cottonseed	149	3.79						193
2-47- 3	80% sorghum/20% glanded cottonseed	149	4.52						
2-47-26	80% sorghum/20% glanded cottonseed	163	3.38	10.66	2.55	0.16	6.27	0.0102	
2-47-28	80% sorghum/20% glanded cottonseed	163	3.28	10.13	2.49	0.17	6.83	0.0096	215
2-47- 7	80% sorghum/20% glanded cottonseed	163	4.01	10.11	2.42	0.15	6.20	0.0079	
2-47-16	80% sorghum/20% glanded cottonseed	171	4.51						
2-47-19	80% sorghum/20% glanded cottonseed	171	3.57						279
2-47-30	80% sorghum/20% glanded cottonseed	171	4.04						
2-47-20	70% sorghum/30% glanded cottonseed	171	3.14		2.96	0.25	8.45	0.0139	
2-47-11	70% sorghum/30% glanded cottonseed	171	3.84		2.77	0.20	7.22	0.0117	236
2-47-27	70% sorghum/30% glanded cottonseed	171	2.45		2.76	0.20	7.25	0.0108	

* Not enough sample delivered to mix with vitamin and mineral premix.

Table 4. Uncooked viscosities of selected cereal/cottonseed samples extruded on the Brady extruder.

FSN Code #	Description	Extrusion temp., °C	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm
2-33-11	60% corn /40% glandless cottonseed	152	3,000	4-20	480	4-50	540	5-20	416	5-50
2-33-21	70% corn /30% glandless cottonseed	150	4,480	5-20	3,128	5-50	3,890	4-20	2,836	4-50
2-33-14	70% corn /30% glandless cottonseed	163	20,600	6-20	13,360	6-50	17,800	7-20	12,160	7-50
2-33-15	70% corn /30% glandless cottonseed	163	13,900	6-20	9,500	6-50	10,400	7-20	7,680	7-50
2-33-20	70% corn /30% glandless cottonseed	163	13,400	6-20	8,600	6-50	5,200	7-20	4,160	7-50
2-33-10	70% corn /30% glandless cottonseed	170	18,550	6-20	12,820	6-50	16,400	7-20	10,880	7-50
2-33- 5	80% corn /20% glandless cottonseed	150	4,650	6-20	3,360	6-50	12,400	7-20	10,880	7-50
2-35- 3	60% corn /40% glanded cottonseed	149	928	3-20	698	3-50	1,043	2-20	770	2-50
2-35-17	60% corn /40% glanded cottonseed	163	12,800	7-20	8,747	7-50	20,767	6-20	13,307	6-50
2-35-22	70% corn /30% glanded cottonseed	163	17,067	7-20	9,893	7-50	28,783	6-20	15,687	6-50
2-35-16	70% corn /30% glanded cottonseed	163	14,533	7-20	9,920	7-50	25,367	6-20	14,607	6-50
2-35-13	70% corn /30% glanded cottonseed	163	9,200	7-20	4,960	7-50	15,417	6-20	10,080	6-50
2-35- 2	70% corn /30% glanded cottonseed	169	29,800	7-20	21,947	7-50				
2-35- 9	80% corn /20% glanded cottonseed	160	26,200	7-20	16,747	7-50				
2-31-19	60% wheat /40% glandless cottonseed	149	208	3-50	339	2-20	261	2-50	246	2-100
2-31- 6	70% wheat /30% glandless cottonseed	159	1,403	4-20	1,195	4-50	1,585	3-20	1,312	3-50
2-31- 5	70% wheat /30% glandless cottonseed	159	1,538	3-20	1,211	3-50	1,657	4-20	1,372	4-50
2-31- 4	70% wheat /30% glandless cottonseed	159	983	4-20	852	4-50	1,038	3-20	814	3-50
2-31-34	60% sorghum/40% glandless cottonseed	160	126	5-20	186	5-50	197	3-20	164	3-50
2-31-25	70% sorghum/30% glandless cottonseed	163	1,160	3-50	1,733	3-20	1,013	4-100	1,273	4-50
2-31-18	80% sorghum/20% glandless cottonseed	160	4,433	6-50	9,000	6-20	3,120	7-50	4,000	7-20
2-47-25	60% sorghum/40% glanded cottonseed	149	55	3-20	62	3-50	60	4-20	48	4-50
2-47-23	60% sorghum/40% glanded cottonseed	163	560	3-20	388	3-50	460	4-20	348	4-50
2-47-24	60% sorghum/40% glanded cottonseed	171	2,450	3-20	1,684	3-50	2,060	4-20	1,512	4-50
2-47-17	70% sorghum/30% glanded cottonseed	149	175	3-20	138	3-50	150	4-20	174	4-50
2-47-18	70% sorghum/30% glanded cottonseed	163	1,430	3-20	1,058	3-50	1,590	4-20	1,140	4-50
2-47- 4	70% sorghum/30% glanded cottonseed	163	1,240	5-20	904	5-50	950	6-20	700	6-50
2-47- 8	70% sorghum/30% glanded cottonseed	163	1,345	3-20	966	3-50	1,080	4-20	780	4-50
2-47-12	80% sorghum/20% glanded cottonseed	149	1,150	3-20	838	3-50	1,050	4-20	732	4-50
2-47-28	80% sorghum/20% glanded cottonseed	163	2,930	4-20	2,112	4-50	3,000	5-20	2,104	5-50
2-47-19	80% sorghum/20% glanded cottonseed	171	24,650	6-20	15,060	6-50	14,400	7-20	9,040	7-50
2-47-11	70% sorghum/30% glanded cottonseed	171	10,860	5-20	7,120	5-50	11,150	6-20	7,160	6-50

Table 5. Cooked viscosities of selected cereal/cottonseed samples extruded on the Brady extruder.

FSN Code #	Description	Extrusion temp., °C	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm
2-33-11	60% corn /40% glandless cottonseed	152	1,600	5-20	944	5-50	1,750	4-20	1,024	4-50
2-33-21	70% corn /30% glandless cottonseed	150	1,440	5-20	920	5-50	1,730	4-20	960	4-50
2-33-14	70% corn /30% glandless cottonseed	163	1,120	5-20	696	5-50	1,220	4-20	732	4-50
2-33-15	70% corn /30% glandless cottonseed	163	1,460	5-20	856	5-50	1,620	4-20	920	4-50
2-33-20	70% corn /30% glandless cottonseed	163	1,500	5-20	928	5-50	1,620	4-20	964	4-50
2-33-10	70% corn /30% glandless cottonseed	170	340	5-20	240	5-50	370	4-20	260	4-50
2-33- 5	80% corn /20% glandless cottonseed	150	1,600	5-20	944	5-50	1,570	4-20	944	4-50
2-35- 3	60% corn /40% glanded cottonseed	149	2,055	3-20	1,214	3-50	2,150	4-20	1,228	4-50
2-35-17	60% corn /40% glanded cottonseed	163	1,765	3-20	1,014	3-50	1,840	4-20	1,048	4-50
2-35-22	70% corn /30% glanded cottonseed	163	1,600	3-20	944	3-50	1,640	4-20	992	4-50
2-35-16	70% corn /30% glanded cottonseed	163	1,925	3-20	1,122	3-50	1,930	4-20	1,168	4-50
2-35-13	70% corn /30% glanded cottonseed	163	1,485	3-20	934	3-50	2,410	4-20	644	4-50
2-35- 2	70% corn /30% glanded cottonseed	169	1,190	3-20	720	3-50	1,230	4-20	740	4-50
2-35- 9	80% corn /20% glanded cottonseed	160	654	3-50	985	3-20	1,012	2-20	675	2-50
2-31-19	60% wheat /40% glandless cottonseed	149	1,360	3-20	836	3-50	1,400	4-20	908	4-50
2-31- 6	70% wheat /30% glandless cottonseed	159	1,840	3-20	1,096	3-50	1,790	4-20	1,152	4-50
2-31- 5	70% wheat /30% glandless cottonseed	159	1,695	3-20	1,128	3-50	1,730	4-20	1,044	4-50
2-31- 4	70% wheat /30% glandless cottonseed	159	1,800	3-20	1,194	3-50	1,910	4-20	1,280	4-50
2-31-34	60% sorghum/40% glandless cottonseed	160	1,645	3-20	954	3-50	1,690	4-20	964	4-50
2-31-25	70% sorghum/30% glandless cottonseed	163	3,740	3-20	2,248	5-50	3,680	4-20	2,180	4-50
2-31-18	80% sorghum/20% glandless cottonseed	160	2,800	5-20	1,664	5-50	3,370	4-20	1,864	4-50
2-47-25	60% sorghum/40% glanded cottonseed	149	2,400	4-20	1,380	4-50	2,460	5-20	1,298	5-50
2-47-23	60% sorghum/40% glanded cottonseed	163	2,400	4-20	1,348	4-50	2,240	5-20	1,280	5-50
2-47-24	60% sorghum/40% glanded cottonseed	171	2,230	4-20	1,200	4-50	2,140	5-20	1,200	5-50
2-47-17	70% sorghum/30% glanded cottonseed	149	3,540	4-20	2,020	4-50	3,460	5-20	1,912	5-50
2-47-18	70% sorghum/30% glanded cottonseed	163	4,090	4-20	2,272	4-50	3,860	5-20	2,400	5-50
2-47- 4	70% sorghum/30% glanded cottonseed	163	3,380	4-20	1,832	4-50	3,040	5-20	1,736	5-50
2-47- 8	70% sorghum/30% glanded cottonseed	163	2,800	4-20	1,504	4-50	2,560	5-20	1,488	5-50
2-47-12	80% sorghum/20% glanded cottonseed	149	4,150	4-20	2,360	4-50	4,060	5-20	2,264	5-50
2-47-28	80% sorghum/20% glanded cottonseed	163	4,370	4-20	2,412	4-50	4,160	5-20	2,376	5-50
2-47-19	80% sorghum/20% glanded cottonseed	171	650	4-20	416	4-50	600	5-20	392	5-50
2-47-11	70% sorghum/30% glanded cottonseed	171	2,450	4-20	1,360	4-50	2,380	5-20	1,344	5-50

Table 6. Cereal/Cottonseed samples extruded on the Insta-Pro extruder.

FSN Code #	Description	Extrusion temp., °C	% Moisture	% Fat	% Total Nitrogen	% Water Sol. N	NSI	% Free Gossypol	% Water Absorption
2-57-10	80% corn /20% glandless cottonseed	Raw	7.71						
2-57- 4	80% corn /20% glandless cottonseed	138	6.60	9.41	2.44				
2-61- 5	70% corn /30% glandless cottonseed	138	6.19		3.05	0.39	12.79		133
2-61- 9	70% corn /30% glandless cottonseed	149	5.58	15.47	3.15	0.31	9.84		204
2-61- 8	60% corn /40% glandless cottonseed	135	5.60	18.56	3.35				
2-61- 6	60% corn /40% glandless cottonseed	147	4.99		3.37	0.33	9.79		157
2-57- 9	80% corn /20% glanded cottonseed	Raw	7.72						
2-57- 3	80% corn /20% glanded cottonseed	140	6.13		2.27	0.17	7.49	0.0232	285
2-57- 6	80% corn /20% glanded cottonseed	146	5.55	8.32	2.31	0.18	7.79	0.0204	299
2-57- 1	80% corn /20% glanded cottonseed	152	4.86		2.49	0.21	8.43		
2-69- 2	70% corn /30% glanded cottonseed	138	5.86	13.72	2.86	0.28	9.79	0.107	203
2-69- 8	70% corn /30% glanded cottonseed	143	4.53		3.32	0.24	7.23	0.058	164
2-69- 4	60% corn /40% glanded cottonseed	138	4.70					0.083	
2-69- 5	60% corn /40% glanded cottonseed	149	4.20	15.80	3.27	0.25	7.65	0.073	213
2-57- 8	80% sorghum/20% glandless cottonseed	Raw	7.38						
2-57- 5	80% sorghum/20% glandless cottonseed	135	4.70	12.06	2.76	0.24	8.70		
2-61- 7	70% sorghum/30% glandless cottonseed	140	4.57						
2-61- 2	70% sorghum/30% glandless cottonseed	149	4.24	14.99	3.07	0.29	9.45		111
2-61- 1	60% sorghum/40% glandless cottonseed	140	4.02	18.61	3.43				
2-61- 3	60% sorghum/40% glandless cottonseed	146	3.80		3.65	0.40	10.96		140
2-61- 4	60% sorghum/40% glandless cottonseed*	146	3.98		3.46	0.34	9.83		141
2-57- 7	80% sorghum/20% glanded cottonseed	140	6.08					0.0204	225
2-57- 2	80% sorghum/20% glanded cottonseed	149	5.29	8.60	2.48	0.17	6.85	0.0122	269
2-69- 3	70% sorghum/30% glanded cottonseed	138	3.48		3.01	0.24	7.97	0.048	224
2-69- 1	70% sorghum/30% glanded cottonseed	147	3.77	13.78	3.06	0.23	7.52	0.046	208
2-69- 7	60% sorghum/40% glanded cottonseed	138	3.00	15.79	3.21			0.077	
2-69- 6	60% sorghum/40% glanded cottonseed	149	2.96		3.36	0.26	7.74	0.067	213

* Sieve size = 0.79.

Table 7. Uncooked viscosities of cereal/cottonseed samples extruded on the Insta-Pro extruder.

FSN Code #	Sample description	Extrusion temp., °C	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Bostwick value
2-61-8	60% corn /40% glandless cottonseed	135	135	3-20	116	3-50					>24
2-61-6	60% corn /40% glandless cottonseed	147	185	3-20	178	3-50					>24
2-61-5	70% corn /30% glandless cottonseed	138	170	3-20	134	3-50					>24
2-61-9	70% corn /30% glandless cottonseed	149	3,165	3-20	1,840	3-50					14.2
2-57-4	80% corn /20% glandless cottonseed	138	26,200	7-20	16,080	7-50	24,300	6-20	41,650	6-50	
2-69-4	60% corn /40% glanded cottonseed	138	1,540	3-20	1,108	3-50					13.1
2-69-5	60% corn /40% glanded cottonseed	149	735	3-20	578	3-50					19.5
2-69-2	70% corn /30% glanded cottonseed	138	980	3-20	1,820	3-50					19.4
2-69-8	70% corn /30% glanded cottonseed	143	>1,000	3-20	>2,000	3-50					4.2
2-57-3	80% corn /20% glanded cottonseed	140	25,200	7-20	16,400	7-50	28,800	6-20	18,780	6-50	
2-57-6	80% corn /20% glanded cottonseed	146	31,800	7-20	20,240	7-50	31,850	6-20	19,180	6-50	
2-57-1	80% corn /20% glanded cottonseed	152	20,000	7-20	12,720	7-50	20,300	6-20	13,840	6-50	
2-61-1	60% sorghum/40% glandless cottonseed	140	100	3-20	80	3-50					>24
2-61-3	60% sorghum/40% glandless cottonseed	146	50	3-20	50	3-50					>24
2-61-4	60% sorghum/40% glandless cottonseed*	146	115	3-20	100	3-50					>24
2-61-7	70% sorghum/30% glandless cottonseed	140	85	3-20	74	3-50					>24
2-61-2	70% sorghum/30% glandless cottonseed	149	125	3-20	104	3-50					>24
2-57-5	80% sorghum/20% glandless cottonseed	135	405	3-20	314	3-50	370	4-20	292	4-50	
2-69-7	60% sorghum/40% glanded cottonseed	138	55	3-20	48	3-50					>24
2-69-6	60% sorghum/40% glanded cottonseed	149	100	3-20	78	3-50					>24
2-69-3	70% sorghum/30% glanded cottonseed	138	65	3-20	58	3-50					>24
2-69-1	70% sorghum/30% glanded cottonseed	147	78	3-20	72	3-50					>24
2-57-7	80% sorghum/20% glanded cottonseed	140	7,800	7-20	5,200	7-50	13,300	6-20	21,700	6-50	
2-57-2	80% sorghum/20% glanded cottonseed	149	16,000	7-20	10,560	7-50	26,900	6-20	16,560	6-50	

* Sieve size = 0.79.

Table 8. Cooked viscosities of cereal/cottonseed samples extruded on the Insta-Pro extruder.

FSN Code #	Sample description	Extrusion temp., °C	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Bostwick value
2-61-8	60% corn /40% glandless cottonseed	135	2,607	4-20	1,459	4-50					15.3
2-61-6	60% corn /40% glandless cottonseed	147	1,700	4-20	1,043	4-50					18.6
2-61-5	70% corn /30% glandless cottonseed	138	2,583	4-20	1,581	4-50					14.0
2-61-9	70% corn /30% glandless cottonseed	149	1,563	4-20	935	4-50					17.7
2-57-4	80% corn /20% glandless cottonseed	138	220	4-20	172	4-50	230	3-20	180	3-50	
2-69-4	60% corn /40% glanded cottonseed	138	887	4-20	557	4-50					21.3
2-69-5	60% corn /40% glanded cottonseed	149	1,313	4-20	777	4-50					18.4
2-69-2	70% corn /30% glanded cottonseed	138	2,207	4-20	1,396	4-50					17.4
2-69-8	70% corn /30% glanded cottonseed	143	1,710	4-20	1,023	4-50					18.3
2-57-3	80% corn /20% glanded cottonseed	140	530	4-20	384	4-50	590	3-20	420	3-50	
2-57-6	80% corn /20% glanded cottonseed	146	870	4-20	600	4-50	955	3-20	634	3-50	
2-57-1	80% corn /20% glanded cottonseed	152	460	4-20	344	4-50	510	3-20	368	3-50	
2-61-1	60% sorghum/40% glandless cottonseed	140	1,527	4-20	896	4-50					18.3
2-61-3	60% sorghum/40% glandless cottonseed	146	1,670	4-20	987	4-50					17.0
2-61-4	60% sorghum/40% glandless cottonseed*	146	1,840	4-20	1,017	4-50					16.9
2-61-7	70% sorghum/30% glandless cottonseed	140	1,100	4-20	763	4-50					23.4
2-61-2	70% sorghum/30% glandless cottonseed	149	2,670	4-20	1,537	4-50					14.4
2-57-5	80% sorghum/20% glandless cottonseed	135	2,780	4-20	1,656	4-50	2,795	3-20	1,604	3-50	
2-69-7	60% sorghum/40% glanded cottonseed	138	2,133	4-20	1,216	4-50					16.9
2-69-6	60% sorghum/40% glanded cottonseed	149	2,053	4-20	1,137	4-50					17.0
2-69-3	70% sorghum/30% glanded cottonseed	138	4,190	4-20	2,292	4-50					12.6
2-69-1	70% sorghum/30% glanded cottonseed	147	3,420	4-20	2,028	4-50					13.5
2-57-7	80% sorghum/20% glanded cottonseed	140	870	4-20	556	4-50	625	3-20	552	3-50	
2-57-2	80% sorghum/20% glanded cottonseed	149	730	4-20	480	4-50	750	3-20	482	3-50	

* Sieve size = 0.79.

show any discernible pattern. Although these values were low, representing considerable denaturation of protein, it should be remembered that the samples were essentially cooked. Water absorption values ranged from 130 to 300%. Although considerable variation was encountered, water absorption was reduced as expected by a higher level of cottonseed flour in the blend. Also, sorghum appeared to give lower water absorption values than did corn at similar levels in the blends. This is consistent with the uncooked viscosity data to be discussed, and indicates that corn and sorghum starches have different functional properties, at least following extrusion.

Uncooked and cooked viscosity data for these same blends are summarized in Tables 4 and 5, respectively. All viscosity data were obtained using a Brookfield viscosimeter. Previously, it was reported that the uncooked viscosity of corn/soy blend (CSB) was quite high. A potential problem may exist when it is mixed cold. Based on present knowledge, our recommendation for using CSB as a gruel is to boil the mixture at least two minutes. This much boiling, if not more, is desirable from a sanitation standpoint and reduces the viscosity of the mixture. Nevertheless, it would be desirable to produce blended foods on the extruder with lower uncooked viscosities than is the case for extruded CSB.

As shown in Table 4, uncooked viscosities for corn blends with either glandless or glanded cottonseed were quite high. Generally, viscosity was lower with more cottonseed in the blend. Glanded cottonseed blends gave higher uncooked viscosities than did blends from glandless cottonseed. Increasing the temperature from 149° to 163°C increased the uncooked viscosity of glanded cottonseed blends. The most

interesting observation, however, is that sorghum blends with glanded cottonseed resulted in considerably lower uncooked viscosity values than was the case for similarly processed blends with corn. This observation was consistent with the water absorption data previously mentioned. If this proves to be the case also for sorghum/soy blends, it may prove to be possible to produce a weaning food with a satisfactory uncooked viscosity from a mixture of soy with sorghum and corn. However, it is also possible that the sorghum is less gelatinized and the question is currently under investigation.

The cooked viscosity data listed in Table 5 show no important trends and in all cases the cooked viscosity values were in an acceptable range.

The corresponding data for cottonseed/cereal blends made on the Insta-Pro are shown in Tables 6, 7 and 8. However, in addition to the Brookfield viscosity data as reported for the Brady samples, Bostwick values are listed.

The NSI's, free gossypol and water absorption data listed in Table 6 for the Insta-Pro are comparable to values obtained for the Brady. Operating temperatures on the Insta-Pro ranged from 138-149°C, compared to Brady operating temperatures of 149-171°C.

Uncooked and cooked viscosity data for samples extruded on the Insta-Pro are summarized in Tables 7 and 8. Uncooked viscosities were generally higher with corn than with sorghum, and with glanded rather than glandless cottonseed. Mixtures of sorghum with glandless cottonseed gave very low uncooked viscosities, regardless of whether the blend was 80/20 or 60/40. Corn/glandless cottonseed blend (70/30) extruded at 149°C had a lower viscosity than was the case for a similar blend

extruded at a similar temperature on the Brady. If the temperature on the Insta-Pro was further reduced to 138°C, the resulting gruel became very thin indicating inadequate cooking. The corn or sorghum blends with glandless cottonseed showing very low uncooked viscosities typically increased in viscosity when cooked. Since the cooked samples, when evaluated, actually contained more water than did the uncooked, it indicates that these samples were probably not adequately cooked during the extrusion process.

2.1.4 Nutritional Properties

Several rat growth studies were carried out in which the effects of extrusion on the protein quality of full-fat cottonseed flour and cottonseed blends have been evaluated. In these studies the AOAC method for measuring PER's was used with minor modifications. In addition, protein retention efficiencies (PRE's) were calculated from two week growth data. PRE's were mathematically similar to NPU's and as such took into account protein used for maintenance as well as growth. In assessing the relative nutritive values of a series of protein sources, PRE is a better measure than is PER. However, the PER is a more sensitive measure especially to the nutritional effects of heat processing. Therefore, PER values will be discussed in this section.

The results of the first experiment are summarized in Table 9. In this study all of the samples had been extruded on the Brady at the temperatures shown in the table.

Glandless cottonseed flour was of excellent quality and had a PER equal to casein. As is well known, gossypol in glanded cottonseed flour is toxic to rats, and rats fed this flour lost weight and several died.

Table 9. Results of rat growth experiment 1 (4 weeks growth).

FSN Code #	Description	Extruder & Temp., °C	Weight gain, g[1]	PER	Corrected PER[2]	PRE[3]
2-15-13	100% glanded cottonseed	Brady 138	79.3±6.7	2.39±0.09	1.89±0.07	55.4±1.3
2-15-14	100% glanded cottonseed	Raw	-16.9±1.6	-0.90±0.13	-0.76±0.10	-10.5±3.9
2-15-15	100% glandless cottonseed	Raw	136.2±4.0	3.15±0.05	2.49±0.04	65.6±1.0
2-13- 9	70% corn/ 30% glanded cottonseed	Brady 171	57.9±4.9	1.92±0.11	1.52±0.09	46.4±2.1
2-13- 7	70% corn/ 30% glanded cottonseed	Brady 138	79.1±4.6	2.41±0.05	1.90±0.04	51.9±0.9
2-13-10	70% sorghum/ 30% glandless cottonseed	Brady 171	73.2±3.6	2.22±0.05	1.75±0.04	47.7±2.4
2-13-12	70% sorghum/ 30% glandless cottonseed	Brady 142	77.9±5.2	2.37±0.07	1.87±0.06	54.0±1.3
---	ANRC Casein 1		120.1±3.5	3.13±0.13	---	70.4±1.6
---	ANRC Casein 2		113.0±6.5	3.23±0.08	---	75.6±2.3
---	ANRC Casein 3		123.8±4.3	3.13±0.05	---	69.5±1.6
---	ANRC Casein Average		119.0±4.8	3.16±0.09	2.50	71.7±1.8

[1] Mean ± standard deviation.

[2] Corrected to casein = 2.50.

[3] Based on 2 weeks growth.

However, extruding the glanded cottonseed at approximately 138°C resulted in a corrected PER of 1.89 ± 0.07. For comparison, dehulled soy extruded on the Brady at this temperature gave a corrected PER of 1.98 ± 0.06 in the same experiment. The PER for the extruded glanded cottonseed is surprisingly high in view of the fact that: 1) only 70% of the free gossypol was bound, and 2) presumably the free gossypol that was bound rendered equimolar amounts of lysine unavailable. However, as will be discussed below, it has been confirmed that this was high protein quality for extruded glanded cottonseed in the second rat feeding study (Table 10).

PER's for corn/glanded cottonseed and sorghum/glandless cottonseed blends at two temperatures are also listed in Table 9. Whole corn/glanded cottonseed (70/30) extruded at 171°C gave a corrected PER of 1.52 ± 0.09, much below the 2.4-2.5 values obtained for similar corn/soy blends. When the extrusion temperature was dropped to 138°C, the PER significantly increased to 1.90 ± 0.04, still much below corn/soy blends. The corrected PER's for the sorghum/glandless cottonseed blends were 1.75 ± 0.04 and 1.87 ± 0.06 and were not significantly affected by temperature in the range studied.

A second rat feeding experiment was conducted in which extruded cottonseed flours and cottonseed blends were processed on both the Brady and the Insta-Pro extruders. The data are presented in Table 10. The results for the Brady were generally consistent with the results of the first experiment. In the repeat experiment, glanded cottonseed extruded on the Brady at 139°C had a corrected PER of 1.97 ± 0.04, which was similar to PER's obtained for extruded full-fat soy flour. Glanded cottonseed extruded on the Insta-Pro at 140°C gave a corrected PER of 1.80 ± 0.08. Extruding glandless cottonseed reduced

Table 10. Results of rat growth experiment 2 (4 weeks growth).

Code #	Description	Extruder & Temp., °C	Weight gain, g[1]	PER	Corrected PER[2]	PRE[3]
2-39-19	100% glandless cottonseed	Raw	124.2±6.5	2.88±0.08	2.50±0.07	60.2±1.3
2-39-20	100% glandless cottonseed	Brady 132	116.0±5.6	2.74±0.07	2.38±0.06	59.6±0.9
2-39-16	100% glanded cottonseed	Brady 139	96.5±3.7	2.26±0.05	1.97±0.04	49.6±1.2
2-39- 9	100% glanded cottonseed	Insta-Pro 140	73.2±3.7	2.07±0.09	1.80±0.08	47.9±1.5
2-41- 1	70% corn/ 30% glanded cottonseed	Brady 171	50.4±3.8	1.73±0.09	1.51±0.08	46.6±2.4
2-41- 2	70% corn/ 30% glanded cottonseed[4]	Brady 171	94.9±4.8	2.54±0.07	2.21±0.06	57.1±1.1
2-41- 3	70% corn/ 30% glanded cottonseed	Brady 139	70.9±4.4	2.12±0.05	1.84±0.04	49.1±0.8
2-41- 8	70% sorghum/ 30% glandless cottonseed	Brady 174	65.4±3.4	1.98±0.08	1.72±0.07	48.4±2.0
2-41- 5	70% corn/ 30% glanded cottonseed	Insta-Pro 149	93.6±5.8	2.55±0.08	2.22±0.07	55.8±1.9
2-41- 4	70% sorghum/ 30% glanded cottonseed	Insta-Pro 138	65.5±5.6	2.01±0.10	1.75±0.09	45.2±1.8
2-41- 7	70% sorghum/ 30% glandless cottonseed	Insta-Pro 149	83.2±3.8	2.38±0.08	2.07±0.07	54.8±0.9
---	ANRC Casein (3 groups)		111.4±4.2	2.88±0.09	2.50	60.3±1.7

[1] Mean ± standard deviation.

[2] Corrected to casein = 2.50.

[3] Based on 2 weeks growth.

[4] 0.5% LMH was added to mixture.

the PER from 2.50 ± 0.07 to 2.38 ± 0.06. Although this difference was not significant, a slight reduction in protein quality was not surprising because of the known effects of heat processing on lysine availability.

PER's for blends extruded on the Insta-Pro were comparable to those obtained for blends extruded at similar temperatures on the Brady. Whole corn/glanded cottonseed extruded on the Insta-Pro at 149°C gave an excellent corrected PER of 2.22 ± 0.07. For comparison purposes, a similar blend extruded at 171°C on the Brady gave a corrected PER of 1.51 ± 0.08. This low PER for corn/glanded cottonseed extruded at 171°C was predicted to be most likely caused by a lysine deficiency. Therefore, the exact sample which gave the PER of 1.51 was also fed with the addition of 0.5% L-lysine monohydrochloride. In this case the corrected PER increased significantly to 2.21 ± 0.06, confirming the hypothesis.

The data obtained in these experiments, combined with the literature on cottonseed, suggest the following tentative conclusions. Cereal blends made with low-gossypol cottonseed are of good to excellent nutritional value. Although glandless cottonseed was used in our experiments, degossypolized cottonseed, such as produced by the cyclone process, undoubtedly would also be satisfactory. Depending on the extrusion temperature, such blends might respond to lysine fortification. Cottonseed has a real advantage over soy in blended foods because of its additional oil. Although glandless cottonseed does not require heat processing as does soy, the cereal blends undoubtedly benefit in terms of digestibility and acceptability by the extrusion. From a cost and processing standpoint, it may not be desirable to extrude the blend, but

rather to extrude only the cereal, perhaps with 5% cottonseed to provide a small amount of oil to aid in extrusion. However, this point has not yet been investigated.

Extrusion has real merit in making blends of cereals with glanded cottonseed. It would appear desirable to add an iron salt and lysine prior to extrusion to assist in gossypol inactivation, but this point requires more investigation. Extrusion of glanded cottonseed does not at this point result in a satisfactory full-fat cottonseed flour based on the safety of the product, because free gossypol levels are too high. It may well be that adding an iron salt prior to extrusion would produce a satisfactory product.

It would appear that more work is necessary and desirable to explore the full potential and assure the safety of cottonseed foods processed on a low-cost extrusion cooker.

2.2 TSP

Effort has been made to investigate the potential of using LEC's to produce texturized soy protein (TSP). Mr. Ronald Flier and Mr. Wayne Moore of Ralston-Purina visited on April 11, 1977, for consultation on production of TSP. Discussions were held on:

1. Ingredient requirements
2. Operational and operating conditions
3. Product evaluation
4. Mechanical changes to LEC's.

A 50% protein, defatted soybean meal with PDI of 25-50% was recommended for extrusion. The meal should be in the form of grits or unground flakes. Tempering of the flakes was recommended to 28-35% moisture which would help feeding problems.

Product evaluation will consist of standard tests as recommended by Ralston. These include:

1. Bulk density - standard of 0.32 g/cc
2. Particle size - coarse: -3 +10 mesh
   medium: -10 +20 mesh
   fine : -20 mesh
3. Moisture
4. Fiber structure test - a test using low concentrations of TSP in water, followed by screening
5. Hydration test - industrial standard is 2.5/1.0 for hydrated to original product.

Mr. Flier and Mr. Moore spent two days at CSU, July 21-22, 1977, to help begin the study of TSP extrusion on the Brady and Insta-Pro extruders.

The extrusion laboratory was set up to accommodate preprocessing requirements to extrude TSP. Defatted soybean grits (50 PDI or higher) were available for the extrusion test. The defatted soy grits (DSG) were adjusted to various moisture levels, steamed to 71°C, and then extruded. The formula used was: 100% DSG, 0.1% sulfur, 25-30% moisture, and steam. Sulfur was added initially as an extrusion aid but should not be considered for processes manufacturing human food.

The DSG was tried on both extruders with few modifications. Notes of the runs are given below.

2.2.1 Brady

Several runs were made on the Brady in an attempt to extrude TSP. Several factors were explored:

1. Moisture
2. Sulfur content

3. Extrusion screw speed

4. Feed rates.

Observations made during the run indicated that the major problem with the Brady was feeding. The Brady was tried with the standard feeder supplied, however, a feed transition plug occurred due to the high moisture condition of the feed. The original feed hopper was removed and replaced by a gravity hopper fed with an Eriez magnetic feeder, which enabled continuous feeding with some external prodding of the hopper to clear blockages. Keeping the moisture content constant was critical to uniform feeding and texturization.

Best results were obtained with the following conditions:

Preprocessing--100 parts DSG (50 PDI)
30 parts water
0.1 parts sulfur
steam to 82°C

Operating Conditions (approx.)--rotor speed, 450 rpm
feed rate, 272 kg/hr
cone opening, less than one turn open

Results indicated a textured product could be produced with difficulty, which was judged to be acceptable but not optimal. Flakes of textured soy were made which resembled a slightly puffed and fibrous chip. It was felt that the Brady had limited capability in producing TSP due to the feeding problem and the screw design. Changes in both these areas would be beneficial in manufacturing TSP, and further study will clarify the machine operating conditions required.

2.2.2 Insta-Pro

A number of runs were made on the Insta-Pro extruder exploring several variables:

1. Screw speed
2. Size of steam locks
3. Orifice size
4. Moisture
5. Sulfur content
6. Feed rates.

In general the Insta-Pro seems well adapted to manufacturing TSP. It was noted that in all runs, it was very critical to maintain a positive and consistent feed rate for texturization. Runs made indicated that the Insta-Pro had high shear rates which made temperature control difficult but control was achieved by changing to the large single orifice (12.7 mm) and small steam lock. The Eriez feeder was used in place of the vibratory feeder to make feeding more consistent.

In general, TSP production was best achieved with the following conditions:

Preprocessing--100 parts DSG
30 parts water
0.1 parts sulfur
steam to 82°C

Operating Conditions (approx.)--Steam locks, 10P, 10P, 10P
(smallest locks)
Orifice, single 12.7 mm dia.
Screw speed, 350 rpm
Feed rate, 227 kg/hr

The product manufactured was a rope of approximately 2.5 cm in diameter, highly expanded and fibrous. Structure within the rope seemed quite developed and was judged to be a highly acceptable product. Low feed rates would cause the extruder to surge and stop the production of the textured rope. Higher feed rates were found best for continuous production of TSP.

The TSP tests in general were not conclusive in determining the utility of either LEC machine. However, the initial experience has given a basis for further research in the area where work will emphasize the Insta-Pro extruder. Tests will be run to investigate the specific operating conditions required for steady texturization of defatted soy.

2.3 Chickpeas

2.3.1 Processing

Chickpeas (garbanzo beans) were used in conjunction with cereals in a LEC test. Dr. Shah, Ministry of Health, Pakistan, had expressed an interest in combining chickpeas with various cereals at approximately a 50% level.

Tests run on the Brady indicated that the chickpea/cereal combinations can be extruded successfully without any preconditioning of ingredients. Due to the lower oil content, the combinations extruded more like high cereal/low soybean combinations.

Chickpeas were combined with wheat, corn, sorghum and rice. Physical extruder operations indicated that the wheat/chickpea and rice/chickpea combinations did not extrude easily due to the lower oil contents of the combinations compared to the corn or sorghum mixtures.

2.3.2 Nutritional Evaluation

Cereal/chickpea/nonfat dry milk (NFDM) blends were made with the general formula of cereal, 44%; chickpeas, 44%; NFDM, 10%; and vitamins and minerals, 2%. The four cereals used were corn, wheat, sorghum and rice, as described in Section 2.1.1.

Data showing the proximate analyses and nitrogen solubility indexes (NSI's) for these samples are presented in Table 11. These samples are

Table 11. Proximate analysis and NSI's for chickpea blends.

FSN Code #	Sample	Moisture %	Fat %	Nitrogen %	Protein[1] %	Ash %	Fiber %	NSI[2]
2-63-4	44% corn, 44% chickpea, 10% NFDM, 2% V&M	5.97	3.27	2.70	16.88	4.42	1.28	34.07
2-63-5	44% wheat, 44% chickpea, 10% NFDM, 2% V&M	4.88	3.50	3.40	21.25	4.24	1.51	27.65
2-63-6	44% sorghum, 44% chickpea, 10% NFDM, 2% V&M	5.06	3.20	2.62	16.38	4.15	1.58	30.92
2-63-7	44% rice, 44% chickpea, 10% NFDM, 2% V&M	5.50	2.19	2.57	16.06	4.20	0.43	35.02

[1] (N x 6.25).

[2] Nitrogen solubility index.

all quite low in fat. Except for wheat, they all contain somewhat less protein than CSB (70/30), 16% versus about 18% for CSB. However, the blend with wheat contained over 21% protein. NSI's for the blends were quite high, ranging from 28 to 35%. This compares to NSI's of around 8-9% for CSB and indicates a lesser amount of protein denaturation occurred.

Both "uncooked" and "cooked" viscosity data for these samples are presented in Table 12. The uncooked viscosities for the corn, sorghum and rice blends are quite high, giving Bostwick values of zero or near zero. The uncooked viscosity of the wheat blend was moderate, giving a Bostwick value of 8.4. The four cereal blends, in descending order of uncooked viscosities, were corn > sorghum > rice > wheat. Cooked viscosities for all blends were much lower than was the case for uncooked viscosities, giving Bostwick values of 13 to 24. Interestingly, when the cooked viscosities were ranked in descending order, reverse order was seen, that is, wheat showed the highest cooked viscosity and corn the lowest.

The rat growth evaluation of three of these blends and two blended foods from Sri Lanka is summarized in Table 13. Chickpea/NFDM blends with wheat, sorghum or rice all gave corrected PER's equal to or greater than that of casein. The corrected PER for the blend with rice, 2.94 $\pm$ 0.09, actually was significantly higher than casein. The reason for this is not understood at this time and it is sufficient to conclude that all three blends have a protein quality at least as good as casein. The production line sample of Thriposha gave a corrected PER equal to casein. A corn/soy blend (80/20) extruded in Sri Lanka gave an acceptable corrected PER of 2.23 $\pm$ 0.04, which is a good PER for a 80/20 blend.

Table 12. Viscosity data for chickpea blends.

FSN Code #	Sample description	Centi-poise	Spindle No. - rpm	Centi-poise	Spindle No. - rpm	Bostwick value
				Uncooked Viscosity		
2-63-4	44% corn, 44% chickpea, 10% NFDM, 2% V&M	71,200	7-20	43,040	7-50	0
2-63-5	44% wheat, 44% chickpea, 10% NFDM, 2% V&M	5,920	7-20	4,000	7-50	8.4
2-63-6	44% sorghum, 44% chickpea, 10% NFDM, 2% V&M	50,860	7-20	28,208	7-50	0
2-63-7	44% rice, 44% chickpea, 10% NFDM, 2% V&M	34,260	7-20	22,768	7-50	0.5
				Cooked Viscosity		
2-63-4	44% corn, 44% chickpea, 10% NFDM, 2% V&M	692	3-20	427	3-50	24.0
2-63-5	44% wheat, 44% chickpea, 10% NFDM, 2% V&M	4,018	3-20	>2,000	3-50	13.0
2-63-6	44% sorghum, 44% chickpea, 10% NFDM, 2% V&M	710	3-20	476	3-50	21.8
2-63-7	44% rice, 44% chickpea, 10% NFDM, 2% V&M	903	3-20	601	3-50	22.2

Table 13. Rat growth evaluation of chickpea blends and Thriposha.

FSN Code	Sample	Weight gain, g[1]	PER	Corrected PER[2]
2-75- 8	44% wheat, 44% chickpea, 10% NFDM, 2% V&M	141.7±2.9	3.01±0.05	2.50±0.04
2-75- 9	44% sorghum, 44% chickpea, 10% NFDM, 2% V&M	156.2±6.7	3.12±0.05	2.59±0.04
2-75-10	44% rice, 44% chickpea, 10% NFDM, 2% V& M	167.8±6.4	3.54±0.11	2.94±0.09
2-75-11	Thriposha (80% ICSM, 16% corn, 4% soy)	139.6±5.6	3.05±0.03	2.53±0.03
2-75-12	80% corn, 20% soy extruded in Sri Lanka, 154°C	126.9±4.6	2.09±0.05	2.23±0.04
2-75-13	ANRC casein	119.6±5.6	3.01±0.10	2.50

[1]Mean ± standard deviation.

[2]Corrected relative to casein = 2.50.

2.4 Preclinical Evaluation of CSB

A preclinical evaluation of three samples of CSB that were made at Colorado State University on a Brady Crop Cooker was performed. The same samples have been submitted to Dr. George Graham's laboratory for clinical evaluation.

The samples are identified in the report as follows:

2-39-14 Degermed corn and dehulled soy (70/30), extruded at 163°C.

2-39-15 Whole corn and whole soy (70/30), extruded at 163°C.

2-39-17 Whole corn and dehulled soy (70/30), extruded at 163°C.

Following extrusion, all samples were ground in a Fitz mill and fortified with a 0.1% vitamin and antioxidant premix and 2.7% mineral premix according to AID specifications for Title II CSB. The vitamins and minerals were added in a stainless steel Falcon blender.

2.4.1 Methods

Proximate analysis and particle size determination was carried out using AACC standard procedures. The amount of antitrypsin activity was determined by the standard AOCS method and protein efficiency ratios were obtained using the AOAC method, except that corn oil was substituted for cottonseed oil. Viscosity measurements for cooked and uncooked material were made using the procedure described in the specifications for Title II CSB. Besides obtaining Bostwick values, a Brookfield viscosimeter was also used to obtain more precise data.

The microbiological analysis was conducted by Dr. Jack Avens in the Department of Animal Sciences, and experimental details are to be found in his report, which is summarized here. Ten separate samples of each blend were taken for microbiological analysis. Using standard microbiological procedures, levels of coliforms, E. coli, staphylococci, salmonella and total aerobic plate count were determined.

2.4.2 Results

Proximate analysis data are listed in Table 14. Title II specifications for protein and fat were met by all blends. The whole corn and soy products slightly exceeded the fiber specification which was 2.0%. Particle size measurements, listed in Table 15, were quite variable, both for Krause CSB and our materials. In general, all three blends are similar in particle size to Title II (i.e., Krause) CSB.

Table 14. Proximate analysis.

FSN Code #	Sample Description	Moisture %	Fat %	Nitrogen %	Protein[1] %	Ash %	Fiber %	Carbohydrate[2] %
2-39-14	Degermed corn/ dehulled soy (70/30) 163°C, Brady	2.82	6.75	2.72	17.00	4.25	0.8	68.38
2-39-15	Whole corn/ whole soy (70/30) 163°C, Brady	3.58	8.63	2.84	17.75	5.07	2.3	62.67
2-39-17	Whole corn/ dehulled soy (70/30) 163°C, Brady	3.27	9.22	2.97	18.56	5.09	1.9	61.96

[1] (N x 6.25)

[2] (By diff.)

Table 15. Particle size distribution.

Sample and Description	Run #	% Retained on #10 Sieve	#20 Sieve	#30 Sieve	#60 Sieve	% through #60 Sieve
Krause corn/soy blend	1	0.5	--	58.0	38.5	1.4
	2	0.5	--	93.4	4.8	0.0
	3	1.0	--	94.8	1.6	0.2
	4	0.7	51.4	45.3	2.3	0.3
	5	0.4	53.5	42.0	4.2	0.4
2-39-14 Degermed corn/dehulled soy (70/30) 163°C, Brady	1	0.0	--	91.6	8.1	0.1
	3	0.2	--	89.4	10.3	0.1
	4	0.4	33.1	57.1	9.5	0.0
	5	0.3	41.4	57.6	6.6	0.0
2-39-15 Whole corn/ whole soy (70/30) 165°C Brady	1	0.0	--	57.2	41.3	1.2
	3	0.1	--	66.0	33.6	0.2
2-39-17 Whole corn/ dehulled soy (70/30) 163°C, Brady	1	0.1	--	87.2	12.7	0.1
	3	0.2	--	79.8	19.9	0.1

Data on nitrogen solubility, water absorption, urease and antitrypsin activity are listed in Table 16. As previously reported, CSB produced on the Brady has low NSI's but higher water absorption values than Title II CSB. The urease and antitrypsin data demonstrate that heat treatment has been ample to inactivate antinutritional factors to a high degree. The viscosity data given in Table 17 are consistent with the water absorption data. Also, the Brady extruded blends have higher uncooked viscosities than does Title II CSB, but lower cooked viscosity. All products meet the Title III specifications for CSB, whether cooked or uncooked. To use the product most satisfactorily, it will be desirable to boil it for 2-3 minutes, in order to prevent the product from being too thick to be satisfactorily consumed by young children, and to eliminate contamination from the water used for reconstitution.

Table 16. Physical and chemical properties,

FSN Code #	Sample Description	NSI[1]	Water Absorption %	Urease Activity	Trypsin Inhibitor Loss %
2-39-14	Degermed corn/ dehulled soy (70/30) 163°C, Brady	4.8	34.9	0.02	84.7
2-39-15	Whole corn/ whole soy (70/30) 163°C, Brady	6.7	32.0	0.01	76.9
2-39-17	Whole corn/ dehulled soy (70/30) 163°C, Brady	6.4	33.9	0.02	91.7

[1]Nitrogen Solubility Index

Table 17. Viscosity studies of corn/soy samples extruded on the Brady extruder.

FSN Code #	Sample description*	Centipoise	Spindle No. - rpm	Centipoise	Spindle No. - rpm	Bostwick value
			Uncooked Viscosity			
2-39-14	70% degermed corn/ 30% dehulled soy	3,280	7-20	6,720	7-50	3.3
2-39-15	70% whole corn/ 30% whole soy	8,000	7-20	5,840	7-50	6.3
2-39-17	70% whole corn/ 30% dehulled soy	9,400	7-20	7,600	7-50	7.2
			Cooked Viscosity			
2-39-14	70% degermed corn/ 30% dehulled soy	3,350	3-20	>2,000 2,820	3-50 4-50	13.3
2-39-15	70% whole corn/ 30% whole soy	1,935	3-20	1,220	3-50	16.7
2-39-17	70% whole corn/ 30% dehulled soy	3,045	3-20	1,698	3-50	14.3

*All samples were extruded at 163°C.

The results of the rat growth evaluation are presented in Table 18. As previously reported, CSB (70/30) made on the Brady, whether from whole or degermed corn, and whole or dehulled soy has a PER approximately equal to that of casein. In this particular study, all three samples gave PER's higher than reference casein. The PER for whole corn/dehulled soy, 2.91, was significantly higher than the 2.5 for casein. The higher PER in this study may be more related to palatability for the rat of this sample, rather than protein quality. It is sufficient to consider that in the rat, all three samples being submitted had PER's at least as good as casein.

A summary of the microbiological analysis is presented in Table 19. All three samples were devoid of detectable levels of E. coli, coagulase positive staphylococci and salmonella. Levels of coliforms and the aerobic plate counts were well below acceptable limits. The only microbiological standard listed for Title II CSB is a limit of 50,000 organisms per gram for the standard plate count. The data listed in Table 19 show that, based on the means for 10 subsamples, none of the three CSB samples exceeded 1,000 organisms per gram.

2.4.3 Conclusion

The preclinical evaluation of the three CSB samples studied indicated that all were safe and suitable for feeding to young children. The only significant question relates to the crude fiber level in the whole corn/whole soy product which, as expected, was high. Clinical tests are currently in progress which should help define the fiber levels that can safely be consumed by infants and young children. For older children, the fiber levels in whole corn/whole soy CSB would

Table 18. Rat growth evaluation of CSB samples.

Sample No.	Description	Weight gain (g)	PER	Corrected PER[1]
2-39-14	Degermed corn/dehulled soy (70/30) 163°C, Brady	129.9 ± 6.4[2]	3.02 ± 0.06	2.63 ± 0.05
2-39-15	Whole corn/whole soy (70/30) 163°C, Brady	137.5 ± 5.6	3.04 ± 0.08	2.46 ± 0.07
2-39-17	Whole corn/dehulled soy (70/30) 163°C, Brady	150.1 ± 3.6	3.34 ± 0.06	2.91 ± 0.05
—	ANRC casein	111.4 ± 4.2	2.88 ± 0.09	2.50

[1]Corrected relative to casein = 2.50

[2]Mean ± standard error

Table 19. Microbiological analysis of CSB samples

Sample No.	Description	Organisms/gram				
		Coliforms	*E. coli*	Coagulase Positive Staphylococci	Salmonella	Aerobic Plate Count
2-39-14	Degermed corn/dehulled soy (70/30) 163°C, Brady	8	--[1]	--[1]	--[1]	380
2-39-15	Whole corn/whole soy (70/30) 163°C, Brady	--[1]	--[1]	--[1]	--[1]	300
2-39-17	Whole corn/dehulled soy (70/30) 163°C, Brady	230	--[1]	--[1]	--[1]	960

[1]None detected by the "most probable number" method.

likely not pose a problem per se although effects on mineral availability could be significant, depending on the level of consumption.

2.4.4 Storage Studies

The storage conditions utilized for the CSB storage study were:

1. 29°C at 40% relative humidity
2. 31°C at 50% relative humidity
3. 48°C at 60% relative humidity
4. Frozen storage which served as a control.

Samples of corn/soy blend extruded at 163°C were subjected to the above conditions for three months with a flavor profile analysis being performed initially and then at monthly intervals. The samples were packaged in either 4 mil polyethylene or 2 mil polyethylene/Kraft paper. Preliminary studies had indicated that 2 mil packaging may present a problem due to free-fat leakage, especially at high (>38°C) storage temperatures. This observation was not apparent when 4 mil thick polyethylene packaging material was utilized.

The flavor profile panel consisted of three individuals well versed in the technique. Gruels (11.75%) were prepared and served hot to the panel. Overall aroma and flavor intensities were obtained using a four-point scale [)(= threshold; 1 = slight; 2 = moderate; 3 = strong]. In addition, individual aroma and flavor sensations, along with their intensities using the same scale as described above, were recorded.

The products had initially been processed to include the normal vitamin, mineral and antioxidant mixtures, and perhaps the key observation in these storage studies is the fact that no signs of rancidity were detected in any product/packaging material/storage condition

evaluated. Also, storage conditions and time did not alter overall aroma and flavor intensities. They were in the slight to moderate range. The major aroma notes were toasted at a level of 1, and starch at 1 with green at)(. Their intensities also did not change during the study.

In the case of flavor, a sweet sensation was found to decrease with time from an original level of 1 to)(. Other notes that did not change include cooked/toasted at a level of 1 and bitter at a level of)(. The samples remain in storage and it is planned to evaluate their condition at the end of a six-month period.

Thus, these data would indicate that extruded corn/soy fortified with vitamin/mineral premix containing antioxidants can be stored under conditions approaching 49°C and 60% relative humidity for periods up to three months without any detectable differences occurring in the aroma and flavor properties of these products. Since no apparent change has been detected in three months, it would appear that little change can be anticipated at the end of six months.

2.5 Full-fat Soy Flour

2.5.1 Nutritional Properties

Samples of full-fat soy flour extruded on either the Brady or Insta-Pro extruder under varying conditions have been evaluated for gross composition and protein nutritional value. Proximate analysis was carried out by standard AACC methods. In the case of fat, diethyl ether was used in a Goldfisch extractor with an extraction time of 6-8 hours. Urease was determined using AACC method 2290 and antitrypsin activity using AOCS tentative method Ba12-75. Protein efficiency ratios were

carried out using essentially the AOAC method with minor modifications and a 28-day growth period.

Proximate analysis data for the extruded and raw soy samples are listed in Table 20. A lower fat value in raw dehulled beans is almost certainly a result of incomplete extraction under the conditions used. Extrusion makes the fat considerably more extractable. It appears that an extraction time longer than 6-8 hours with diethyl ether is needed to completely extract the fat from raw soybeans.

Data illustrating the effect of extrusion on urease and antitrypsin activity in raw and extruded soy are presented in Table 21. Both the Brady and the Insta-Pro extruders were effective in reducing antitrypsin activity at least 55% and in essentially eliminating urease activity. At an operating temperature of 139°C, the Brady reduced antitrypsin activity 55% and 70% for dehulled and whole soybeans, respectively. In the case of the Insta-Pro at 143-146°C, antitrypsin activity was reduced 86% and 81% for dehulled and whole soybeans, respectively. At this point, it is not known whether the greater destruction of antitrypsin activity is related to the slightly higher operating temperature or to a difference in the configuration of the extruder.

Protein efficiency ratios (PER's) for full-fat soy flour extruded on both the Brady and Insta-Pro extruders are shown in Table 22. There were no significant differences among the PER's for full-fat soy flour processed from whole or dehulled soybeans using either extruder. All corrected PER's were at least 2.0, confirming the high protein nutritional value for full-fat soy flour extruded on either the Brady or Insta-Pro extruders.

Table 20. Proximate analysis for extruded and raw soy samples.

FSN Code #	Sample description	Moisture %	Fat %	Nitrogen %	Protein %	Ash %
2- 9-15	Raw whole soy	7.1	23.7	5.59	34.9	4.6
2-39- 3	Whole soy, Brady, 139°C	3.6	22.7	5.95	37.2	---
2-39- 4	Whole soy, Insta-Pro, 143°C	3.0	22.6	5.74	35.9	---
2- 9-16	Raw dehulled soy	6.3	19.7	5.88	36.8	4.6
2-39- 2	Dehulled soy, Brady, 139°C	3.4	24.6	6.13	38.3	---
2-39- 1	Dehulled soy, Insta-Pro, 146°C	2.8	23.6	5.67	35.4	---

Table 21. Effect of extrusion on antitrypsin and urease activity.[1]

FSN Code #	Sample description	Trypsin inhibitor Activity		Urease activity
		TIU, g	% Inhibitor destroyed	
2- 9-15	Raw whole soy	74,750	--	1.92
2-39- 6	Whole soy, Brady, 139°C	22,675	69.7	0.03
2-39- 4	Whole soy, Insta-Pro, 143°C	14,000	81.3	0.09
2- 9-16	Raw dehulled soy	80,000	--	1.97
2-39- 2	Dehulled soy, Brady, 139°C	36,200	54.7	0.00
2-39- 1	Dehulled soy, Insta-Pro, 146°C	11,200	86.0	0.02

[1]All data are reported on an "as-is" basis.

Table 22. PER's for extruded full-fat soy flours.

FSN Code #	Sample description	Rat growth evaluation	
		Weight gain g	Corrected PER[1]
2-39-6	Whole soy, Brady, 139°C	89.6	2.04
2-39-4	Whole soy, Insta-Pro, 143°C	103.4 ± 5.4	2.24 ± 0.05
2-39-2	Dehulled soy, Brady, 139°C	100.8	2.15
2-39-1	Dehulled soy, Insta-Pro, 146°C	114.8 ± 6.2	2.25 ± 0.08

[1]PER's corrected to standard value of 2.50 for ANRC casein.

In one earlier rat feeding experiment it appeared that an extrusion temperature of 138°C was marginal in terms of inactivating antitrypsin activity in soybeans. Therefore, another experiment was carried out in which dehulled soybeans were extruded on the Brady at 138°, 143° and 149°C. Trypsin inhibition data are presented in Table 23. The results demonstrated that an extrusion temperature of at least 138°C gave a maximum PER and destruction of antitrypsin activity which were not further increased by higher extrusion temperatures. In a future experiment, the effect of extrusion temperatures lower than 138°C will be studied in order to better understand the relationship between temperature and the protein quality of extruded full-fat soy flour. In an earlier experiment, as shown in Table 24, increasing the moisture content during extrusion appeared to significantly increase the destruction of antitrypsin activity. In the next experiment, temperature and moisture

Table 23. Effect of extrusion temperature on nutritional value of dehulled soy.[1]

FSN Code #	Extrusion temp., °C	Lipoxogenase activity, U/mg	Trypsin inhibitor[2]		Corrected PER[3]
			TIU/mg	% Destruction	
2-81- 9	Not extruded	4706	85.8	--	1.24±0.18
2-81-10	138	<1	23.0	73.2	2.17±0.07
2-81-11	143	<1	33.5	60.9	2.14±0.03
2-81-12	149	<1	26.3	69.4	2.20±0.06

[1]Samples were extruded on the Brady extruder.

[2]Linear regression equation used to obtain values.

[3]Corrected relative to casein = 2.50.

Table 24. Effect of moisture level on the inactivation of antitrypsin activity and urease.

FSN Code #	Temperature °C	Whole soy	Dehulled soy	Retained steam[1]	Water added	No. of passes	% Trypsin inhibitor destroyed	Urease activity	Moisture %
2-51- 9	139	x		x		1	46.5	0.07	4.06
2-51- 4	139	x				1	30.6	0.09	4.72
2-51- 5	138	x		x	1.5	1	33.7	0.12	4.52
2-51- 7	138	x		x	3.0	1	53.7	0.13	5.18
2-51- 8	143	x		x		2	66.1	0.07	1.55
2-51- 2	143	x		x		3	74.7	0.12	1.17
2-51- 1	149	x		x			57.9	0.09	3.00
2-51- 3	154	x		x			81.2	0.23	3.02
2-51-12	156		x	x			79.0	0.02	2.80
2-51-10	145		x	x			39.1	0.06	2.73
2-51- 6	138		x	x	1.5		47.6	0.13	3.62
2-51-11	139		x	x	3.0		67.8	0.03	4.00

[1]Steam captured with product at the die.

content will both be varied and antitrypsin activity and PER measured in the resulting products.

2.5.2 Baking Properties

Full-fat soy flour was made from dehulled soybeans processed on a Brady extruder at 138-140°C and ground using a pin mill. The flour was incorporated into bread at 5%, 10% and 15% levels and compared to Nutrisoy 220 at the 5% level.

Bread formulation and the results are shown in Table 25. Average particle size of the pin-milled, full-fat soy flour was very similar to that of the commercial product Nutrisoy 220 and quite satisfactory for bread baking. The pin-milled sample, however, contained small black specks which had been found previously in other samples. These black specks were apparent only in the dough. They were not noticeable in the breads.

Breads were baked without using any improvers such as CSL or SSL. The experimental sample performed as well as the commercial Nutrisoy 220 at the 5% replacement level.

Bread volumes did not change when replacing up to 15% of the wheat flour with full-fat soy. The crust color and crumb color of the breads were slightly darker and the grain slightly more open at the highest level, which is expected. Normally, the level of usage of full-fat soy will not exceed 12% of the wheat flour/soy blend.

The flavor of all breads was quite satisfactory.

The pin-milled, full-fat soy product was quite satisfactory and equal to the commercial Nutrisoy 220 in bread baking performance. The black specks in the product, however, might be objectionable to the baker.

Table 25. Effects of pin milled full-fat soy flour added to bread.

Formulation:

Ingredient	%	Grams	Procedure
Flour blend	100.0	250.0	Mix to optimum
Water	--[1]	--[1]	Ferment 1 1/2 hours
Yeast	2.5	6.25	Divide - 200 g (2 loaves)
Yeast food	0.5	1.25	Round - rest 10 min.
Salt	2.0	5.0	Mold
Sugar	6.0	15.0	Proof to height
NFDM (control only)	4.0	10.0	Bake 18 min. at 218°C.
Shortening	3.0	7.5	
Potassium bromate	--	10 ppm	

Dough	Blend composition	Absorption %	Mixing time[2] min.	Proof time min.
1	Wheat flour control	72	4 1/2	51
2	95% wheat flour/ 5% Nutrisoy 220	76	4 1/2	51
3	95% wheat flour/ 5% AE pin milled soy flour	76	4 1/2	51
4	90% wheat flour/ 10% AE pin milled soy flour	78	4 1/2	51
5	85% wheat flour/ 15% AE pin milled soy flour	80	4 1/2	47

Bread Scores:[3]

Dough	Specific volume cc	Crust color (7)	Symmetry (7)	Break (6)	Crumb color (10)
1	3.97	7	7	6	9
2	3.92	6	7	6	8
3	4.18	6	7	6	8
4	4.06	5	7	6	7
5	3.90	5	7	5	7

Dough	Flavor (15)	Grain (20)	Texture (20)	Volume (15)	Total score (100)
1	14	17	19	10	89
2	14	15	17	10	83
3	14	15	19	11	86
4	14	15	18	11	83
5	14	13	17	10	78

[1] See Absorption %, below.
[2] National Manufacturing Co. mixer was used.
[3] Numbers in parentheses under each bread characteristic indicate maximum number of points.

2.6 Rice Bran

Stabilization of rice bran has important significance in the rice industry. Rice bran has a large percentage of oil (about 14%) which can be recovered with oil presses or solvent extraction. A significant problem exists since the relationship between the oil press capacity and the bran available for this process do not match. Rice is generally milled on a seasonal basis at high rates. This milling produces large quantities of rice bran which surpass the throughput capacities of the presses. Consequently, the rice bran must be stored.

Currently, the oils in the rice bran must be recovered quickly after milling to prevent rancidity from the lipases present in the raw bran. This biological problem can be reduced and sometimes eliminated through heat treatment, which heat deactivates the enzyme system, rendering the rice bran stable. Heating to 135°C appears sufficient.

LEC's lend themselves to the stabilization of rice bran since they are a high temperature/short time process. The particular application envisioned would involve the installation of an LEC in a rice mill which would heat process the bran prior to storage. Thus, the rice bran would be stabilized and could be stored until the oil could be extracted. If mills were present, one portable LEC could be moved from mill to mill on a three- or four-day rotation to stabilize the bran which was available.

Several countries have shown interest in using the LEC to heat process rice bran:

1. Pakistan
2. The Philippines
3. Guyana.

Presently, Pakistan is initiating tests to study the effects of LEC extrusion on rice bran. Their objective is to identify the proper operating conditions and determine the feasibility of using an LEC in a rice mill for heat treatment of the bran after it is removed from the rice as discussed above.

In the Philippines there is also interest in stabilizing rice bran, should the opportunity be present. However, this is secondary to their major objective of making a weaning food. During the training session in the Philippines, rice bran was extruded (see Section 5.2.1.2) at several temperatures. Samples brought back to CSU are presently in storage studies to determine the long-range stability of the product.

Guyana is also considering the use of rice bran for warming up and shutting down their LEC extruder due to a short supply of soybeans. Initial attempts during the training session indicated that the extruder could be satisfactorily warmed up with rice bran. Problems with transition plugs resulted due to the high moisture and/or long storage of the bran.

3.0 EQUIPMENT EVALUATION

During 1977, evaluations were made of some basic LEC plant components for their durability and suitability as continuous-use items. A major mechanical evaluation was made of the Brady 206 extruder. As an extension of this evaluation, a survey was made of the major processing and handling equipment manufacturers to determine typical operating and maintenance characteristics of various functional equipment types.

In this section, a description is also given of a dehulling laboratory installed at CSU which utilizes a Sturtevant scourer-aspirator

with cyclone for separation of fines and hulls. This machine is the type that has been recommended for installation in the new plants located in Costa Rica and Sri Lanka.

3.1 Brady

3.1.1 Mechanical Evaluation

The mechanical evaluation of the Brady Crop Cooker has been complete by Dr. James L. Smith, Department of Agricultural and Chemical Engineering, Colorado State University. The objectives were:

1. To evaluate the mechanical components of the Brady extruder with respect to duty rating and longevity (time before major overhaul and replacement of parts).
2. To recommend minor alterations to the Brady that would increase the duty rating and longevity of the equipment.

The Brady extruder was initially designed for intermittent duty under farmstead conditions. Areas which limit continuous duty applications are:

1. Hydraulic system
2. Bearing housing weldment lubrication
3. Drive train components.

Minor modifications to alleviate these limitations will require little additional cost and should increase the longevity of the equipment to at least 10,000 hours. Ten thousand hours represent 1.5 years of continuous, 24-hour operation or 4.5 years of 8-hour shift operation. It is expected that after this period, maintenance consisting of replacement of the barrel and bearings and rotor weldments would be required. The cost of these replacement parts would be approximately $1,000, which

is nominal per operating hour. Such replacement of machine operating components after extensive operation is a normal maintenance procedure on processing equipment.

3.1.2 Suggested Field Modifications

3.1.2.1 Hydraulic System. The hydraulic system was found to be adequate for intermittent duty. Improvement of the hydraulic system could be made by upgrading components such as pumps, motors, and valving with continuous duty components. An alternative would be to remove all hydraulic components by replacing the current feeder with an open-hopper system directly above the screw feed port. A design of this type will be utilized in the new Sri Lanka installation.

Currently, one modification has been to place a valve into the hydraulic system of the Brady that will reverse the direction of the feed injector auger. This was installed to assist in unplugging the auger when necessary. The device has been tested and works very well. Disassembly of the injector system no longer seems necessary except for the most difficult jamming of the barrel inlet. The valve itself was installed with the control directly under the cone adjustment handle which has proved convenient. The valve is a standard hydraulic directional control valve of the open center design with 9.5-mm pipe fittings. A Teledyne Republic Model 8052B-3/8 1PT-H52 would be ideal, however, a similar substitute was used at CSU. The valve should be rated for 140 kg/cm^2 and have a detented rather than spring loaded control so the valve may be left in the reverse or forward position. Three 90-cm, 9.5-mm hydraulic hoses with pipe thread ends and swivels were also

required for the modification which were purchased for less than $100 (Fig. 1).

3.1.2.2 Bearing Housing Weldment Lubrication. Although the bearing housing weldment is of a continuous duty design, lubrication while the extruder is running is quite difficult. A design which could utilize an automatic lubrication system would solve a majority of the bearing problems stemming from lubrication difficulties.

The bearing housing was designed so the lubrication point does not permit adequate application to the front bearing (which is subjected to heat during extrusion). For this reason, an additional grease passage was drilled into the housing so that adequate lubrication could be provided to the bearing. The modification is shown in Figure 2.

3.1.2.3 Drive Train Components. Drive train components have been primarily designed for farm duty operation. Power transmission through the drive train of the extruder presently involves high torque loadings. Although the components were designed for the continuous load, our experience in Sri Lanka indicates universal bearing failure after 1,500 hours of operation due to shock loadings. It is felt that the easiest way to overcome problems with the drive train would be to drive the extruder with belts. The belt drive coupled with a gear reduction at the extruder would reduce the high torques transmitted through the present drive train. In addition, some safety override protection would exist with belt slippage at high loads.

3.1.2.4 Further Modifications. In addition to the aforementioned modifications, the following list describes some further minor modifications

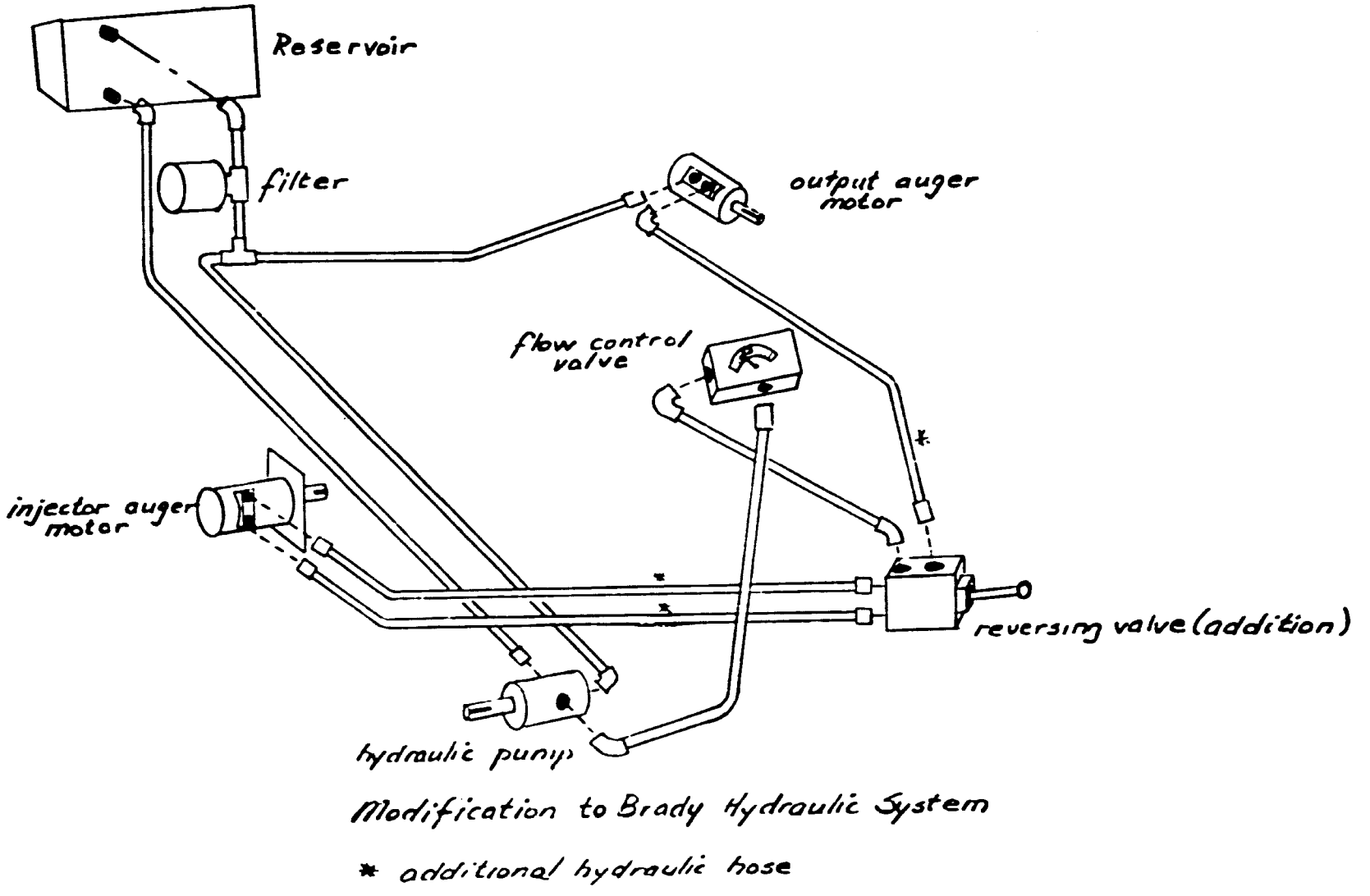

Figure 1. **Brady hydraulic system with injector auger reversing valve.**

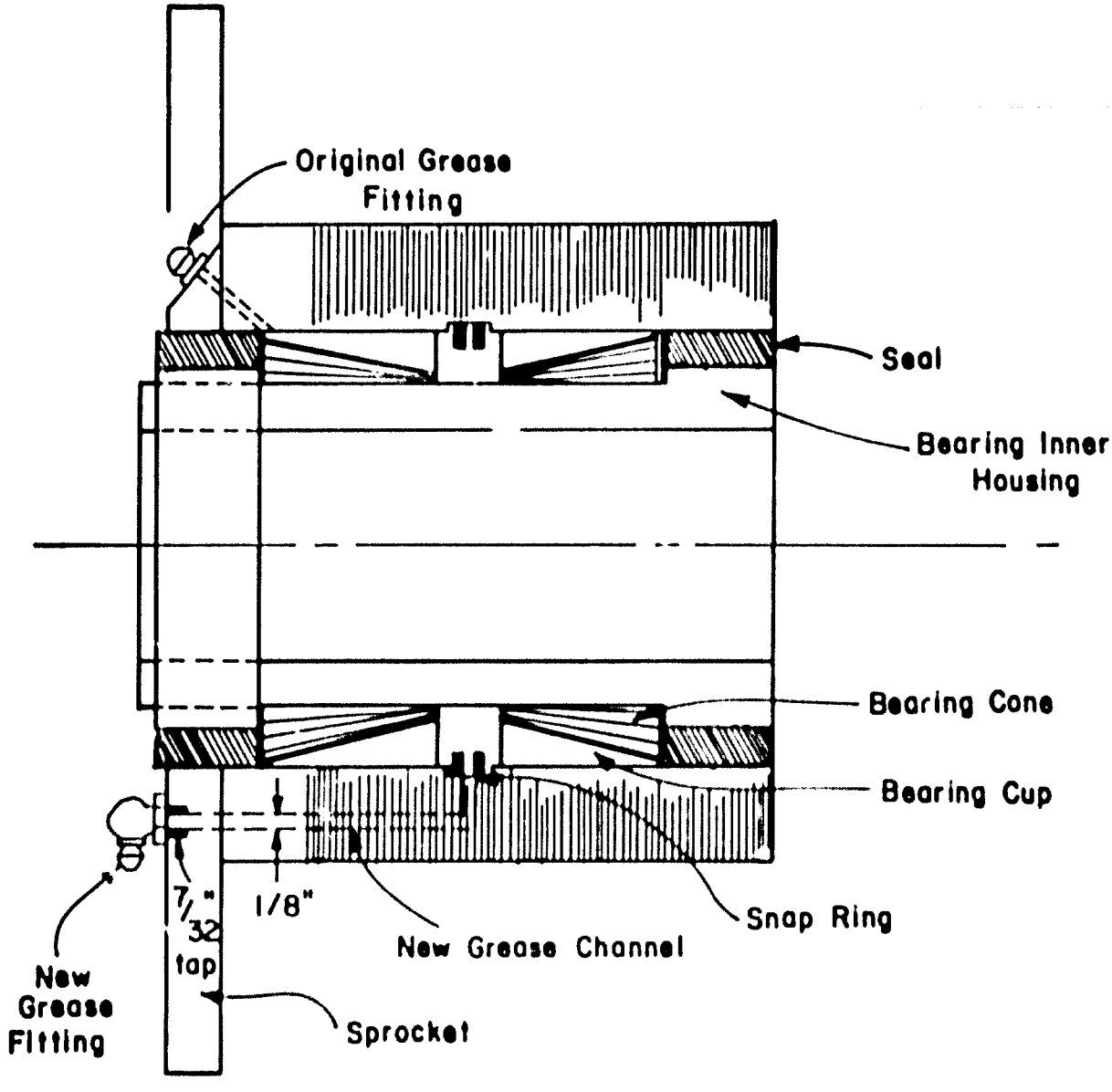

Figure 2. Brady extruder front bearing, showing the new grease channel and fitting added as a modification.

whereby the life and reliability of the Brady could be significantly improved.

1. Hardening of Screw Flights - In order for the extruder screw to have a 1,500-2,000 hour life as stated earlier, it was decided that a severe abrasion-moderate impact hardness would be necessary (Rc 58 or higher). Tests in Sri Lanka, extruding CSB-type products, indicated that a rotor rebuilt with a Rc hard-surface welding rod lasted several thousand hours.

2. Elimination of All 1/2-inch Bolts - The present design utilizes 1/2-inch, Grade 5 machine bolts to attach the cone to the rotor. These bolts have adequate strength: however, they physically resemble 13 mm bolts and accidental use of a 13-mm bolt would damage the threads in the rotor. The problem can be remedied by increasing the bolt size to 9/16-inch, a size which does not have a metric equivalent.

3. Replace Temperature Measuring Device and Add a Temperature Sensor in the Screw Feed Section to Detect Impending Plugging - A capillary type temperature probe and gauge is furnished with the Brady. There are several problems associated with this gauge.

a. The gauge does not have capability to read above 163°C.

b. The sensitivity of the gauge is low and considerable lag time occurs between adjustment of the extruder and changes in the gauge reading.

c. Accuracy is low.

A surface type thermometer has been used to overcome some of the problems mentioned above. Although this sensor has sufficient accuracy, foreign material lodges in the sensor coils with time, causing erroneous readings.

Two solutions can be considered:

1. Thermocouples

2. A more durable thermometer.

A standard bimetallic thermometer would be an improvement, however, the location of the sensor on the barrel is critical. If not placed properly, the temperatures would be read incorrectly.

A copper-constantan thermocouple with sensing device could be installed at minimal cost. High sensitivity and accuracy would be possible, thus reducing operational problems.

The temperature sensor should be retained in the feed section of the screw. Location of a temperature sensor in this region allows detection of impending plugging and permits stopping the flow of input material or the extruder before it becomes plugged. The sensor could be connected to an alarm system to alert the operator and/or directly to the controls on the power source to automatically stop operation. A standard bimetallic thermometer would be suitable for the detector system sensor.

3.1.3 Parameters Affecting the Performance of the Brady

Mr. Jaime F. Sahagun recently completed the requirements for his Master's degree. His thesis work was involved in evaluating the Brady Crop Cooker with respect to several extrusion parameters:

1. Rotational speed of screw

2. Screw geometry

3. Throughput.

The effects of these parameters on extrusion performance were examined through measurement of selected dependent variables:

1. Energy (torque, speed)
2. Throughput
3. Temperature of extrusion
4. Temperature distribution along the barrel
5. Output product characteristics
6. Residence time.

A mixture of 70% whole corn and 30% whole soybean was used throughout the experiment and the evaluation. Raw ingredients were ground in the Modern Mill to a +40 mesh. Sections 3.1.3.1 through 3.1.3.3 contain the results of the research.

3.1.3.1 Temperature Profiles. Thermocouples attached to the extruder barrel surface at selected lengths were used to record the temperatures along the barrel. Temperature profile changes were measured under varying extrusion conditions. Figures 3 and 4 represent typical temperature profiles for the extruder when running at 600 and 1,000 rpm for outlet product temperatures of 149, 163 and 171°C. The increased rpm's of the screw caused higher temperatures at the feed section of the extruder, which indicates an increase in the extruder's energy requirements. In general, the first 60 cm of the barrel from the feed input showed a profile 20°C higher for the 1,000 rpm runs than for the 600 rpm runs. This increase was due to higher shear and mechanical forces in the feed region which occurred because of greater backfilling of the screw at 1,000 rpm. Once the material entered the last 20 cm of the extruder, the profiles were essentially equivalent.

Examination of Figures 3 and 4 indicate that the product was exposed to relatively high temperatures for only a short barrel length

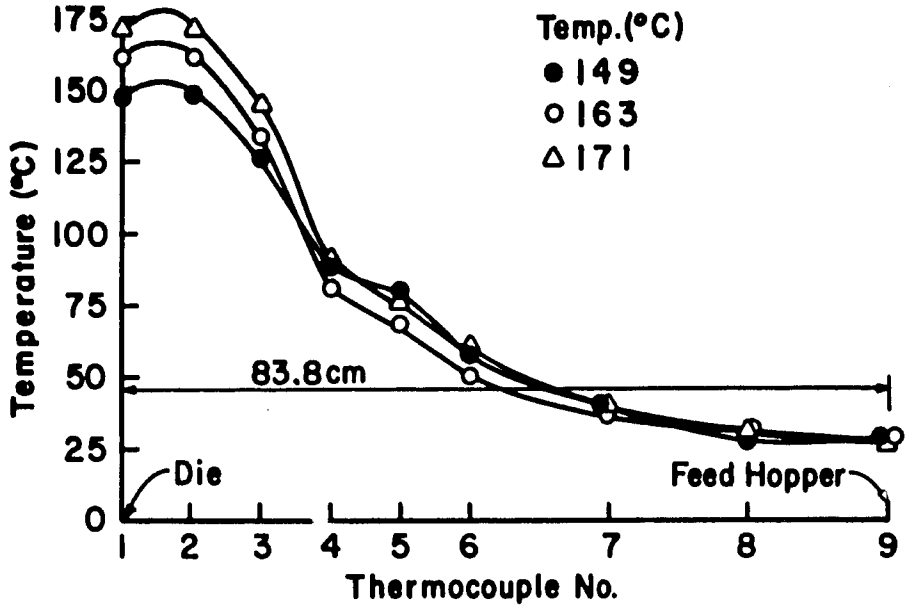

Figure 3. Temperature profile along the barrel for three final temperature settings (N=600 rpm, $\dot{m}$=6 kg/min, original screw).

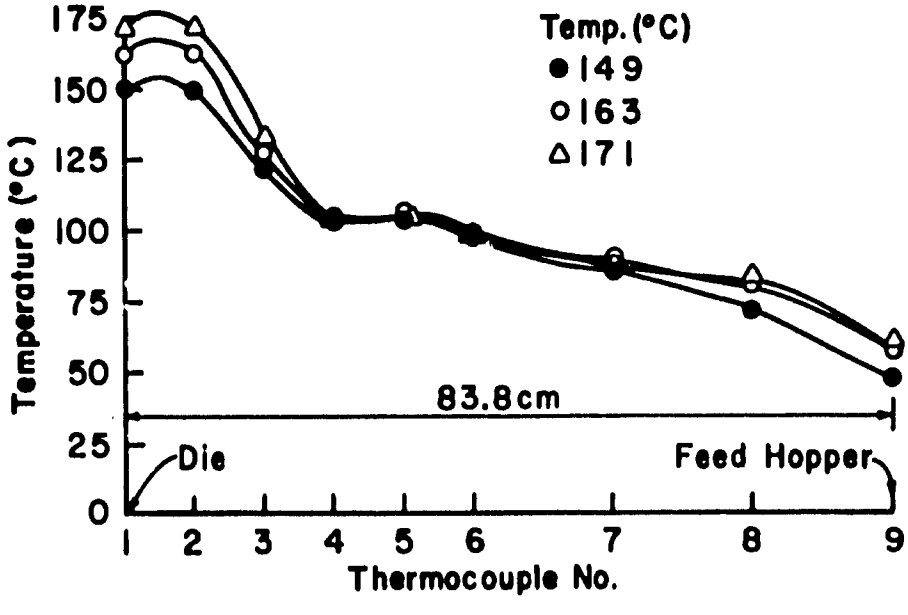

Figure 4. Temperature profile along the barrel for three final temperature settings (N=1000 rpm, $\dot{m}$=7 kg/min, original screw).

and that variations in temperatures at the orifice had only negligible influence on the temperatures in the first 60 cm of the extruder barrel.

The rapid decrease in temperatures measured in the last 7 cm of the barrel length can be attributed to heat transfer from the product to the large steel mass of the cone at the output (acting as a large heat sink). The cone was cooled because the extruded product lost temperature rapidly once it left the annulus around the cone and its pressure became ambient.

Effects on the temperature profile due to changes in throughput can be found in Figure 5. In all instances, the temperatures at each point along the barrel were higher for the lower feed rates. Since residence time was increased at lower feed rates and the energy input per unit length was roughly constant, higher product temperatures at the feed end

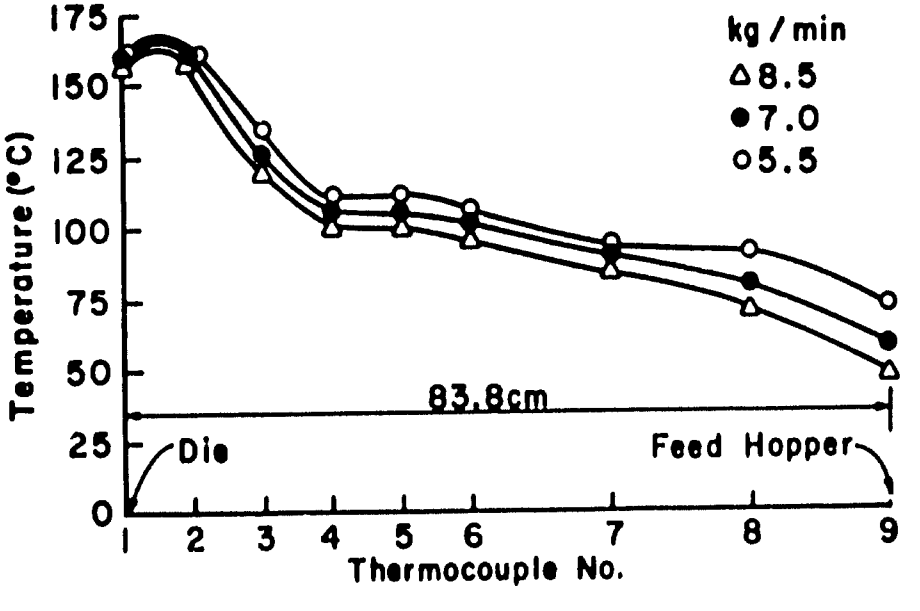

Figure 5. Temperature distribution along the barrel as a function of mass flow rate (N=1000 rpm, T=163°C, original screw).

should be expected. High temperatures at the feed inlet of the barrel could cause sticking of material and plugging in this region. Feed rates below 5 kg per minute are, therefore, not recommended for continuous operation.

A series of rotor weldment configurations were evaluated (Fig. 6). Beater bars [welded ridges placed across extrusion screw (flights)] were added or deleted selectively to determine the effects of their numbers and locations on extrusion. Typical temperature profiles for the various screw configurations are shown in Figure 7.

For the five screw configurations used, the following conclusions can be made:

1. The number of beater bars along the screw is not as critical and does not affect the operational performance of the extruder as much as their placement and distribution. Bars placed closer to the discharge end (die) were found to exert higher influence on energy requirements than bars placed further down the screw.
2. Temperature distribution along the barrel can be somewhat controlled by accurate placement of beater bars.
3. Consistency tests for all extruded samples indicated that different screw configurations gave products with different consistency characteristics. Higher consistencies (meaning higher degree of starch gelatinization) were obtained from screw configurations having increasing number of bars, and also having bars placed further down the screw (away from the die).

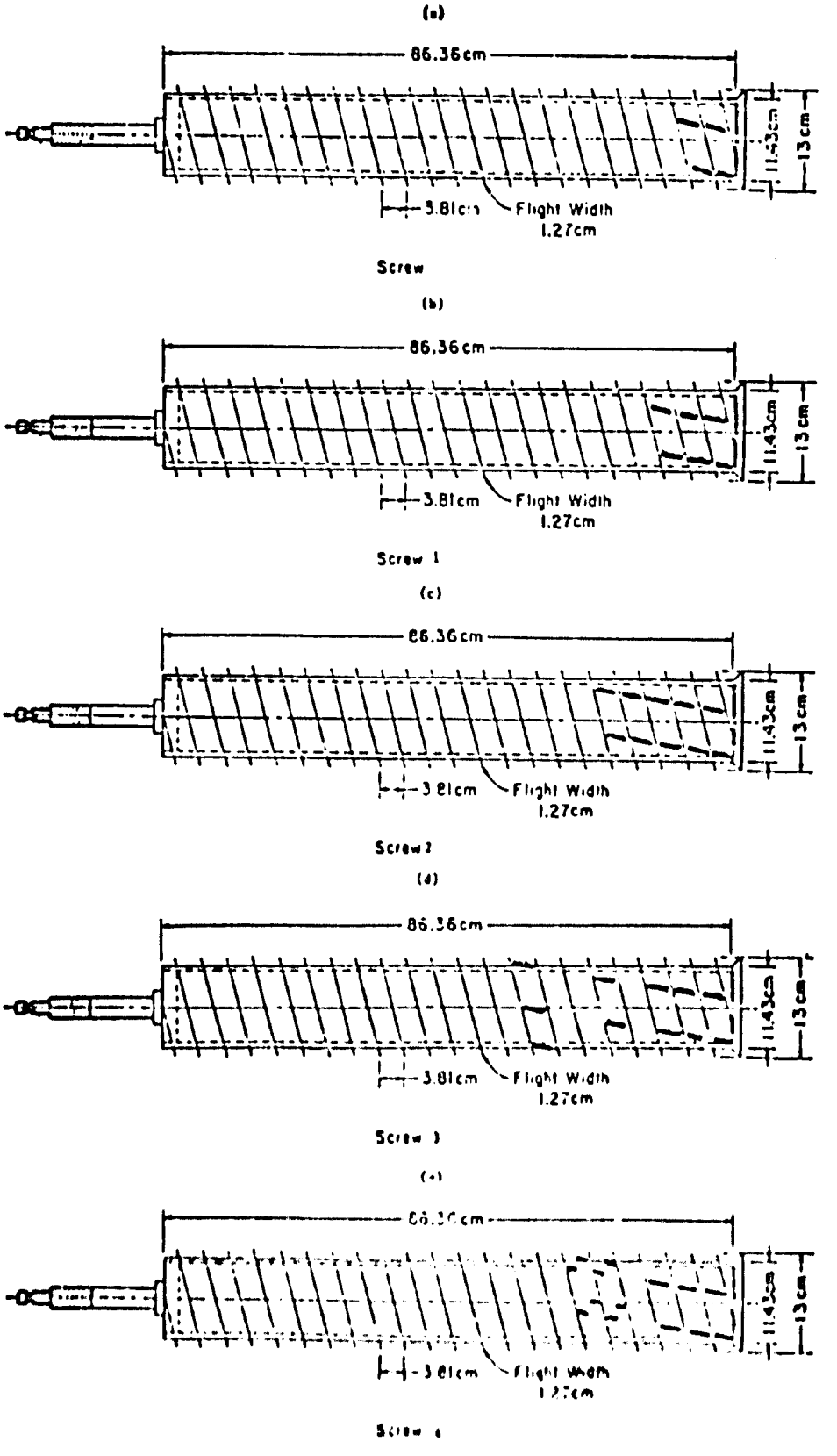

Figure 6. Beater bars placement in the original screw (a) and in each one of the four configurations tested (b, c, d, and e).

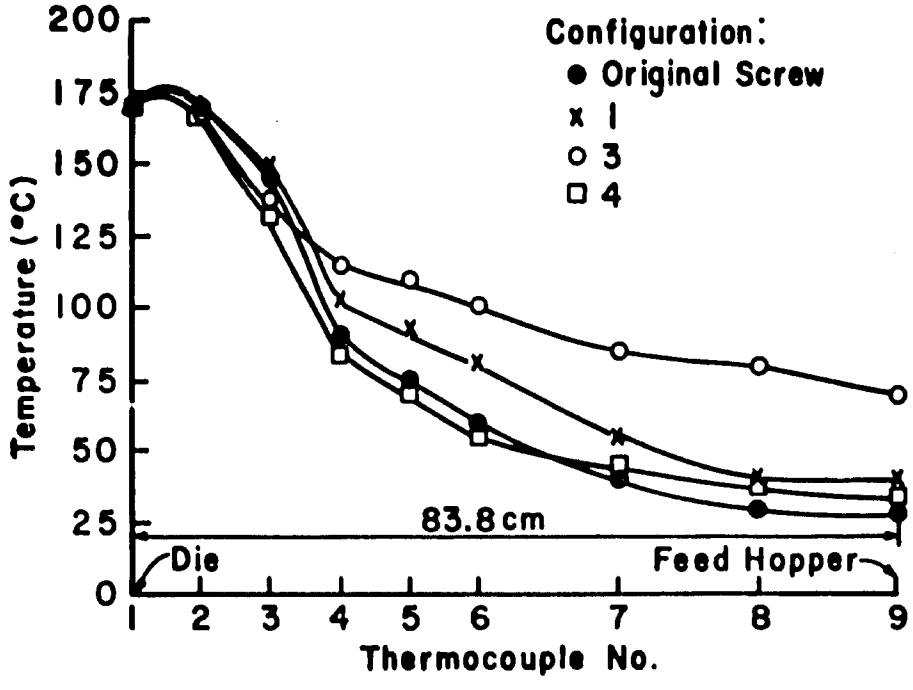

Figure 7. Effects of screw geometry on temperature distributions along the barrel ($T=171^{o}C$, $\dot{m}=5.5$ kg/min, N=600 rpm).

4. Puff indices and bulk densities were not found to be markedly affected from the different screw configurations used. However, greater variations were observed in the total bulk density test than in the puff index test. Temperature of extrusion was once again found to be a major variable affecting expansion of the extruded pieces.

3.1.3.2 Energy Input to Extruder. Power measurements were made using the BLH torque sensor and Servo-Tek generator for rpm. Thus, specific energy could be determined.

Energy was measured for the following extrusion variables:

1. Product temperature
2. Screw speed

3. Throughput

4. Screw configuration.

Energy measurements for different feed rates at different temperatures indicated that the energy increased approximately 12% when extrusion temperature increased from 149° to 163°C and from 163° to 171°C. Energy increases were found to be linearly proportional to feed rates, as would be expected, assuming a constant heat capacity for extrusion feed materials.

Specific energies were found nearly independent of rotor speeds at constant temperature. Slight increases in energy were found when the rotor speed was higher than 1,000 rpm due to higher shear and mechanical forces leading to increased starchy component modification. The relationship between specific energy and rotor speed at constant temperature and feed rate is shown in Figure 8.

Figure 9 indicates the specific energy of each of the four rotor configurations that were tested. Each configuration affected energy requirements differently. Higher specific energy demands were consistently required with increased number of beater bars closer to the discharge end of the screw (configuration 1, 2 and 3 were higher than the original screw). With bars located in helix turns close to the discharge end, the increased power requirements made extruder operation extremely sensitive to adjustments. Therefore, use of such configurations is not recommended for all but high moisture or high oil content ingredients.

Minimum specific energy demands were attained when using screw configuration 4, where bars measuring half of the length of the

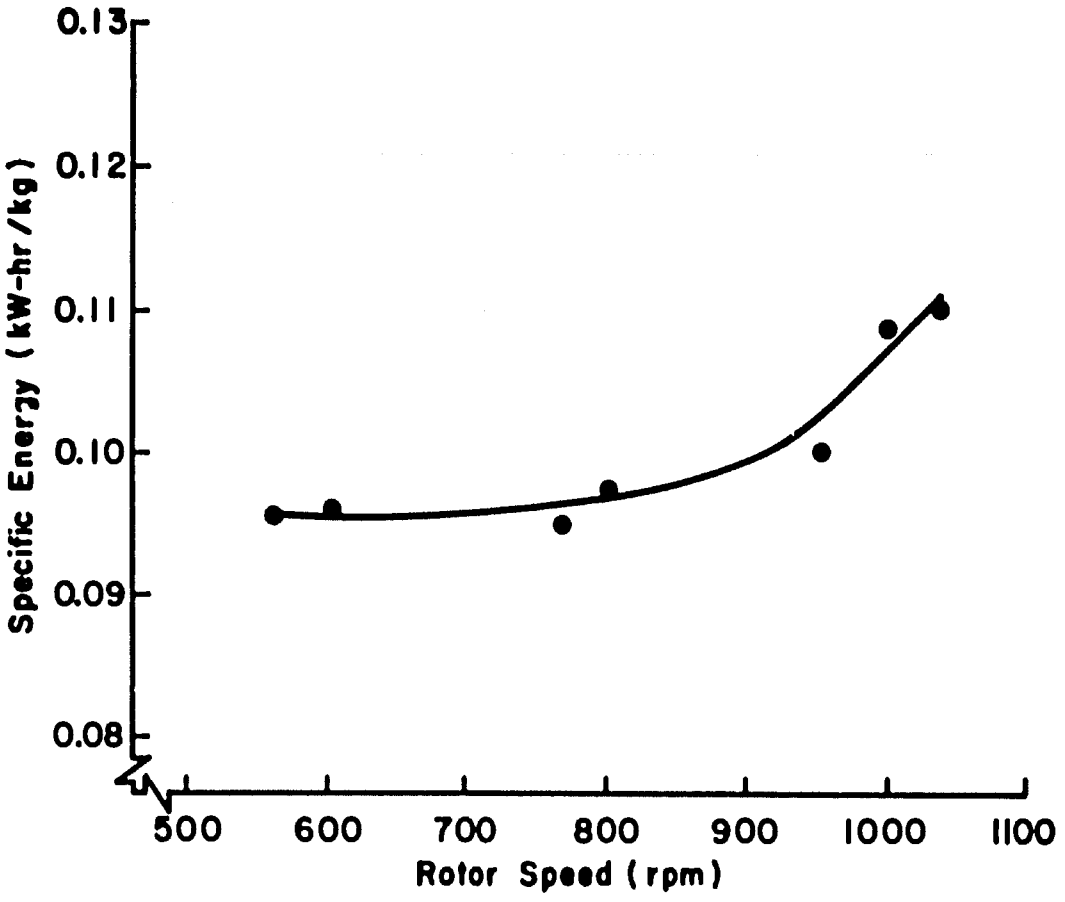

Figure 8. Specific energy as a function of rotor speed (T=149°C, original screw).

conventional bar size were located at opposite sides of the screw channel, allowing for better mixing while reducing the back flow in the channel.

3.1.3.3 Product Characteristics. Tests were performed on the extruded products to determine how the functional properties were affected by extrusion parameter variations. Results indicated that temperature and rotor geometry have a greater influence on product characteristics than do rotor speed and feed rate.

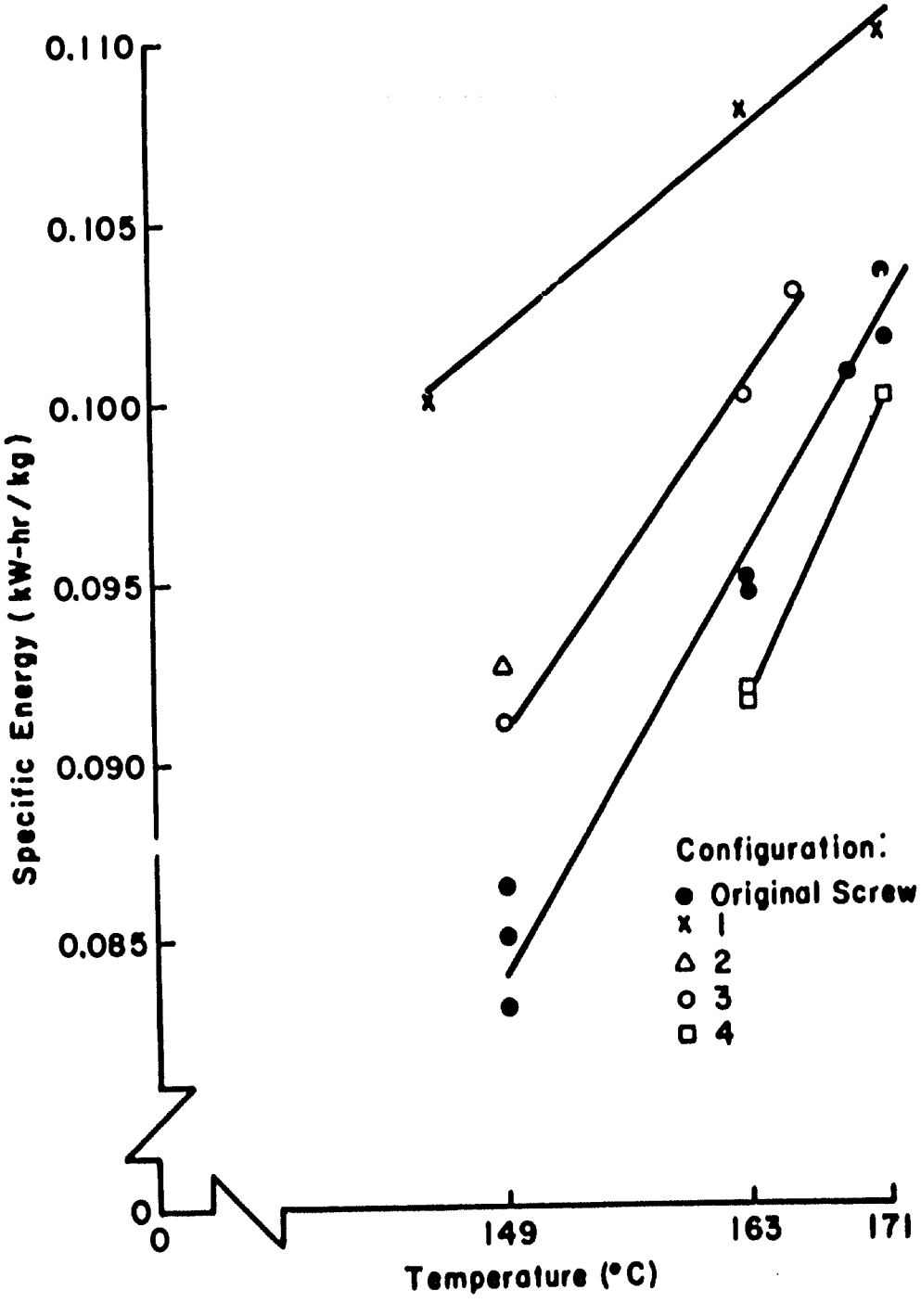

Figure 9. Specific energy as a function of temperature of extrusion and screw geometry (N=600 rpm, $\dot{m}$=5 kg/min).

Damaged starch tests were performed on the extruded products. Results are shown in Figure 10. Cleavage of starch molecules (as measured by concentration of reducing sugars) was higher when the temperature was increased. Rotor geometry was found to be a major parameter affecting modifications to the starch molecules. The addition of more beater bars to the screw increased the shear stress and energy input, resulting in a greater number of damaged starch molecules. Using the original screw as a reference, percentage increases in starch damage were tabulated below.

Rotor configuration	Temperature °C	% increase in glucose concentration (starch damage)
Original	163	0
1	163	-29
2	163	46
3	163	30

The negative value for screw configuration 1 can only be attributed to unobserved variations in the ingredient formulation used in the run.

Consistency tests on the extruded products are shown in Figure 11. In all instances, lower processing temperatures result in higher consistometer readings. Changes in rotor configuration altered consistometer values as would be expected. As more shear force was applied to the product with increased beater bars near the discharge end of the screw, the product had a higher viscosity and a smaller consistometer patty diameter. Potentially, changes in the number and location of the beater bars on the screw could allow the operator to control the viscosity of the resulting cooked product.

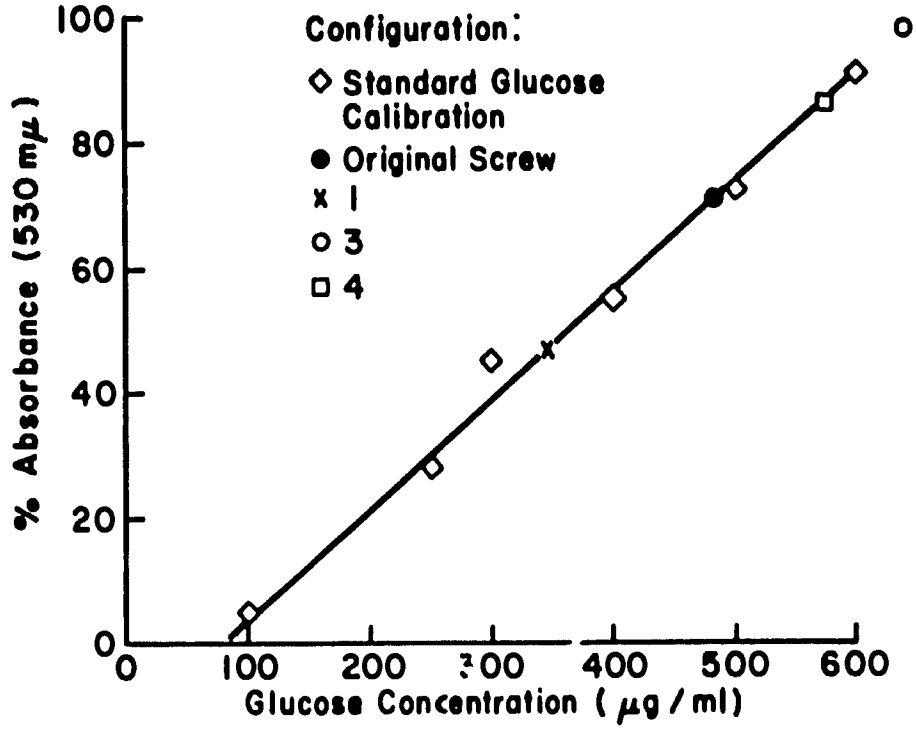

Figure 10. Variations on the reducing sugar concentration of products extruded with different screw configurations.

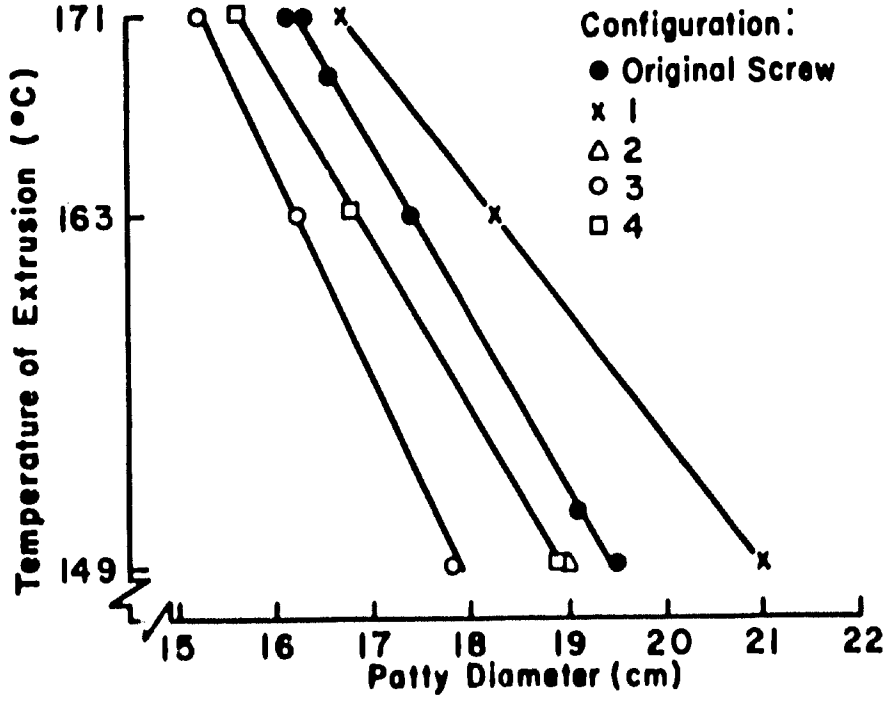

Figure 11. Consistometer test results for five screw configurations and three temperatures of extrusion.

In summary, the tests on beater bar locations on the screw of the Brady extruder showed that their location near the discharge end greatly affected the product by increasing energy input. Feed rate and screw rotational speed were also important parameters. Based on these studies, it is now possible to better recommend optimal operating conditions and screw configurations to achieve the desired results from the extruder.

3.2 Capabilities and Limitations

3.2.1 Brady Extruder. Through the extensive testing and evaluation program, the capabilities and limitations of the Brady extruder have been determined on a variety of products. A summary of these findings is given below.

Cereal/Oil Seed or Legume Mixtures--

Suitable cereals tested[2]: Corn (flint and dent), rice, wheat and sorghum.

Suitable oil seeds tested[2]: Soy, cottonseed (glanded and glandless), sesame and coconut.

Legumes tested[2]: Chickpeas and mung beans.

Ingredient requirements: All ingredients must be clean and free from foreign debris and stones. Dehulling is not necessary from an extruder operating perspective, but is necessary to reduce fiber concentration in weaning food formulations.

Formulation requirements: Any formulation mixture which contains a minimum of 5% fat but no more than 25% fat is suitable for

[2]Capabilities of the Brady extruder to successfully extrude other ingredients not tested is currently unknown.

extrusion. Mixtures of less than 5% fat have been demonstrated and can be used, however, the amount of wear and stress on the parts is accelerated.

Pregrinding requirements: Pregrinding of ingredients to -20 +50 mesh is essential to accomplish a uniformly well cooked product.

Water addition: Water can be added directly to dry ingredients in the injector auger of the Brady extruder. Ingredient mixtures with only 5% fat require 3-5% water addition. No water addition is required for formulations having more than 10% fat but it increases the destruction of antinutritional factors in the blend and reduces product shrinkage because of moisture losses. The maximum moisture level of feed ingredients is 20% or feeding problems will arise.

Extrusion temperatures: The range of suitable extrusion temperatures varies between 154-171°C. On most blends, the most desirable range is 154-163°C to minimize uncooked viscosities of finished product.

Product drying: No extra product drying is required under the range of conditions listed above to achieve a stable product, assuming initial grain moistures do not exceed 14%. Cooling is required to <70°C for proper grinding of extruded product.

Product shape: The Brady extruder cannot produce uniformly shaped pieces of cooked or expanded product because its die consists of an annular ring which cannot be precisely centered. The typical product is irregular shaped, flat flakes mixed with 40-50% fine material.

Production rate: Production rate should be limited to 340-450 kg/hr. Operation of the extruder is not particularly sensitive to speed of rotation of the screw between 540 and 1,000 rpm. For operation between 540-600 rpm, 75 kW of power should not be exceeded to prevent excessive torque from being transmitted. Screw speeds lower than 540 rpm should not be attempted because of excessive torques required.

Machine design: The current design of the injector auger, drive shaft with universal joints, hydraulic drives on injector auger and take-away conveyor, and rotor bearing weldment limit the mechanical reliability of the extruder. Minor mechanical alterations can eliminate these design deficiencies for operation as a continuous duty extruder. With proper modification, operation for 10,000 hours between major overhauls can be accomplished.

Machine operation: Proper operation and temperature build-up and control are achieved when a cone with a sharp leading edge and well defined beater bars (screw channel restrictions) exist. Replacement of cone or rebuilding of screw components must be done when these components become worn. Normal time interval varies with product and ranges from 250 to 2,000 hours of operation, provided the raw materials are free from stones and dirt.

Product characteristics: Extruded product characteristics can be varied by control of extrusion temperature, water addition and oil level in formulations within the limits described above.

The Brady extruder can produce a well cooked product characteristic of dry extrusion processing. Under these conditions, the starch is partly gelatinized and at high temperatures partially dextrinized. Uncooked viscosities tend to be high. Inactivation of growth inhibitors and antinutritional factors has been found to be very good, producing products with excellent food and protein value. Water absorption index of a well cooked mixture is normally >200% and nitrogen solubility index will vary between 10-25%.

Vitamin/mineral addition: All vitamin and mineral mixtures must be blended into ground, extruded mixtures after extrusion if they are to have long shelf life stability. Extrusion in the Brady extruder seriously alters the productive coating on vitamins which are easily oxidized, making them unstable in storage.

Nutritional characteristics: The Brady extruder is capable of producing a highly nutritious product for consumption as human food. Typical corrected PER's are 2.5, NSI's of about 10% and water absorption index (WAI) about 250%.

Whole Oil Seeds--

Suitable oil seeds tested: Soy

Pregrinding requirements: Cleaned soy need not be preground before extrusion. It is recommended, however, that it be ground to -20 +50 mesh to improve uniformity and reduce energy requirements for extrusion.

Water addition: None required but 1-3% is desirable to enhance destruction of antigrowth and antinutritional factors. Water may be added directly to ground beans in feed hopper.

Dehulling: Not required but desirable.

Product drying: No additional product drying is required beyond the moisture naturally lost following extrusion, as part of the cooling process.

Extrusion temperature: Minimum extrusion discharge temperature of 138°C is required. Higher extrusion temperatures of about 143°C are very desirable and result in greater reduction of antinutritional factors.

Production: Maximum production rate is 340 kg/hr at 540 rpm and 450 kg/hr at 1,000 rpm.

Machine design: The current design of the injector auger, drive shaft with universal joints, hydraulic drives on injection auger and take-away conveyor, and rotor bearing weldment limit the mechanical reliability of the extruder. Minor mechanical alterations can eliminate these design deficiencies for operation as an autonomous duty extruder. With proper modification, operation for 10,000 hours between major overhauls can be accomplished.

Machine operation: Proper operation and temperature build-up and control are achieved when a cone with a sharp leading edge and well defined beater bars (screw channel restrictions) exist. Replacement of cone or rebuilding of screw components must be done when these components become worn. Normal time interval varies with product and ranges from 250 to 2,000 hours of operation, provided the raw materials are free from stones and dirt.

Extruded product: Extruded product resembles coarse, oily saw dust in appearance. A large quantity of surface oil means that the product can only be reduced to flour mesh with a pin mill having counter-rotating milling members. Product milled in this manner is suitable for fortification of bread or other baked products.

Nutritional characteristics: The Brady extruder is capable of producing a highly nutritious product suitable for consumption as human food. Typical PER's are 2.0, NSI's of about 10% and WAI of 150%.

3.2.2 Insta-Pro Extruder. Less testing and evaluation has been performed on the Insta-Pro 500 extruder. This condition has arisen because with the current screw, high cereal formulations have been difficult to process on a continuous basis. A new altered set of screws are being supplied by Triple "F" and these may extensively alter the extrusion of high cereal blends.

Cereal/Oil Seed or Legume Mixtures--

Suitable cereals tested[3]: Corn (flint and dent), rice, wheat and sorghum.

Suitable oil seeds tested[3]: Soy and cottonseed (glanded and glandless).

Ingredient requirements: All ingredients must be clean and free from foreign debris and stones. Dehulling is not necessary

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[3]Capabilities of the Insta-Pro extruder to successfully extrude other ingredients not tested is currently unknown.

from an extruder operating perspective, but is necessary to reduce fiber concentration in weaning food formulations.

Formulation requirements: Any formulation which contains a minimum of 10% fat but not more than 20% is suitable for extrusion.

Pregrinding requirements: Pregrinding of ingredients to -20 +50 mesh is essential to accomplish a uniformly well cooked product. The size of ingredients should be towards the larger mesh size to eliminate extrusion problems which are associated with feeding.

Water addition: Water is added directly through an injector inserted into the thermometer well in the barrel section nearest the feed port. Ingredient mixtures with less than 10% fat require 5-15% water addition to keep the extrusion temperature down and prevent burning in the barrel.

Feed addition: All feed materials are fed using the side-mounted volumetric feeder with a variable speed control. A rear hopper with a vibrating feeder is kept filled with whole soy to add if overheating of the extruder occurs.

Extrusion temperatures: Extrusion temperatures over 150°C typically result in burning the product. Because of lower extrusion temperatures, the uncooked viscosities of the extruded product are lower. Extruded products appear to be more uniformly cooked on the Insta-Pro than on the Brady at lower extrusion temperatures.

Product drying: When greater than 5% of water is added, some product drying may be required since the extrusion temperatures are lower and less moisture is lost in cooling.

Product shape: The Insta-Pro is designed so a single orifice or multiple-hole die can be used. Variable shape die inserts are possible. A variable speed face cutter allows the pieces to be cut at varying lengths.

Production rate: Production rate on the Insta-Pro is limited to a maximum of 300 kg/hr. Rotational speed of the screw is 540 rpm.

Machine operation: No definitive testing has been done to determine machine longevity. Replaceable wear components consisting of steam locks and wear rings should reduce maintenance costs. For high cereal formulations, the smallest set of steam locks should be incorporated.

Product characteristics: Extruded product characteristics can be varied by control of extrusion temperature, steam lock configuration, water addition and oil level in formulations within the limits described above. The Insta-Pro extruder can produce a well cooked product characteristic of dry extrusion processing. Under these conditions, the starch is partly gelatinized and at high temperatures partially dextrinized. Uncooked viscosities tend to be high. Inactivation of growth inhibitors and antinutritional factors has been found to be very good, producing products with excellent food and protein value. Water absorption index of a well cooked mixture is normally >200% and nitrogen solubility index will vary between 10-25%.

Vitamin/mineral addition: All vitamin and mineral mixtures must be blended into ground, extruded mixtures after extrusion if they

are to have long shelf life stability. Extrusion in the Insta-Pro extruder seriously alters the productive coating on vitamins which are easily oxidized, making them unstable in storage.

Whole Oil Seeds--

Suitable oil seeds tested: Soy and cottonseed.

Pregrinding requirements: Cleaned soy need not be preground before extrusion. It is recommended, however, that it be ground to -20 +50 mesh to improve uniformity and reduce energy requirements for extrusion.

Water addition: None required but 1-3% is desirable to enhance destruction of antigrowth and antinutritional factors. Water may be added directly to ground beans in feed hopper.

Dehulling: Not required but desirable.

Product drying: No additional product drying is required beyond the moisture naturally lost following extrusion, as part of the cooling process.

Extrusion temperature: Minimum extrusion discharge temperature of 138°C is required. Higher extrusion temperatures of about 143°C are very desirable and result in greater reduction of antinutritional factors.

Production: Maximum production rate is 200 kg/hr.

Machine operation: To achieve proper temperature distribution and build-up, steam locks 10P-10-8 should be used for whole soy. The second largest steam lock (8) should be used at the discharge.

3.3 Survey of LEC System Components

In actual use, the Brady Crop Cooker has clearly demonstrated its capability to produce the kind and quality of products desired. However, several questions have been raised concerning its suitability and adaptability for continuous operation.

The Brady is one component of a materials handling and processing system. Reliability and maintenance requirements of the Brady must therefore be considered in view of similar criteria for other components which are also commonly used in the system. To secure needed data, a survey was conducted of manufacturers and suppliers of various components. Information on the useful life, maintenance and repair costs were obtained.

Obviously, any machine can have infinite life if preventive and required maintenance are performed when needed, and the costs are economically and/or legally justified. A classic example of this situation is the commercial airliner. In a more practical sense, however, repairs, maintenance, etc., must be considered in terms of costs, expected economic life and timeliness required for functional performance of the machine. In other words, the costs of maintaining an operational machine must be considered in terms of its cost per unit output or kg of product produced, the value added to the product, and the cost of not having the process available for certain time periods. Data contained in this survey can be used to estimate operating and maintenance costs for extruders and related equipment.

From the maintenance point of view, durability and reliability and/or the life of the machine are considered in three categories. They are:

1. Routine or preventive maintenance - This normally includes lubrication and minor adjustments to compensate for wear. It is usually done by the machine operator every few hours.
2. Minor overhaul - This includes cleaning, replacement of expendable parts and adjustments for wear. This is usually done by the machine operator or a mechanic at 1,000 to 2,000 hour intervals.
3. Major overhaul - This includes complete disassembly and replacement of major components including bearings. It is usually performed by a skilled mechanic at 10,000 hour or greater intervals.

Most engineers consider routine maintenance the most critical of the above three categories. It is normally performed by a person having limited skills, and who may, due to boredom or for other reasons, not perform required tasks unless closely supervised. Therefore, any machine modification that can be made to reduce routine maintenance is usually cost effective.

The durability of a machine must also be considered in terms of its intended purpose and the user community. This particular point explains the present design and maintenance schedule for the Brady cooker. For example, the Brady was designed for use on an American farm. In this application, the Brady would be operated by an individual who was very familiar with machinery and extremely conscious of the need for routine maintenance. Further, the operator would also be the owner in most situations. Another feature in this regard, is that the Brady would seldom be run for more than a few hours, i.e., three or four, since this

is actual time available between the farmer's meals. Routine maintenance would be performed each time the machine was operated.

The Brady cooker, as with any machine, can be made to have an infinite life. The important point, however, is to consider the specific application for the machine, and determine a reasonable time interval for specific maintenance or minor modifications that can be made to reduce maintenance. The following data contain information from a survey of ancillary equipment compatible for use in LEC systems and provide a basis for determining reasonable maintenance schedules and modifications for the Brady extruder.

Manufacturers and users were surveyed to determine reasonable estimates of equipment reliability and maintenance costs. The survey included all components that are or could be used in a LEC system. Components included in the survey were:

1. Bucket elevators
2. Screw conveyors
3. Belt conveyors
4. Feeders
5. Vibratory screens
6. Decordicators
7. Extruders
8. Milling machines
9. Dust collectors
10. Blenders.

Selection of manufacturers and users was based on the types of equipment considered. Emphasis was placed on manufacturers who produce continuous duty type equipment, but the survey included a broad spectrum

of equipment quality. Manufacturers and users selected were asked to respond to the following questions based on 24-hour, continuous operation of their equipment.

1. What is the expected useful life of the equipment?
2. What time period will the machine operate before a major overhaul is required?
3. What would be the cost of a major overhaul as a percentage of capital cost?
4. What are the annual maintenance costs as a part of capital costs?

All responses were carefully examined to ensure that reasonable values were obtained from the analysis. The following guidelines were used:

1. Any response of "infinite" was discarded based on experience.
2. Extremely low responses were discarded based on experience.
3. Average values were weighted more heavily to reflect a group of similar responses.

Average results of the survey are shown in Table 26 along with the range of responses. The large variation reflected in the range of responses was expected due to the sample selected.

Experience with and/or projections from LEC systems in current use are compared with average survey values in Table 27. In most cases, the LEC equipment is near the average value, and falls within the range of values given in Table 26. The major exception is the low-cost Brady extruder Model 2160.

Reasonable maintenance for use of the Brady Crop Cooker to process food products in developing countries was determined to be as follows:

Table 26. Survey summary of manufacturers contacted regarding equipment durability.

Equipment item	Number of responses	Normal life expectancy*, yrs.			Time for major overhaul, yrs.			Cost of major overhaul, % capital invest.			Annual maint. cost, % capital costs		
		Min.	Max.	Wt. Ave.	Min.	Max.	Wt. Ave.	Min.	Max.	Wt. Ave.	Min.	Max.	Wt. Ave.
Bucket elevators	3	20	∞	20	5	8	5	15	35	30	2	10	5
Screw conveyors	8	5	25	10	5	25	10	20	50	50	5	16	10
Belt conveyors	7	10	25	10	1	4	2	20	80	40	1	25	5
Feeders													
a. Vibratory	2	15	∞	15	3	15	10	NR	NR	10	5	5	5
b. Screw	3	18	∞	30	2	10	10	10	10	20	1	10	10
Vibratory screens (grain cleaners)	5	8	50	15	5	10	5	20	100	30	5	10	5
Decordicators	3	15	30	20	5	5	5	15	50	15	2.5	20	10
Extruders	7	10	∞	10	1	2	1	10	33	25	5	100	40
Milling													
a. Pin	3	20	50	40	2	50	5	10	50	15	3	5	10
b. Hammer	5	10	50	15	1	10	5	4	40	20	5	10	16
Dust collectors (pulsing bag filters)	3	15	20	15	15	20	15	100	100	100+	1	5	2
Blenders (horizontal batch mixer)	4	20	30	20	20	30	20	60	100	100	2	5	5

*24 hour continuous operation

Table 27. Comparison of LEC system with manufacturers' estimate.

Equipment item	Normal life expectancy*, yrs.		Time for major overhaul, yrs.		Cost of major overhaul, % capital invest.		Annual maint. cost, % capital costs	
	Survey	LEP**	Survey	LEP**	Survey	LEP**	Survey	LEP**
Bucket elevators	20	25	5	8	30	30	5	5
Screw conveyors	10	5	10	5	50	50	10	5
Belt conveyors	10	10	2	2	40	50	5	5
Feeders								
a. Vibratory	15	15	10	15	10	10	5	5
b. Screw	30	40	10	10	20	20	10	10
Vibratory screens	15	20	5	5	30	25	5	5
Decordicators	20	15	5	5	15	15	10	2.5
Extruders	10	5	1	1	25	33	40	60
Milling								
a. Pin	40	40	5	2	15	10	5	3
b. Hammer	15	10	5	10	20	40	10	10
Dust collector (pulsing bag)	15	15	15	15	100	100	2	2
Blender (horizontal batch mixer)	20	25	20	25	100	70	5	5

*24 hour continuous operation

**LEP = low-cost extrusion plant

1. Routine maintenance - Routine maintenance should be eliminated or reduced. Automatic lubrication should be provided, if possible.
2. Minor overhaul - Minor overhaul should be limited to thorough cleaning, tightening of all bolts and clamping devices and possibly resurfacing of wear surfaces such as the screw. This maintenance should be accomplished at intervals of 1,500 to 2,000 hours.
3. Major overhaul - Major overhaul should be accomplished at intervals of approximately 10,000 hours. The machine should be completely disassembled; major components, such as the screw, cone and bearings, should be replaced if required.

The LEC, Brady Model 2160, compares more favorably with industrial models based on actual annual costs per metric ton of capacity. These are shown in Table 28 along with values obtained from the survey. Both extruder types have similar annual maintenance costs, but the LEC has a much lower initial cost. It must be noted, however, that the percentage of down time and the cost of down time is not included in the analysis. Increased down time would increase maintenance costs per ton of output. On the basis of the available information and survey data, it can be concluded that the LEC is more appropriate than the industrial type, because of its lower capital investment requirements and smaller capacity, for the proposed uses to manufacture low-cost nutritious foods in developing countries. Minor modifications of the LEC should result in additional cost savings and further increase its reliability.

Table 28. Comparison of the Brady extruder and an industrial extruder

Criteria	Extruder	
	Low-cost	Industrial
Initial cost (US$)	10,000	80,000
Capacity (metric tons/hr)	0.45	1.4
Life (years)	5	10
Major overhaul period (years)	1.3	2
Approximate cost of overhaul (US$)	1,125	14,000
Approximate annual maintenance (US$)	2,400	3,000
Approximate maintenance cost over 10 years (US$)	32,600	100,000
Approximate average yearly cost (US$)	3,260	10,000
Approximate average yearly cost (US$/metric ton capacity)	7,200	7,275

3.4 Dehulling Laboratory

3.4.1 Description

Colorado State University staff members have designed and installed a dehulling laboratory as a part of the LEC experimental facility at the Agricultural Engineering Research Center/CSU. The equipment will aid CSU in the design and specification of low-cost dehulling equipment for LEC processing systems. The laboratory is designed to remove and separate hulls from seed endosperm of most of the raw grains that are used in LEC systems.

The general design of the system involves two types of components: hull removal devices and devices for separating hulls from the remainder of seeds. Two types of hull removal devices are in the laboratory: 1) a cracking mill for use with soybeans and other seeds in which hulls are removed when the seed is cracked, and 2) an abrasive impact mill which works well in removing tightly attached seed coats from round seeds. The separation device being used is a pneumatic classification system. The separation efficiencies that can be achieved with this system will be sufficient for low-cost processing systems.

The system is designed to accept raw material in batch or from the proportioner mill in the present extrusion laboratory. The raw material will be placed in either of the hull removal devices and will be dropped directly into the pneumatic classifier. Further classification systems could be installed after the pneumatic system to achieve higher separation efficiencies.

Work with flaking mills to loosen the seed coat of soybeans, followed by separation with a gravity table, has worked very well. Such a system has been supplied as a part of the equipment for the NMC plant in Tanzania.

3.4.2 Sturtevant

Tests with corn and soybeans have been run with the Sturtevant scourer-aspirator to determine dehulling efficiencies. The Sturtevant utilizes an abrasive impact to detach the hull from the seed followed by a pneumatic separation of the hull and meat. A flow diagram of the system tested is shown in Figure 12.

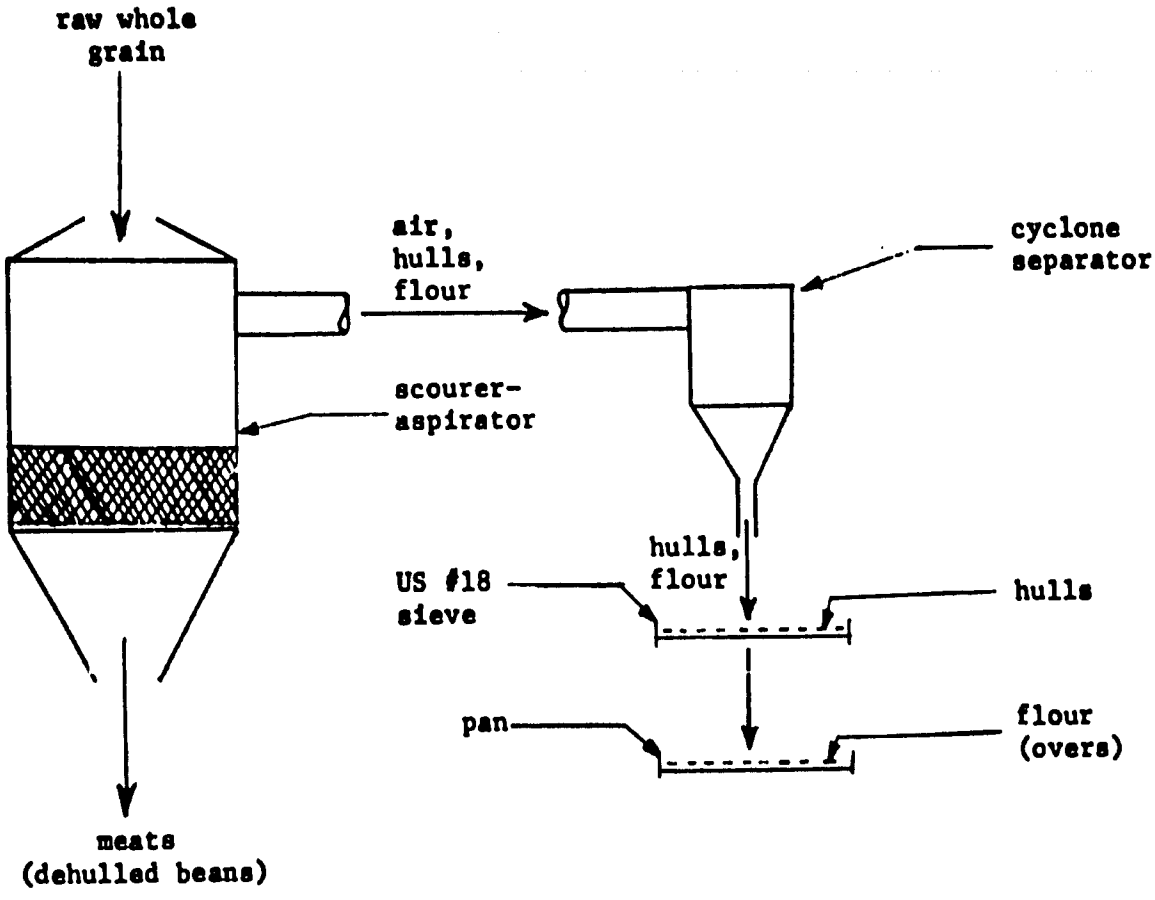


Figure 12. Flow diagram of Sturtevant scourer-aspirator system.

The preliminary results from the tests are shown in Table 29. It can be seen that there was a substantial reduction in fiber content in the soybeans, although the corn dehulling was more difficult. This may be due to the very dry corn available at CSU and the particular operating conditions of the machine for the preliminary tests. Some preliminary work was performed where small amounts of water were added to the corn before dehulling, and the method appears promising. Continued work on methods of operation will be performed with this machine.

Table 29. Evaluation of dehulled samples made on Sturtevant scourer-aspirator.

Seed type	Throughput (kg/min)	Component	Component (%)	Nitrogen (%)	Protein[1] (%)	Moisture[2] (%)	Fiber (%)
Soybean	10.2	dehulled beans	88.20	5.58	34.9	6.72	5.63
		hulls[3]	9.05	1.99	12.4	9.35	32.0
		flour[4]	2.75	5.49	34.3	6.74	8.95
Soybean	19.2	dehulled beans	87.50	5.5	34.4	6.77	5.44
		hulls[3]	6.90	3.49	21.8	8.34	22.2
		flour[4]	5.60	5.25	32.8	7.47	8.7
Corn	13.6	dehulled corn	82.4	1.6	10.0	11.24	1.65
		hulls[3]	3.7	2.15	13.4	9.23	10.5
		flour[4]	13.2	1.59	9.94	10.69	2.61
Corn	10.2	dehulled corn	80.4	1.85	11.6	10.52	4.01[5]
		hulls[3]	3.9	1.84	11.5	9.86	9.60
		flour[4]	15.7	1.48	9.25	10.89	2.11
Soybean		whole	100	5.22	32.6	7.14	8.09
Corn		whole	100	1.53	9.56	11.15	1.65

[1] N x 6.25

[2] Wet basis

[3] Above US #18

[4] Below US #18

[5] Laboratory error

4.0 DEMONSTRATION SITES

4.1 Sri Lanka

4.1.1 Evaluation of Existing Sri Lanka Plant

An evaluation team consisting of E. E. Kuphal, R. E. Gaylord and A. A. Ackels spent approximately two weeks in Sri Lanka evaluating the LEC installation there. The objectives of the evaluation team were to examine the LEC installation at Kundesale and determine:

1. Is the existing system suitable for the manufacture of blended foods in LDC's?
2. Has the Sri Lanka installation adequately demonstrated the suitability of the system?
3. If either of these above have not been attained, what changes or additional work would be required?

The evaluation team presented their findings and conclusions in an oral presentation in Fort Collins on March 28, 1977. In summary, the team felt that the LEC was suitable for the manufacture of nutritious foods, but that further refinement of the system would be required to demonstrate its abilities. The system's productive capability has steadily risen over the life of the installation, giving rise to an attainable production efficiency of >70%. Production efficiency is defined as the actual production of the system over time, divided by the production at nominal operating rate over the same time. These refinements include the use of continuous duty feeders, conveyors, etc., better supply and control of spare parts, more adequate training of plant and operating personnel, and use of consistent productivity formulations.

The presentation suggested work should be continued to improve the performance of the system. The work would involve investigations of grain tempering to reduce extrusion power; preheating of raw materials; work on granulation; mechanical refinements, development of preventive maintenance, management procedures for system, training procedures, etc.

The evaluation team suggested that the elaborate quality control programs implemented in Sri Lanka were excessive. They suggested more reliance on taste and visual inspections.

4.1.2 Status of Kundesale Operations

Production at the Kundesale plant is at the highest efficiency since the start-up. Efficiency data cannot be determined at the present time due to a logistic problem which has prevented 15 hours per day operation on a continuous basis. This condition has arisen due to the inavailability of transportation which is tied up with governmental work. Consequently, production has been limited to a maximum of 450 bags (3 truck loads) stockpile. Greater amounts of product could be stockpiled, however, the limit is being enforced to lower the possibility of contamination or infestation.

Although precise figures were not available, production efficiency was estimated to be greater than 70% when the plant was in operation. The major cause of down time was mainly due to the PTO shaft universals. There is an adequate supply of spare parts available to minimize the down time caused by universal joint failures. Causes of universal joint failure have been outlined in previous reports, however, one cause has been overlooked. The plant does not have adequate tools to replace the universals, therefore, some of the failures could possibly result from incorrect assembly of parts.

There is some concern about the sanitation of equipment at the plant. Inspection of equipment indicated that, in general, the plant was clean. However, leaning was not as thorough as it should have been. Some areas and surfaces were not cleaned as frequently as required, thus resulting in a build-up. An effort was made to point out these areas and instructions in proper cleaning procedures were given to the operators.

Management at the plant has changed slightly in structure. Mr. Alahakoon is managing material acquisition and transport, and the hiring of plant operators. Supervision of the plant is handled by CARE-employed personnel at the plant. These employees include an engineer/mechanic for each shift and one quality control technician. This arrangement appears to be working satisfactorily and is believed to be part of the reason that the plant is operating more efficiently.

4.1.3 Plans for New Plant

CARE/Sri Lanka has made a decision to relocate and expand their present facility. Reasons for this change are as follows.

1. Transportation of finished goods from Kundesale to Colombo is becoming increasingly difficult.
2. Presently, the Kundesale site is removed from industrial areas and Colombo is a location where spare parts and machinery capabilities are more likely to be available.
3. The move will allow closer supervision by CARE.
4. The new plant will consolidate all of the separate operations that presently exist, thus reducing the logistics of material movement and management.

The decision to relocate was made approximately one year ago. Initially, an attempt to find an existing building was made. A structure was located that could be used, however, the past history revealed it was used for storage of pesticides. Both Dr. Lachmann and Mr. Tribelhorn were unable to obtain definitive information pertaining to decontamination procedures. Manufacturers and regulatory agencies who were contacted strongly recommended that this building not be used for the new plant because there was no 100% decontamination procedure. CARE/Sri Lanka was informed and the building was deleted from their plans. A decision was then made to acquire land and erect a new building which would be suitable for a LEC processing plant.

Mr. Justin R. Jackson visited CSU, May 31-June 3, 1977, for purposes of:

1. Briefing CSU and USDA on the intentions of CARE/Sri Lanka with respect to the new plant proposal and the goals which are desired.
2. Finalizing a possible time schedule for the various phases of the plant installation.
3. Determining preliminary specifications for the new plant based on the needs of the Thriposha program.
4. Finalizing arrangements on financing of the new plant and equipment.

Through extensive discussions, it was decided to build a temporary building to house the LEC system until a larger and more comprehensive building could be built which would include room for future expansion. This temporary building would serve as a storage building for raw ingredients once the actual process building was completed.

The plant will consist of two Brady Crop Cookers as well as auxiliary equipment to match the flow rate of the Bradys. In addition, both cleaning and dehulling equipment will be included in this plant. Financing will be made possible by both USDA and CARE. The total plant will be part of a cooperative effort among USDA, CSU, CARE/New York and CARE/Sri Lanka.

From June to December, efforts were made to finalize the plant design and locate the building site. Due to the distance between CSU and CARE/SL and the need for urgent communication, a trip to Sri Lanka was made by Ron Tribelhorn from December 5-14, 1977. The following subjects were discussed during the visit:

1. Responsibilities of each group involved with design in Sri Lanka
2. Engineer and assistant assigned by CARE/SL
3. Site selection
4. Building construction
5. Building layout and clearance requirements
6. Equipment specifications
7. Machine layout, supporting structures and electrical layout
8. Equipment costs and budgets
9. Timing of plant
10. Machinery to be moved from the Kundesale LEC location
11. Plant operations at Kundesale.

Subjects pertinent to the plant design are covered below. Additional information on the subject can be found in Mr. Tribelhorn's trip report entitled "Planning Trip, Phase II, New Plant - Sri Lanka," dated December 28, 1977.

4.1.3.1 Site Selection. CARE/SL had investigated potential sites for the new plant near Colombo since the June meeting at CSU. A total of 30 sites were screened using the following criteria:

1. Location
2. Accessibility to railroads and major highways
3. Site configuration.

A site had been selected at the start of this trip; however, purchase of the land had not been completed, as it was pending approval by the Government of Sri Lanka.

The site selected is located outside of the Kandanna region approximately 16 km from Colombo. A specific description of the site is given in Figure 13.

1. The land borders the railroad for approximately 137 m.
2. The site fronts on the Negombo Road (newly constructed airport road).
3. The area appears appropriate for industrial application as other factories are presently located there.
4. The site is relatively level, thus reducing the amount of excavation.
5. The site has reasonably straight boundaries, although the plan view shape is irregular.
6. The size of the site is approximately 2.4 ha--enough for future expansion.
7. The site is inland from the sea approximately 3.2 km and not susceptible to flood conditions.

4.1.3.2 Project Briefs. A summary of the current and future plans which were discussed during Tribelhorn's trip is given below:

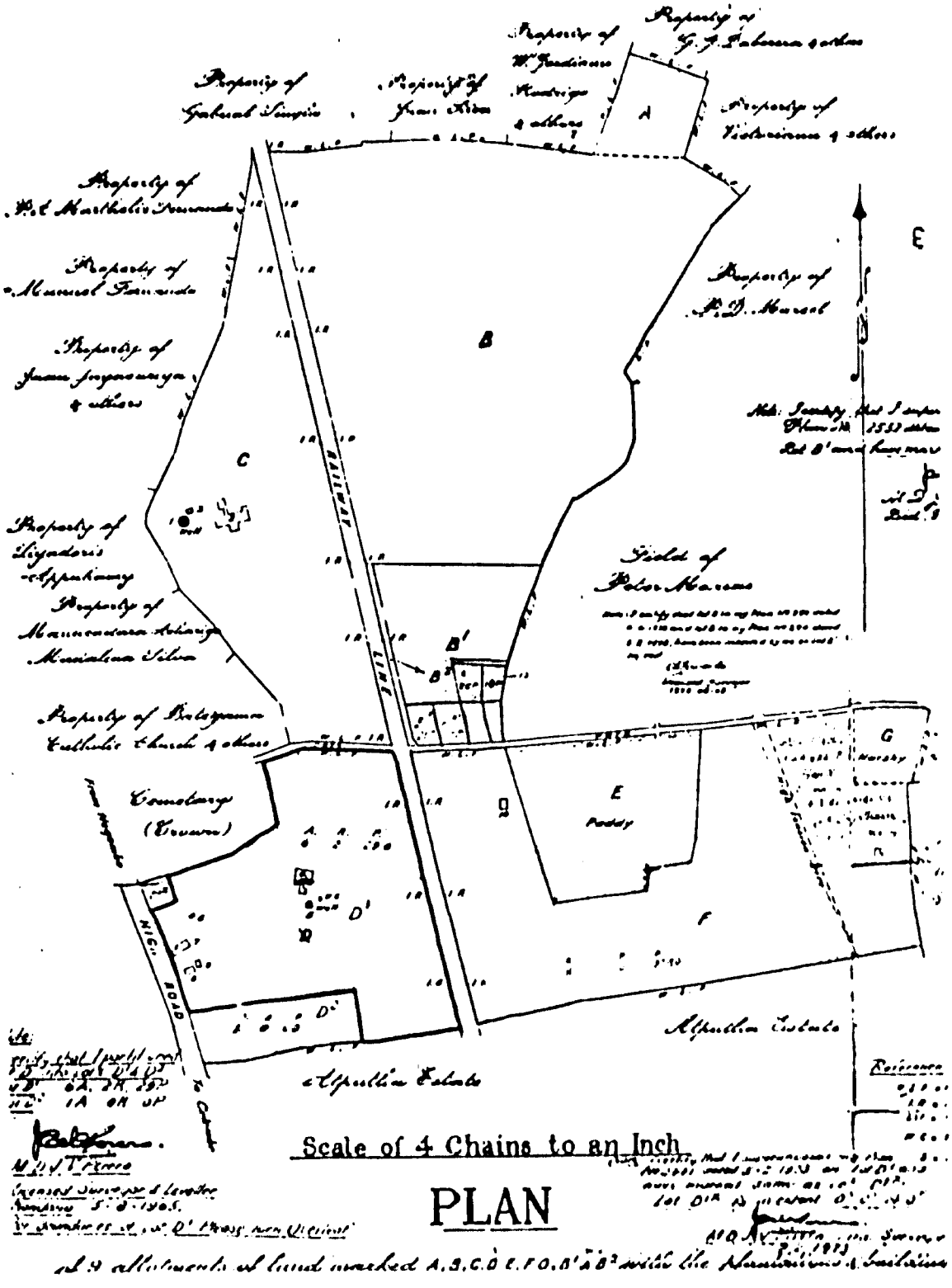


Figure 13. Site plan for the Thriposha plant near Colombo.

Best Available Document

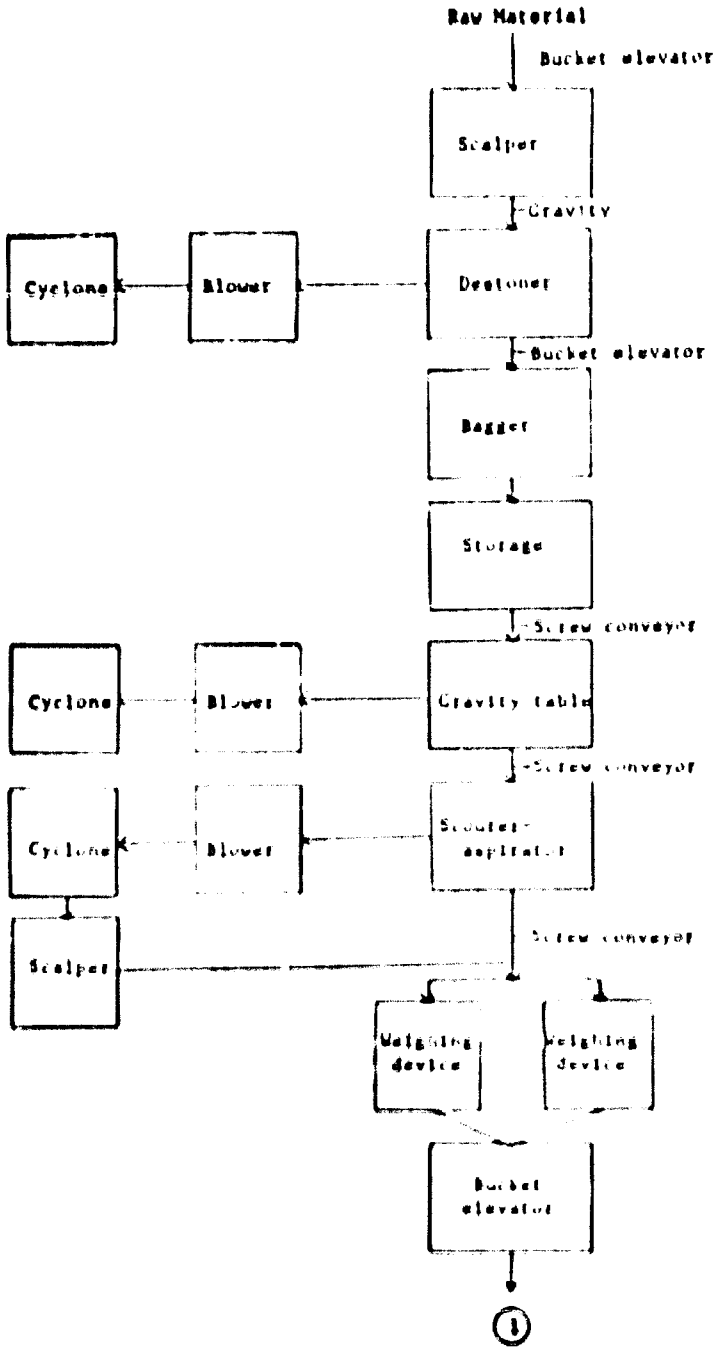
1. The new building will have a 18 m width (clear) span and a 91 m length. (The length was subsequently increased to 100 m.)
2. Lavatories, locker rooms, lunch rooms, and kitchenette will be located in a separate building.
3. Location on the site will facilitate future expansion with either bulk storage or gunny storage.
4. Eventually, the total Thriposha program will be centralized at this site.

4.1.3.3 Plant Design. A meeting between CARE/SL and the architect was held during this visit. Ideas were exchanged so that capabilities and materials of construction in Sri Lanka could be determined. Plant flow was diagrammed to familiarize the new CARE personnel with the LEC processing system required for Sri Lanka. The plant flow is shown in Figure 14.

Space requirements for processing, raw material storage, and finished product storage were examined. Figures for material storage are given in Table 30. The original recommendations by CSU had adequate area for storage until 1980, thus leaving time for planning the next phase of expansion. Considering a 18-m span restriction, and the area required for processing and storage, it was determined that the building would have to be a minimum of 91 m in length for adequate storage.

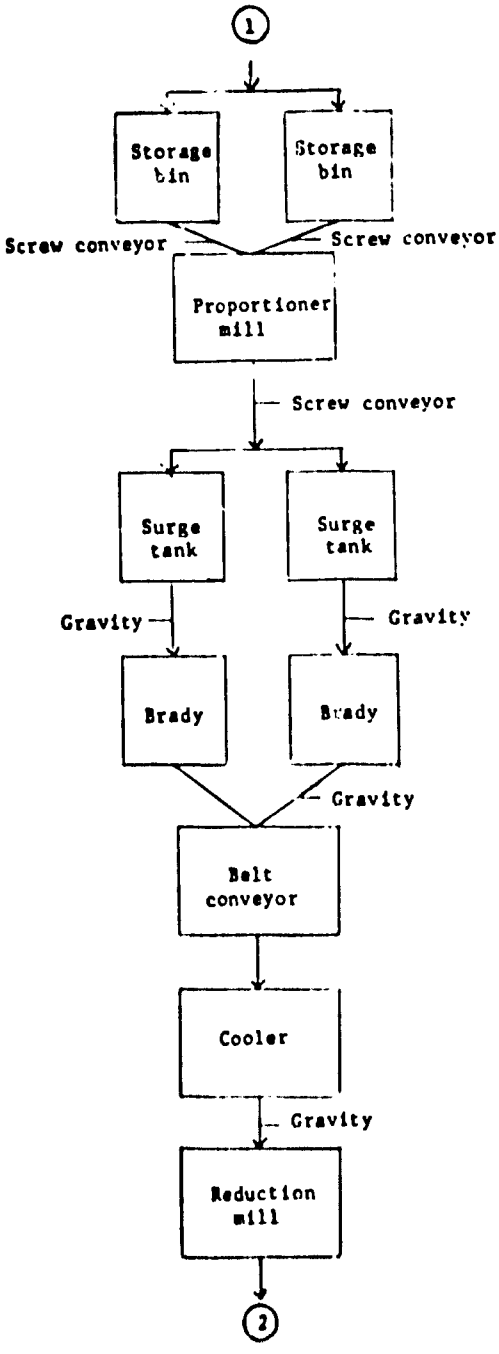
The current layout for the building (18 m x 100 m) is shown in Figure 15. Features of this design include:

1. Maximum cross ventilation of the processing area.
2. Rooms requiring air conditioning are located on outside walls.
3. Material flows in one direction through the plant (100 m length).



(Flow diagram continued on page 102)

Figure 14. Flow diagram of new plant in Sri Lanka.



(Flow diagram continued on page 103)

Figure 14. Flow diagram of new plant in Sri Lanka.

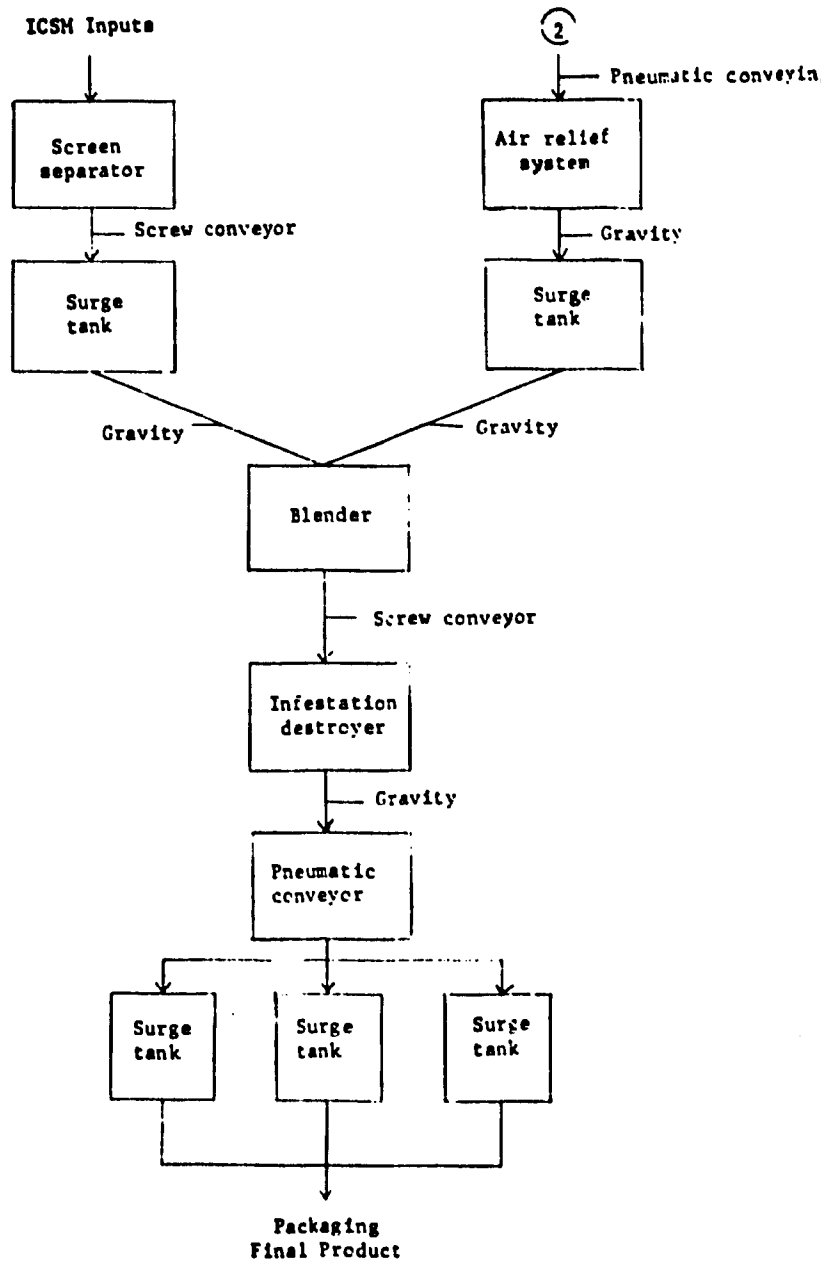


Figure 14. Flow diagram of new plant in Sri Lanka (concluded).

Table 30. Storage space requirements.

Year	Raw materials[1]		ICSM[2]		Local product[3]		Thriposha (local product and ICSM)	Total
	Metric tons	sq. m.	Metric tons	sq. m.	Metric tons	sq. m.	sq. m.	sq. m.
1978	1,700	1,130	460	310	300	380	690	1,820
1979	2,540	1,700	460	310	330	420	730	2,430
1980	3,390	2,260	460	310	370	470	780	3,040
1981	4,240	2,830	460	310	400	510	820	3,650
1982	4,550	3,390	400	270	400	510	780	4,170
1983	5,940	3,960	340	220	400	510	730	4,690
1984	6,790	4,520	260	170	400	510	690	5,210

Note: One year's requirement of master bags = 75 sq. m.
One month's requirement of plastic bags = 9.3 sq. m.

[1] One year's requirement of corn and 6 month's requirement of soy = 0.7 sq. m./metric ton.

[2] One month's requirement = 0.7 sq. m./metric ton.

[3] Two month's requirement = 1.3 sq. m./metric ton.

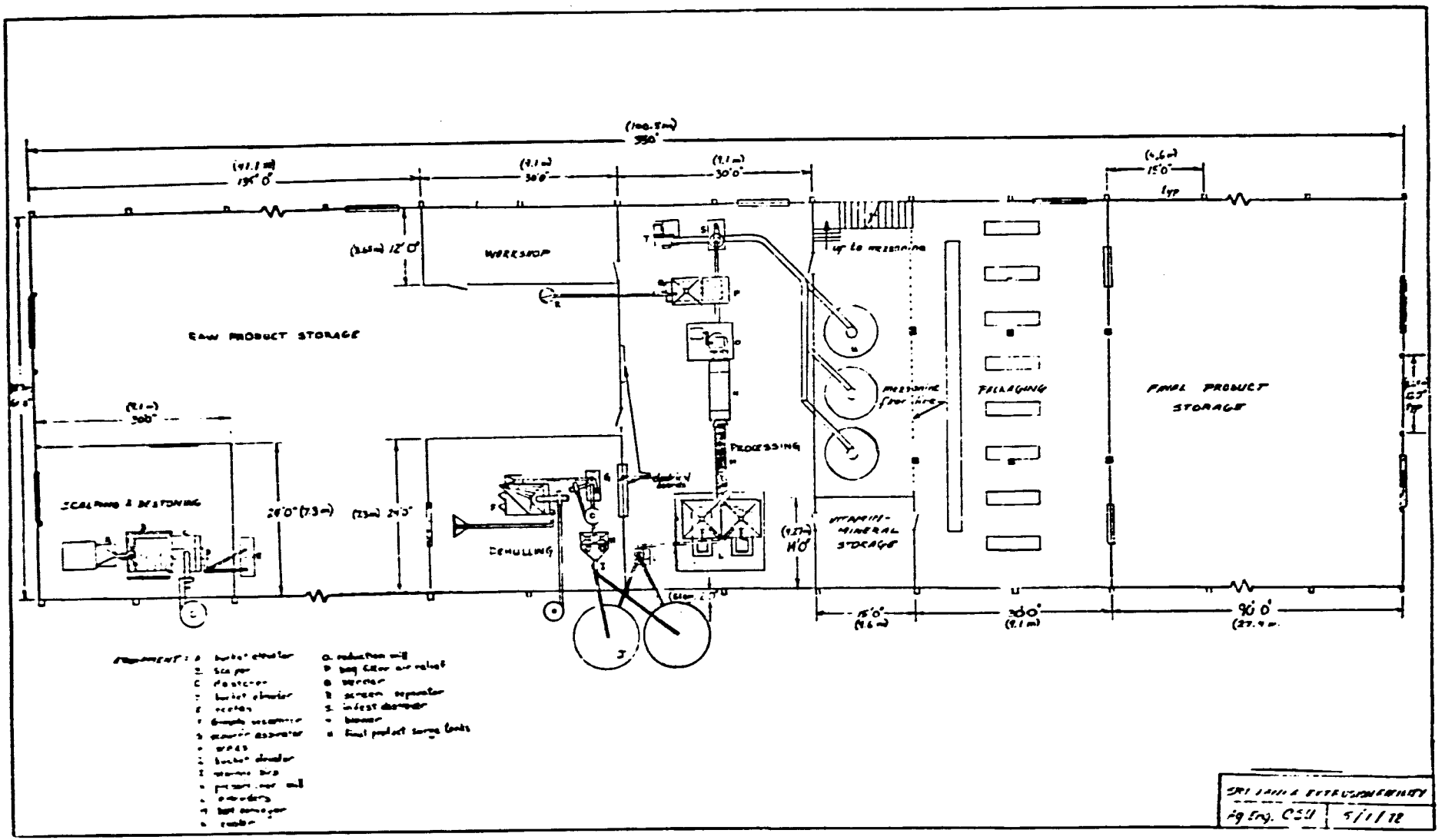


Figure 15. Layout of new building for Thriposha production.

4. Raw materials can be received by rail and/or truck.
5. Finished products can be shipped by truck and/or rail.
6. Construction will allow fumigation.
7. Walls will be flush with columns, creating a smooth internal surface.

The plant design, based on a 18 m x 100 m space, would have the following room areas:

1. Cleaning - 66 m^2
2. Raw material and ICSM storage - 735 m^2
3. Dehulling - 66 m^2
4. Processing - 735 m^2
5. Shop - 33 m^2
6. Quality control - 16 m^2
7. Vitamin/mineral storage - 19 m^2
8. Office - 26 m^2
9. Package storage - 16 m^2
10. Packaging - 236 m^2
11. Final product storage - 498 m^2

4.1.3.4 Equipment Specifications. Equipment for the new processing plant was also reviewed during Tribelhorn's December visit. A specification list (prepared between June and August) was correspondingly checked and found to be adequate for the processing equipment, however, some items were overlooked which normally do not pertain to a plant with an existing structure.

A new set of equipment specifications was written for this plant and can be found in Tribelhorn's trip report dated December 28, 1977.

Note: the specification list includes several items required which did not appear on the original list. Items added to the original list include:

1. Aspiration system for cleaning scalper
2. Surge tanks
3. Single deck separator
4. Infestation destroyer
5. Plastic containers
6. Surge tanks (Miratender) for finished product
7. Additional tools
8. Exhaust fans
9. Air conditioning system
10. Air compressor.

A 91-m belt was included in the revised list, but was subsequently deleted because of the excessive purchase cost.

4.1.3.5 Machine Layout, Support Structures, Electrical. The approximate equipment location and corresponding support structures and electrical requirements were developed. However, due to a time limitation and lack of proper drafting equipment, it was decided that these diagrams could be done at CSU and returned promptly to CARE.

It was agreed that there would be one main electrical distribution point with three sub-panels in the following areas:

1. Processing (excluding Bradys)
2. Dehulling
3. Cleaning.

Due to the large electrical requirement of the Bradys, the main distribution board and Brady disconnects would be on the same board as

near to the Bradys as possible. Electrical conduits will be laid into the floor when it is constructed. The exact locations will be required. Flexible conduit from the floor to the machine will be used to compensate for any errors in location.

4.1.3.6 Equipment from Kundesale. Originally, CARE/SL intended to move all equipment from Kundesale to Colombo. However, some items (Cablevey, bulk tanks, etc.) could be sold to Mr. Alahakoon if he shows an interest. At the time of the visit to Kundesale, Mr. Alahakoon expressed an interest in purchasing the Cablevey. No decision has been made on the sale of any items at the Kundesale plant.

4.1.4 Status of New Plant

As of mid-April, 1978, all equipment has been purchased except a few auxiliary items that require input by manufacturers. Figure 16 shows a tentative time table for the new plant. It appears that the plant will start up in September or October of 1978.

Presently, CSU is modifying the two Bradys as listed below:

1. The existing feed mechanism consisting of the feed hopper and injector auger will be removed. A vibratory feeder and new cowling will take the place of the hopper.
2. The hydraulic circuit will be disconnected since the injector auger will not be used.
3. Surge tanks will be mounted above the Bradys to provide a constant feed source to the vibratory feeders.

The above modifications will be completed by approximately July 1, 1978, at which time they will be disassembled and shipped to Sri Lanka.

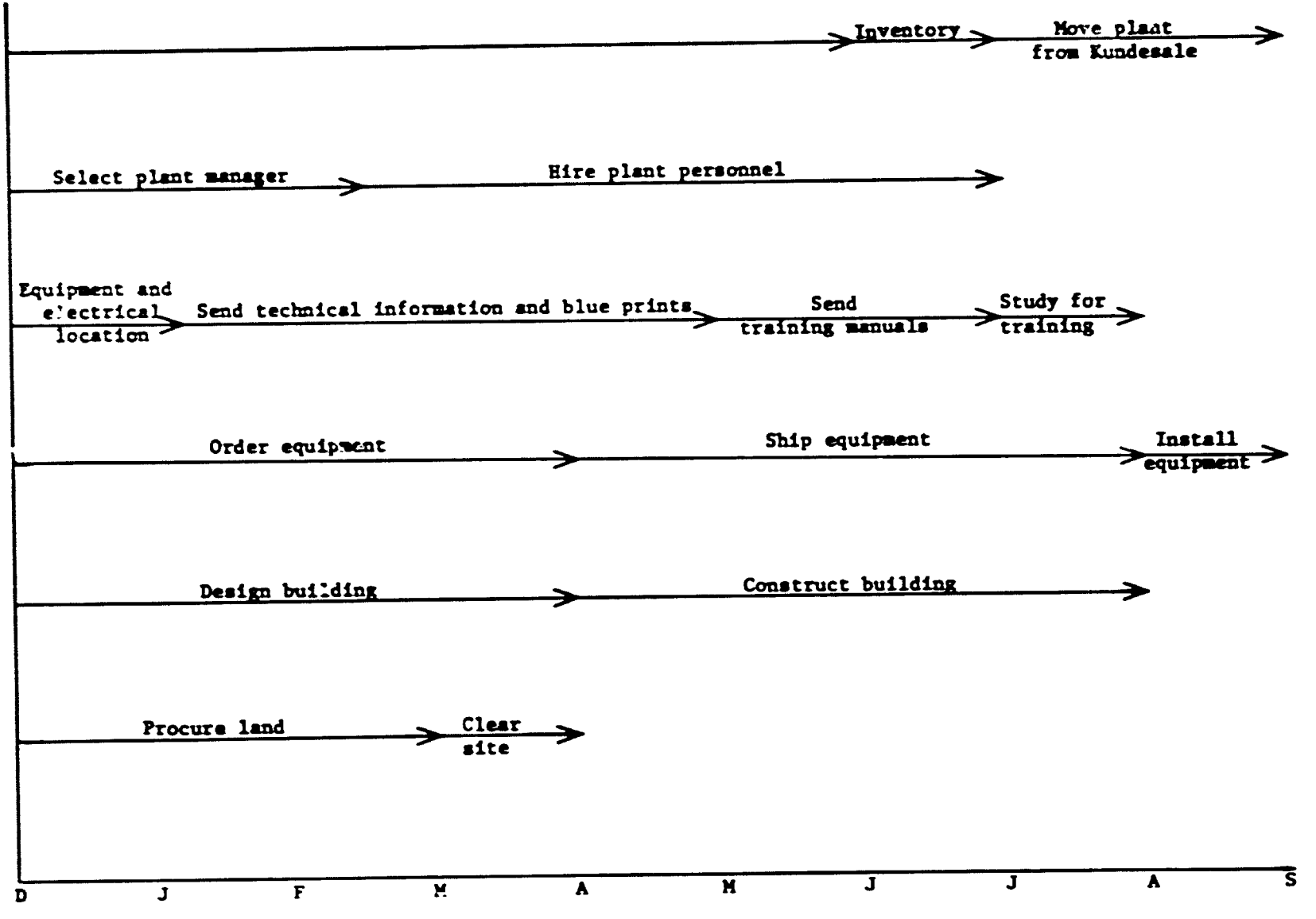


Figure 16. Tentative time table for Sri Lanka plant.

4.2 Costa Rica

In 1976 CARE received an Operational Program Grant (OPG) from AID to improve the nutritional status of primary school age children and pregnant and lactating women in low income groups through production of a corn/soy blend (CSB) and full-fat soy flour (FFSF). The production of CSB and FFSF will be used in feeding programs in place of PL 480 Title II commodities which are being phased out of Costa Rican supplementary feeding programs. USDA has been collaborating with CARE on this program since its inception and has provided the design of the manufacturing plant and other technical assistance through a cooperative effort with CSU for CARE to produce CSB and FFSF using a CARE-purchased Brady Crop Cooker. In addition, CARE requested USDA's assistance in providing a granular bed roaster for consideration as an alternative method for manufacture of FFSF. USDA is interested in demonstrating the use of the roaster for manufacture of FFSF and comparing the performance of the roaster system with the performance of the Brady Crop Cooker/Alpine system through parallel operations of the two systems.

4.2.1 Objectives

To formalize the installation of a soy processing plant in Costa Rica, Harper and Wilson spent the week of February 13-18, 1977, in Costa Rica meeting with officials of CARE/Costa Rica, AID/Costa Rica and GOCR. The objectives of the visit were to:

1. Coordinate arrangements for the soy processing plant construction, installation and operation.
2. Determine bidding and selection procedures for a qualified private sector manager of the soy processing facility.

3. Review equipment requirements for plant and initiate plant design.

After viewing all alternatives, it was determined that it would be best if the soy processing plant was constructed on a site owned by the GOCR under the direction of CARE/Costa Rica. The operations of the plant would be contracted to a private sector food processor. Prequalification specifications were written and the prequalifying process was initiated in April, 1977.

The following operating conditions were determined to define design capacities:

1. CSB portion of plant

   a. 16 hour production day
   b. 5 day production week
   c. 40 week production year
   d. 455 kg/hr production rate
   e. 70% production efficiency

2. Full-fat soy flour portion of plant

   a. 16 hour production day
   b. 5 day production week
   c. 10 week production year
   d. 455 kg/hr production rate
   e. 75% production efficiency

Based on these conditions, it was decided that the plant would consist of an extrusion line and a granular bed roaster line to meet the following objectives:

1. Produce 908,000 kg of CSB-like product during a 40-week production year.

2. Produce 272,400 kg of full-fat soy flour during a 10-week production year, either by extrusion heat treatment or by a granular bed roaster heat treatment.

3. Provide storage for 4 days' production capacity of raw grains and finished products.
4. Provide storage capacity for one year's supply of vitamin and mineral premix.
5. Provide facilities for packaging of final product into 22.7-kg bags.

The plant was designed to use the same line with alternate equipment for the production of full-fat soy flour. These process lines consist of: 1) a granular bed roaster and hammer mill, and 2) a Brady extrusion cooker and pin mill.

4.2.2 Specifications - Building and Equipment

Ing. Juan Antonio Piedra, CARE/Costa Rica, spent the last two weeks of May at CSU actively participating in the determination of the plant equipment specifications and becoming familiar with the operation of the equipment. At the end of his stay, all of the equipment with the exception of the air relief system for the final grinders had been specified. After that, competitive bids from three or more manufacturers on each item were obtained where appropriate. Certain pieces of equipment such as the Alpine Mill and the Sturtevant scourer-aspirator were specified as sole source.

The equipment list compiled for the plant in Costa Rica is given in Table 31. A detailed list of specifications for each item of equipment was prepared and provided to CARE for aid in purchasing. A list of recommended manufacturers was included with the specifications. This detailed list of specifications is available upon request to the Department of Agricultural and Chemical Engineering at CSU.

Table 31. Equipment components for Costa Rican plant.

Item	Manufacturer/Model No.
Grain Cleaning and Dehulling Equipment:	
Grain cleaner	Ferrell-Ross/No. 27
Destoner	Oliver/Model 2448A
Scourer-aspirator	Sturtevant/No. 3
Blower	American Fan
Scalper	Seedburo/Super Speed
1 - 15 metric ton galvanized steel storage bin	Baughman-Oster
1 - 19 metric ton galvanized steel storage bin	Baughman-Oster
1 - 10.6 metric ton galvanized steel storage bin	Baughman-Oster
Processing Equipment:	
Agitated sand bed roaster and associated cooler	Food Processes, Inc.
Proportioner mill	Modern Mill/Model 400
Extruder	Koehring/Brady 2160
Drum-type cooler (large)	Dorsey-McComb
Hammer mill	Prater/Model G6HFS
Pin mill	Alpine/Contraplex A400CW
Dust collection system	Johnson-March/Model PCSB
Blending and Packaging Equipment:	
2 - 500 kg surge tanks with slide valves	Locally constructed
Paddle blender	Marion/Model 2030
Beam scale	Toledo/Model 4181
Sewing machine	Doboy/Model E-3
Conveying Equipment and Miscellaneous:	
Screw conveyors	Baughman-Oster
17 m bucket elevator	Baughman-Oster
Cleated belt conveyor	Burrows/No. 500-12-15
Water application system	Various manufacturers
Screw conveyor motors	Baughman-Oster
Spare parts and tools	Various manufacturers
Lab equipment for quality control	Various manufacturers

Building requirements for the plant in Costa Rica recommended the following features and services:

1. Reinforced concrete floors.
2. Roof and wall support through reinforced concrete columns.
3. Masonry walls.
4. Wooden truss roof support system or equivalent.
5. Corrugated asbestos or metal roof.
6. Roof sealed to side walls.
7. Roof vents screened and a simple means of sealing provided for fumigation of building.
8. Ceiling heights of at least 4.6 m in the roaster room and the extrusion processing room.
9. A roaster room constructed with fireproof materials and provided with an exhaust hood and fan to cover the roaster.
10. Ventilation fans provided in the raw materials cleaning area, the extrusion area and the packaging area.
11. All ceilings and walls painted with a light colored non-porous glossy paint.
12. Screened louvered windows provided on all outside walls except offices and packaging area where glass windows should be provided.
13. All louvered windows provided with a simple means of sealing to aid plant fumigation.
14. Lighting provided throughout the plant with the following specifications.

a. Overall processing equipment - 755 lux

b. Shop, packaging area, quality control laboratory and offices - 1075 lux

c. Other areas - 215 lux.

15. Potable water at a pressure of 2.8 kg/cm^2 provided to the restrooms, packaging area, quality control laboratory and the extruder.

16. Floor drains provided in the restrooms, packaging area and in the quality control laboratory.

17. Washing facilities provided in the restrooms.

18. Electrical power equal to 150 KVA available at the electrical entrance to the building.

19. Propane or LP gas provided to the roaster room.

A plant layout was developed which involved the construction of a mezzanine for offices and quality control facilities combined with the elimination of some of the interior walls. The design facilitated the control of workers by providing an observation deck on the mezzanine. The entire processing area will be visible from the deck.

Figure 17 shows the design proposed by CSU and accepted by CARE/Costa Rica. The partitions within the processing area serve to separate raw material and processed product areas for sanitation purposes.

4.2.3 Method of Plant Operation

The Costa Rican food processing plant is unique in that it was designed to produce two types of products - CSB and FFSF. Furthermore, the plant was set up to compare the performance of the Brady extruder/Alpine mill system with the roaster/hammer mill system in the production

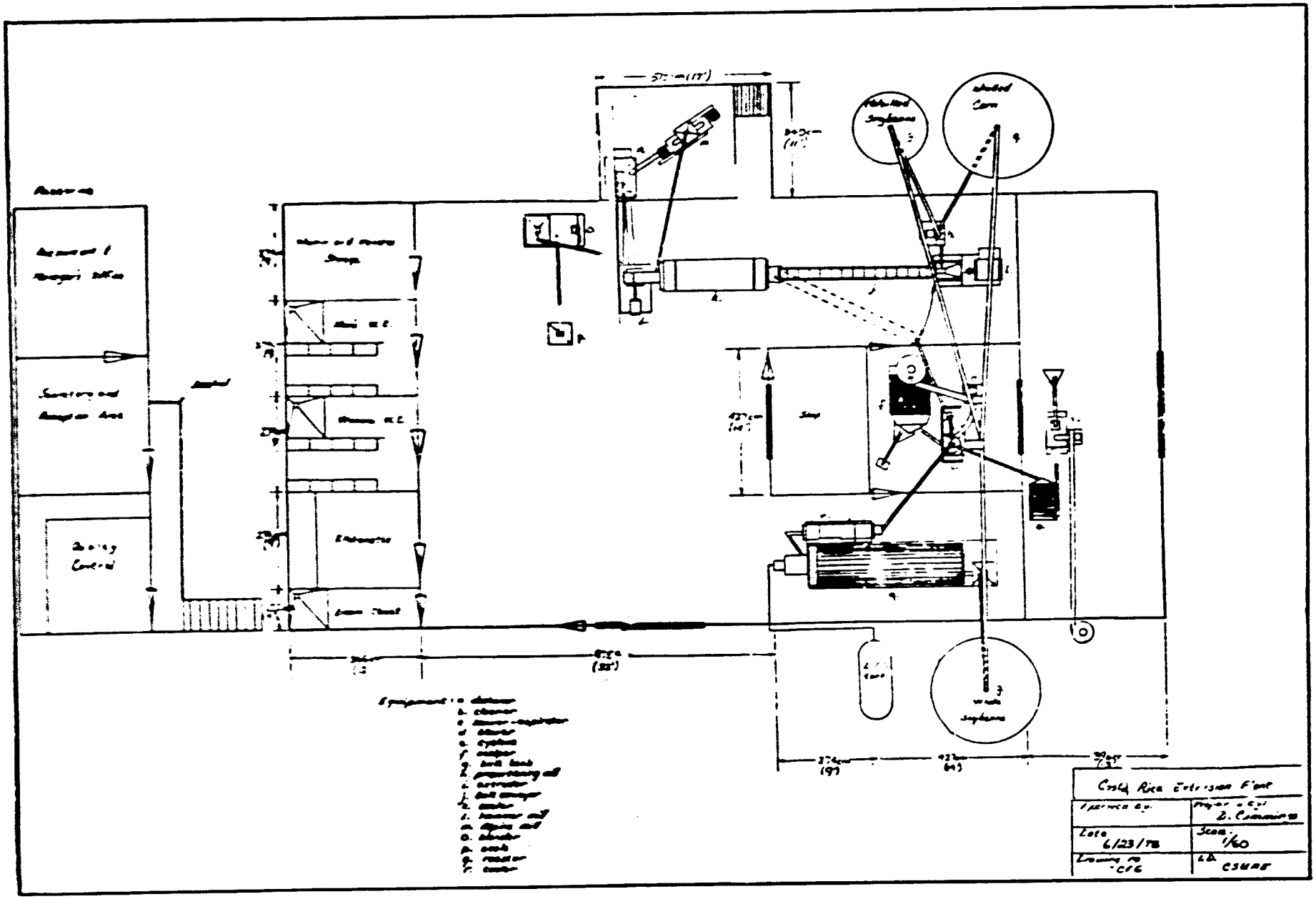


Figure 17. Layout of Costa Rican plant.

of FFSF. Another distinguishing feature of the Costa Rican plant is the inclusion of a bag filter type dust collection system. This system provides negative pressure on the downstream side of the milling equipment and relieves it of the production of fine particles.

A block diagram illustrating the flow of material through the plant is shown in Figure 18.

The grain cleaning operation is the same for both processing systems. The raw, uncleaned grain is dumped into the destoner to remove dirt and stones from the grain and then conveyed to a screening scalper to remove the remaining chaff from the whole grain.

For storage of the cleaned grain, the extruder system includes an impact dehuller with an aspirator and cyclone to remove the hulls and grain fines. The hulls and grain fines are fed back into the stream of dehulled grain and dropped onto a scalper for separation of the hulls. The hulls are bagged and sold to livestock feeders. The clean, dehulled corn or soybeans are then conveyed via a bucket elevator to bulk storage bins outside the building. The roaster system differs in that clean, whole soybeans are conveyed directly to a bulk storage bin via the bucket elevator without dehulling.

The processing of CSB and FFSF by the two systems is discussed in the following paragraphs.

When the extruder system is used for the production of CSB, clean, dehulled corn and soybeans are conveyed to the proportioner mill which mixes the two materials by a preset proportion and grinds the mixture to approximately 40 mesh. The mixture is fed into the extruder with approximately 3% water by weight from a flow control valve and extruded at a temperature of 154-163°C. The extruded CSB chips are then carried

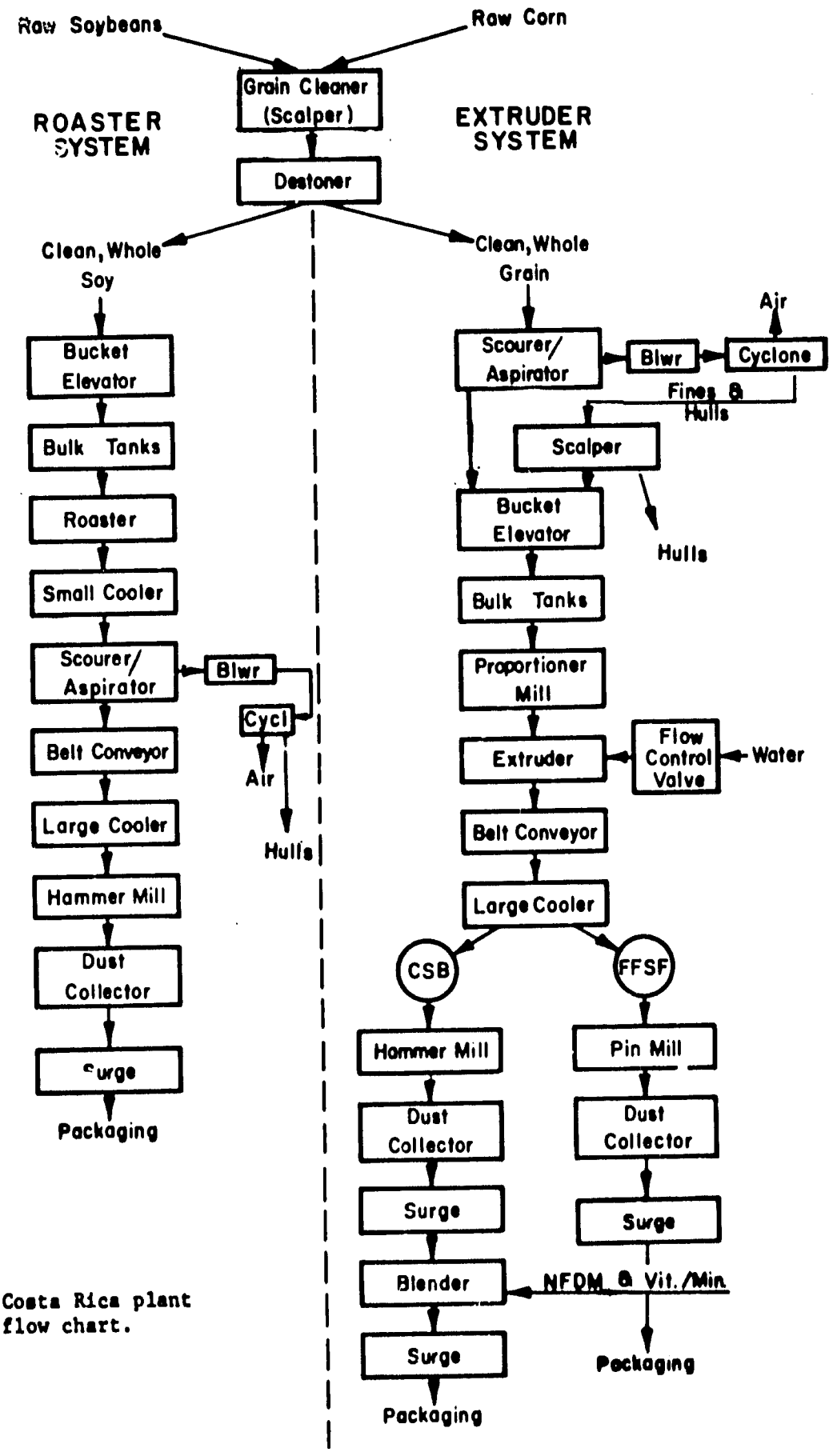


Figure 18. Costa Rica plant flow chart.

via a belt conveyor to a large rotary drum cooler with counter-current air flow. The cooled chips are dropped into a hammer mill for grinding to approximately 50-70 mesh and conveyed to a surge tank over a batch-type blender. The ground CSB is blended with additional vitamins and minerals and then conveyed to another surge tank over the bagging operation. The CSB is bagged in 25 kg polyethylene-lined paper bags with the liner heat-sealed and the paper bag sewn shut.

The extruder system is also used for producing FFSF by exchanging the large hammer mill with a pin mill capable of grinding the extruded soy meal. In this process, only clean, dehulled soybeans are ground in the proportioner mill prior to extrusion. The ground soy is then extruded with no water added at 140°C and conveyed via the belt conveyor to the drum cooler. By changing a valve in the outlet hopper of the cooler, the extruded FFS is conveyed to a pin mill for grinding to -100 mesh. The FFSF then is conveyed via U-trough conveyors to the packaging area where it is bagged similar to the CSB. In each process involving final product milling, a dust collection system is included on the downstream side of the mill to provide suction and aid in the removal of very finely ground materials.

The roaster system is used for producing FFSF. In this process the clean, whole soybeans are conveyed into the input hopper of the roaster where they are fed at a controlled rate into the roaster. The roasted soybeans exit the opposite end of the roaster and are dropped into a small rotary drum cooler. The cooled soybeans next are conveyed to the impact dehuller with aspirator, cyclone and scalper for dehulling and separation of hulls from the fines. The fines are put back into the stream of dehulled, roasted soybeans. The roasted soybeans are then

conveyed via the belt conveyor (which is shared between the two systems) to the large drum cooler and then dropped into the hammer mill for final grinding. The mesh size in this process is approximately -80 mesh w' 'ch is slightly larger than in the extruded process. After grinding, the FFSF is conveyed via U-trough conveyors to the packaging area for bagging.

4.2.4 Costs

Table 32 contains prices of equipment purchased for Costa Rica. The item number corresponds to the number used in the Equipment Specifications list prepared at CSU. In addition to the equipment listed below, an FPI granular bed roaster and a Prater G6HFS hammer mill were purchased through CSU with AID funds at prices of $20,000 and $3,515, respectively. These additional purchases increased the total expenditures for equipment to approximately $120,700.

The initial building design was estimated to cost $75,000 which was deemed inappropriate for a LEC system. Modifications were made to reduce construction costs, such as the elimination of some of the interior walls, but this reduction was expected to be offset by the addition of the mezzanine. New cost estimates were received which resulted in a cost of less than $20,000 for the building. In light of this new cost estimate, it was decided that the initial amount of $75,000 was based on some misinterpretations of the building specifications by the architects and construction agents.

The mezzanine design was accepted by all parties and construction began in early August. The building was completed in about 10 weeks.

Table 32. Equipment costs for Costa Rican plant.

Item	Cost
Grain Cleaning and Dehulling Equipment:	
Grain cleaner	$ 2,150
Destoner	3,056
Scourer/aspirator	5,986
Blower	480
Scalper	549
1 - 15 metric ton galvanized steel storage bin	983
1 - 19 metric ton galvanized steel storage bin	1,079
1 - 10.6 metric ton galvanized steel storage bin	824
Processing Equipment:	
Agitated sand bed roaster and associated cooler	25,000
Proportioner mill	3,009
Extruder	3,900
Drum-type cooler (large)	7,474
Hammer mill	3,487
Pin mill	28,871
Dust collection system	10,500
74.6 kW motor	3,146
Blending and Packaging Equipment:	
Paddle blender	7,535
Beam scale	331
Sewing machine	715
Conveying Equipment and Miscellaneous:	
Screw conveyors	1,330
17 m bucket elevator	2,831
Cleated belt conveyor	1,896
Water application equipment	167
Magnets	687
Screw conveyor motors	1,221
10 cm downspouts and flexible tubing	230
10 cm and 15 cm directional control valves	165
Bag holder	86
Tools	500
Lab equipment for quality control	1,000
SUBTOTAL	$119,188
Spare parts (12%)	14,303
Electrical estimate	3,700
TOTAL COSTS	$137,191

4.2.5 Bidding Procedures for the Plant Manager

A variety of alternatives for the location of the plant and the selection of a manufacturer with prior food processing experience were considered by CARE and AID/CR. Initial plans to locate the plant on the grounds or in a building of a manufacturer selected by a bidding procedure were rejected by AID/CR and the GOCR Ministry of Health because:

1. Plant equipment is to revert to the GOCR at the end of three years, and having it located in a private company would make such a consequence difficult.
2. Specifying and soliciting bids for such an arrangement would be difficult or at the very minimum cumbersome. It was believed going this route would seriously delay the project.
3. Reversing an incorrect selection of participating firm would be difficult to rectify.

As an alternative, it was suggested that the plant be constructed on available government land. Funds appeared to exist in the project to cover this contingency and time was sufficient to assure plant construction.

Under the above arrangement, a bidding procedure to select a qualified manager with food processing experience was discussed. After discussing the options with AID/CR officials, it was deemed best to replace a typical bidding procedure with a prequalification step. Such a procedure called for all interested parties to prequalify themselves as to their capabilities, personnel, financial status, costs, etc. From the list of potential candidates, the top two or three selected were brought in for interviews and negotiations. A contract agreement negotiated with the most qualified firm was signed without further bidding.

The above prequalification approach appeared desirable for the following reasons:

1. Firms were selected on the basis of prestated criteria.
2. Only qualified firms were seriously considered.
3. Prequalification was open to all potential candidates.
4. The prequalification procedure was acceptable to both AID and GOCR officials.

The prequalification proposal forms were put into required format by a lawyer from the GOCR Ministry of Health and 20 days were required for responses.

It was anticipated that qualified firms would respond to such a management contract offer for the following reasons:

1. Management reimbursed on a direct cost basis.
2. Management fee would be negotiated.
3. Private firms would have a very low risk opportunity to become involved with a new technology.

Using the above technique, a contract was consummated with Ing. Delbert Clark of Pro-Nutre in Costa Rica in June, 1977, to provide operating personnel and manage the plant. He has participated in reviewing plant plans and preparing for plant production.

4.2.6 Status Report

The plant start-up date has been postponed, due primarily to delays caused by the shipping strike and a delay in procuring the dust collection system and some miscellaneous spare parts. Original plans for a 440 volt, 74.6 kW electric motor to drive the extruder had to be changed after delivery had been taken. As a result, the motor will be replaced

with a 220 volt motor from the United States. The probable date for plant start-up and training of personnel will be July 1, 1978.

4.3 Tanzania

The second LEC production facility has been designed and constructed in Dar es Salaam, Tanzania. The plant will be operated by the National Milling Corporation (NMC) with quality control and marketing assistance from the Tanzania Food and Nutrition Center (TFNC). Plant management and operating personnel are currently being selected by NMC and the plant will start into production during May, 1978. The plant will produce an extruded weaning food composed of 70% dehulled, degermed maize and 30% dehulled soybean, fortified with vitamins and minerals, and will be ground to a fineness of approximately -40 +60 mesh. The weaning food will be packaged into 2-kg bags for distribution by the Ministry of Health and into 1-kg bags for commercial marketing.

4.3.1 Objectives

The objectives for the weaning food plant established in Tanzania are listed below.

1. To produce a CSB-type product at low cost for supplementary feeding programs aimed at malnourished children and for a limited distribution to the commercial market.
2. To produce approximately 700 metric tons of weaning food the first year and up to 1,800 metric tons by the third year of operation.
3. To support the Tanzanian government's efforts to become self-reliant in food production, thereby conserving its foreign

exchange and becoming independent of United States PL 480 Title II donation programs.

4.3.2 Specifications - Building and Equipment

The site selected by NMC for the Tanzanian weaning food plant is on plot 74/2 Pugu Road in Dar es Salaam. The site included an existing building which had been used as a oil mill. The total floor area available for the LEC facility measures 36.5 m x 11 m and has an open ceiling with the bottom of the roof trusses 5.8 m from the floor. The processing room measures 16.4 m x 9 m. The floor plan for the plant is shown in Figure 19.

The site is near the headquarters of NMC, and a maize mill is also on the plot. The maize mill will supply the maize grits needed by the plant.

The equipment that was purchased and installed in the plant is listed in Table 33 with the associated expenditures. In addition, three components were constructed at the Agricultural Engineering Research Center at CSU and shipped to Tanzania. These components include a dispensing hopper, a micro-ingredient feeder for the Modern Mill and a cyclone separator for the aspirator of the dehulling system. The dispensing hopper incorporates a simple sliding cylinder to dispense material from the hopper to the bag-filling chute. The cylinder is adjustable in height so different sized packages and different product densities can be accommodated.

The modification of the Modern Mill to add the micro-ingredient feeder for the vitamin and mineral mix was designed and constructed at CSU. However, at a later time it was decided that the use of a batch

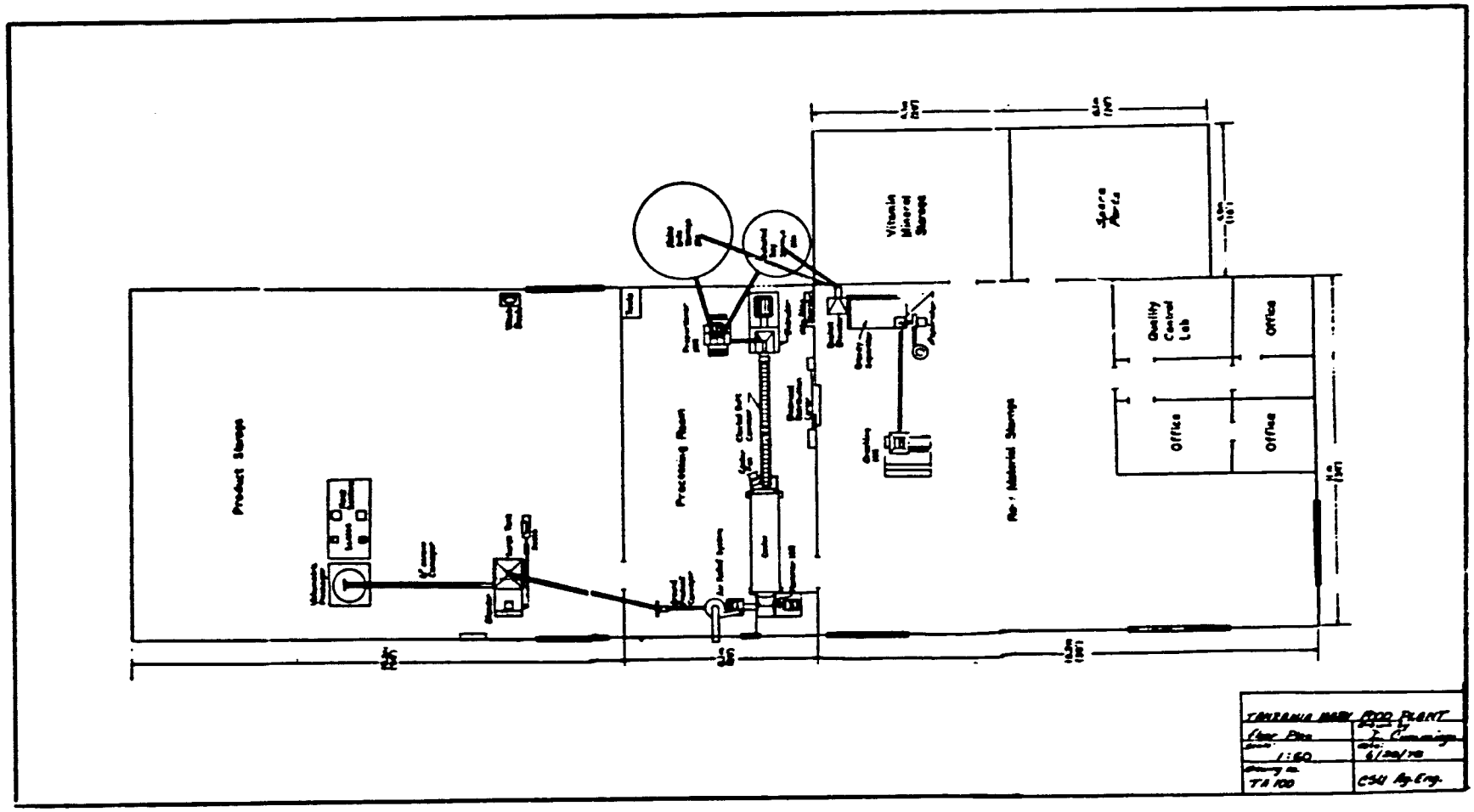


Figure 19. Tanzanian plant floor plan.

Table 33. Equipment purchased for Tanzanian plant.

Component	Manufacturer/Description	Expenditure
Cracking mill	Davis/Model 10 x 10	$ 1,230.00
Gravity table with aspirating feeder	Oliver/Model #50	2,235.02
Bucket elevator	Universal/Model C2	2,505.90
Paddle blender	Marion/Model 2030	6,838.00
Incline belt conveyor	Versa Ferguson/Model 600-R	1,356.00
Bulk tanks	Read/Model BF10 Model BS18	2,341.25
Proportioner mill and parts	Modern Mill/Model 400	5,053.20
Extruder and parts	Brady/Model 2160	10,919.01
Water application equipment	Fisher Porter/Hoke/Watts	200.00
Conveyor	Modern Mill/15 cm x 6 m	540.85
Cooler	Dorsey McComb/Cooler	6,840.00
Final grinder with air relief system	Prater/G6HGSI	4,589.00
Exhaust fans (2)		436.64
Electrical distribution control and protection equipment	Square D/Misc.	2,360.09
Heat sealers (2) and parts	Allied Automation/Sergeant 312	583.00
Prater parts	Prater - Modern Mill	345.28
Motors	Baldor	256.00
Welding rod	Ranite C	62.60
Belts		86.64
Filters		35.10
Packaging scales (2)	Accu-Weigh/Model M-410	168.00
Laboratory equipment		902.88
TOTAL		$49,884.46

blender for post-extrusion addition of vitamins and minerals was more feasible. This was decided because of increased vitamin degradation in storage following the heat treatment.

4.3.3 Method of Plant Operation

The important aspects of the Tanzanian plant which differ from the original Sri Lanka installation include: 1) a soybean dehulling system, 2) a bucket elevator for loading bins, 3) an electric-powered extruder, 4) a Prater-designed air relief system on the Prater final grinder, and 5) the elevation of the Modern Mill, eliminating a vertical auger.

A block diagram which illustrates the flow of material through the plant is shown in Figure 20. The cleaning and dehulling part of the plant was designed on the basis of arrangements with the National Milling Corporation to provide clean, whole soybeans and dehulled, degermed maize grits.

The soybeans are poured into the roller-type cracking mill which loosens the hulls. They are then conveyed to a gravity table for separation of the hulls, after which the dehulled soybeans enter the input hopper to the bucket elevator. The elevator lifts the beans and discharges them by gravity to a bulk storage bin. The maize grits are poured directly into the input hopper of the bucket elevator and are similarly conveyed to another bulk storage bin.

During extrusion, the maize grits and dehulled, degermed soybeans are fed by screw conveyors to the proportioner mill where the ingedients are coarsely ground and combined in the appropriate mixture. The raw maize/soy mixture is then conveyed horizontally to the extruder where it is combined with a small continuous stream of water (approximately

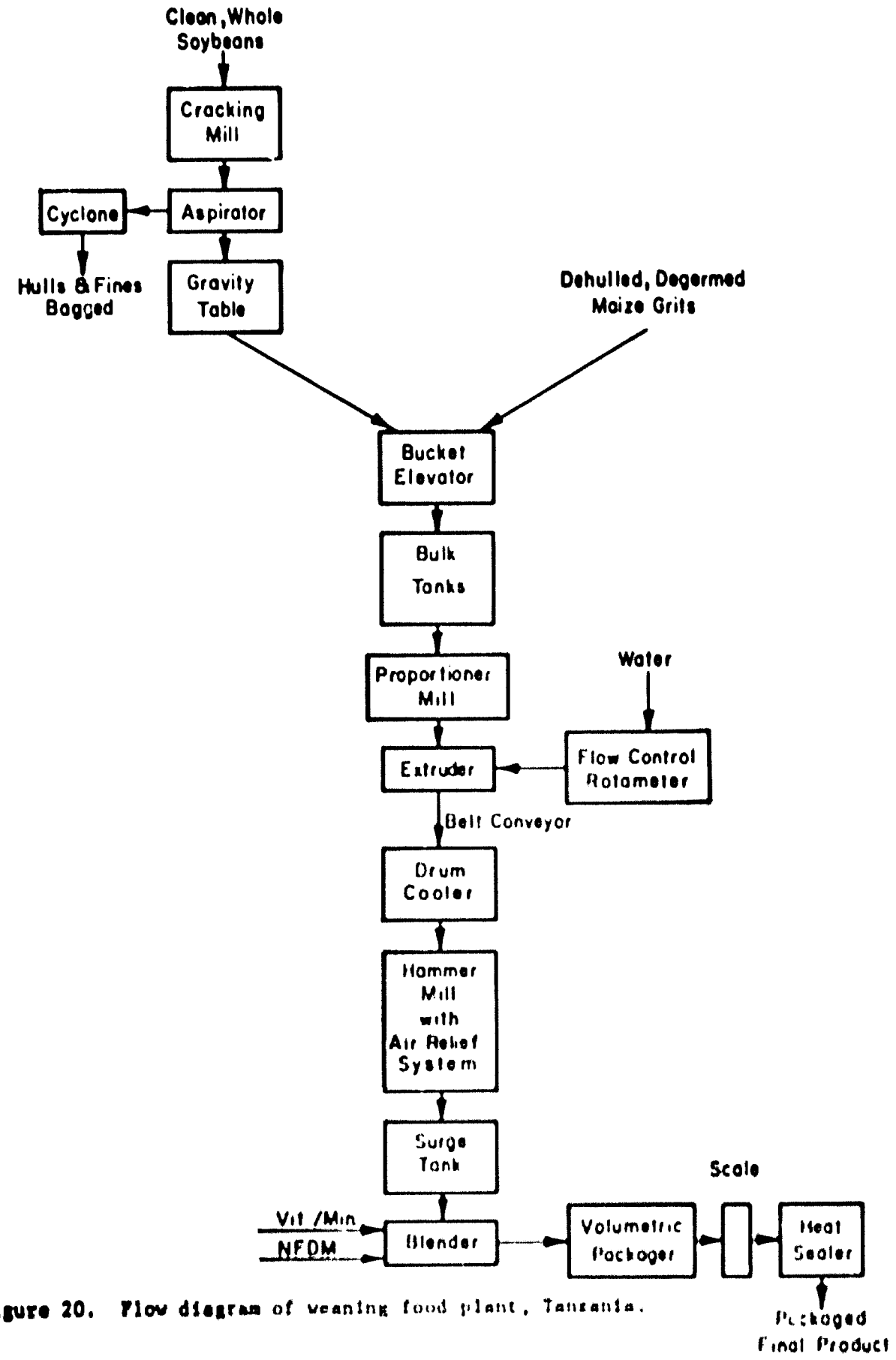


Figure 20. Flow diagram of weaning food plant, Tanzania.

30 l/hr). Extrusion will be performed at 154-163°C. The extruded chips are dropped onto a cleated belt conveyor and carried to the rotating drum-type cooler. The cooler operates with forced-air flowing in a counter-current direction with the extruded chips. The cooled chips are then dropped by gravity into the hammer mill for final grinding.

An air relief system creates a low pressure condition on the outlet of the hammer mill which helps to move ground material into a U-trough conveyor located below the mill. The ground product is carried to an inclined screw conveyor which transports the product to a surge tank above the paddle blender. Through a method of periodic batch blending, the ground product is mixed with vitamins and minerals for fortification and conveyed to the surge tank above the volumetric packager. Plant personnel manually fill polyethylene bags using the volumetric packager, check the net weights on a scale, and then seal the bags using an electrical heat sealer.

4.3.4 Budget and Costs Incurred

The breakdown of funds budgeted for the weaning food project is given in Table 34. As listed in Table 33 in Section 4.3.2, the costs incurred thus far for equipment purchases have totaled approximately $50,000. Shipping costs thus far have totaled approximately $15,000.

4.3.5 Status of Plant Development

During the last week of April, 1978, Mr. Ron Tribelhorn and Mr. David Cummings went to Tanzania to begin equipment debugging, personnel training and plant start-up. At that time, the two-month supply of vitamin and mineral mixes provided by USAID/W had been received in Dar es Salaam. Also, the additional ancillary equipment which was

Table 34. Funds budgeted for the Tanzanian weaning food project.

Purpose	Agency	Amount
Equipment and installation	USAID	$50,000 U.S.
Building preparation	NMC	150,000 Schillings ($19,200 U.S.)
Manufacturing and operating funds	NMC	4,500,000 Schillings ($577,000 U.S.)
Funds for purchase of product - TFNC has first right of refusal on product	TFNC	3,500,000 Schillings ($488,700 U.S.)

ordered late was scheduled to arrive by the end of April. These ancillary items include the following:

1. Paddle blender and associated scale
2. Cleated belt conveyor
3. Exhaust fan
4. Electric heat sealers (2)
5. Bucket elevator pulleys
6. V-belts
7. Hydraulic reversing valve parts for the Brady
8. Miscellaneous Square D electrical parts.

The work on the plant building was virtually complete by the end of April, and all on-site equipment had been installed. The necessary tables and containers had been made and the offices were remodeled. The National Milling Corporation had selected the following personnel as of April 3, 1978:

1. Plant Supervisor, in charge of daily operations.
2. Initial Production Supervisor, in charge of coordinating production start-up and providing production requirements, such as packaging materials, delivery schedules, etc.
3. Four equipment operators and technicians.

At the time of this writing a permanent Production Supervisor had not been chosen, but NMC was in the process of interviewing candidates for the position.

After his arrival in Tanzania at the end of April, Mr. Tribelhorn reported that most of the equipment items were ready to operate. Some of the equipment was to be started and debugged the first week of May. It is currently anticipated that debugging of the equipment and training of personnel will continue through the third week of May. The plant is then expected to start into production and produce at approximately 70% capacity by the end of May.

The following specific production goals have been established for the weaning food plant:

First year - 635 to 725 metric tons

Second year - 910 to 1,090 metric tons

Third year - 1,820 metric tons

The increases in production will develop as plant personnel become more proficient at equipment operation, and with the addition of a second work shift as market and material supply conditions permit.

The methods of maintaining product quality up to required food standards will be covered during the training period led by Tribelhorn and Cummings. During regular operation, the staff of TFNC will continue to provide quality control assistance.

The laboratories which could be used for quality control at the plant are listed below with the type of analysis done at the lab.

Laboratory	Location	Analysis
TFNC	Dar es Salaam	Proximate
NMC	Dar es Salaam	Proximate and QC for NMC
Government Chem. Lab	Dar es Salaam Morogoro	Proximate, some pesticides Amino Acid
University Faculty of Medicine	Dar es Salaam	Microbiological + toxins
Central Vet. lab	Dar es Salaam	Microbiological + toxins

Some quality control standards for cereal baby foods have been adopted by TFNC as well as other food production standards. Dr. Aleck Mosha of TFNC will be in contact with NMC to assure these standards will be met by the new weaning food plant.

4.4 Full-fat Soy Flour Plant - Chihuahua, Mexico

In May 1977, members of CIATECH visited Colorado State University to examine our work on LEC's for the production of full-fat soy flour (FFSF). Initial interest in LEC processing by the CIATECH resulted from a visit to Pro-Nutre in Alajuela, Costa Rica. The technical staff of CIATECH (Dr. Francisco del Valle, Ing. Armando Comacho and Ing. Hector Acosta) spent two days in Fort Collins reviewing their plans for the production of FFSF, examining preliminary plant layouts and equipment selection, providing information on the operation of the Brady extruder and making samples of extruded soy for their evaluation in Mexico. Using the information provided in this short visit, reports from the Colorado State University LEC project and information gathered from local sources, the technical staff of CIATECH have designed, installed and started a

FFSF processing plant in Delicias, Chihuahua, which was inaugurated by the President of the Republic of Mexico, José Lopez Portillo, on April 1, 1978. Judson Harper from CSU attended the inauguration.

CIATECH, a technical group in the state of Chihuahua, is providing technical assistance and development in the area of improved food processing and utilization for the State. Their funding comes from the state of Chihuahua, CONACYT (Mexican NSF) and through contracts with private industry. One of their initial projects has been the design and construction of the FFSF plant and to work with local industry in the utilization of the product in a variety of food product applications.

4.4.1 FFSF Plant Design

The extrusion processing plant for soy was designed under contract to an agricultural cooperative in Delicias, Chihuahua. Private capital amounting to $300,000 was raised by this group; 51% from the members of the cooperative (80) and 49% private outside capital. CIATECH signed a contract to design, specify and procure equipment, and to oversee installation and start-up of the soy flour factory. The design capacity of the plant is 3.6 metric tons per day or approximately 910 metric tons per year on a one-shift basis. The output of the plant is slated for commercial sales and CIATECH will receive a small percentage on sales as continuing support of their activities. To enhance commercial sales, CIATECH has been actively working on product applications with a wide variety of local industries. These applications will be discussed later.

4.4.2 Processing Plant

The process layout for the plant is shown in Figure 21. The product flow is conventional with first cleaning of the soy by the

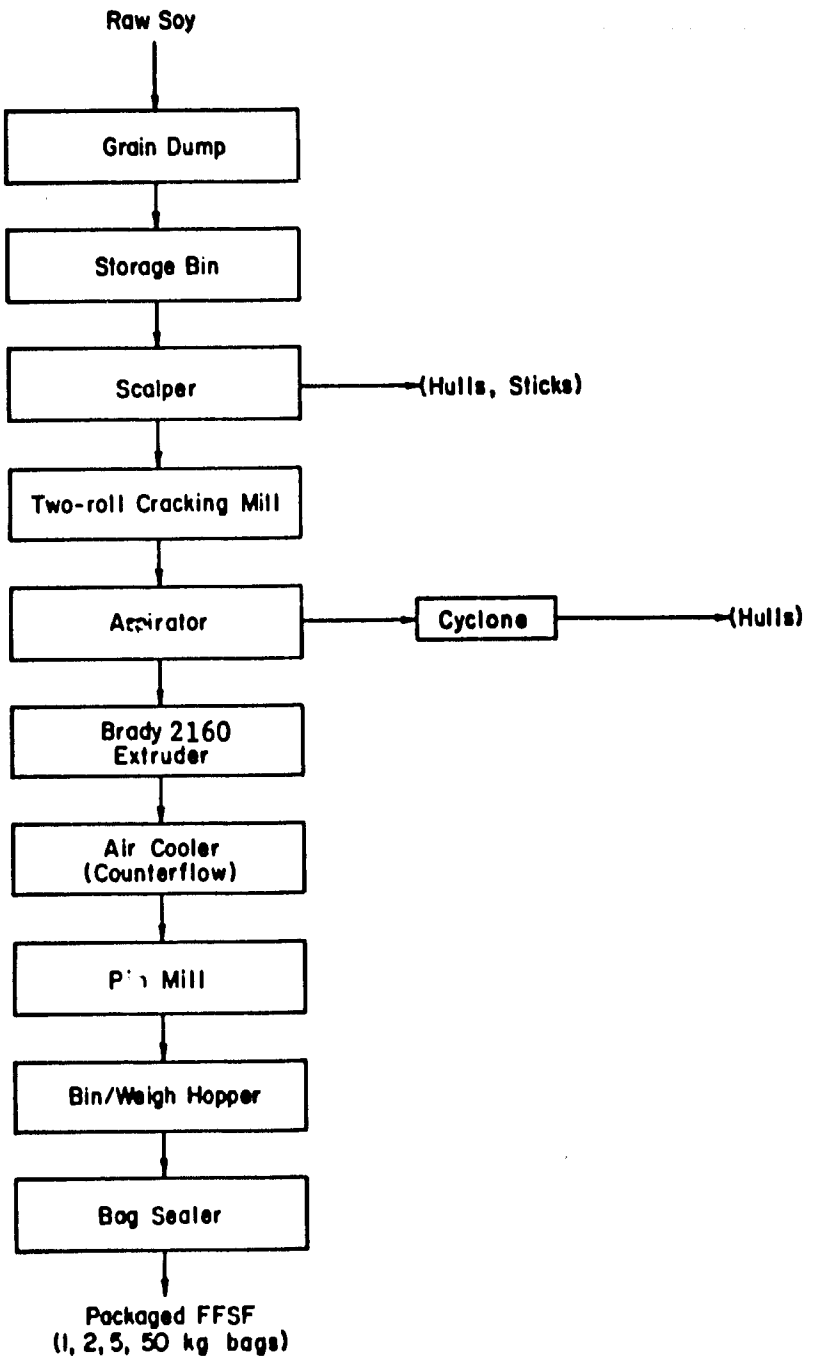


Figure 21. Full-fat soy processing line at Productos Alimenticios Delicias, SA.

scalper, followed by cracking in a double roll mill and then aspirating the hulls away from the meats in a ladder aspirator. The cracked, dehulled meats are fed into a small surge tank above the Brady, Model 2160, equipped with a right-angle drive. After extrusion, the product passes through a cooler/tumbler (locally manufactured) with a counter-current flow of air. The cooled extruded product (~40-50°C) is next ground in a counter-rotating pin mill relieved by a bag filter dust collector. The ground product is conveyed to a product storage hopper and packaged into a variety of sizes. The small polyethylene packages are placed on a belt which passes them through a semi-automatic heat sealer.

The process was in the initial stages of shake-down and start-up. All components of the process through the cooler were working satisfactorily. About 500 kg of extruded product had been ground in the pin mill and the initial product was too coarse. Thus, testing and adjustment of the mill will be continued.

The plant equipment, installation and engineering cost $150,000. Raw soybeans cost 22-26 cents per kg and the finished product's sale price is anticipated to be 48-55 cents per kg. Initial sales of 365 metric tons per year have been made and this will be expanded through a variety of food product applications. Details on the plant design are given in a trip report by Harper. Also, papers have been written for Food Engineering International and Front Lines.

4.4.3 Food Products

Dr. del Valle has been actively engaged in the development of a wide variety of food applications to develop a demand for commercial sales. These include:

1. Substitution of FFSF for egg solids in sweet breads (pan dulce)--This application allows total substitution and elimination of eggs in the sweet bread formulation at about 15% the cost of raw eggs.
2. Fortification of bread--Addition to bread and buns at the 10% level.
3. Pasta--Soy fortification of vermicelli at approximately the 10% level.
4. Ice cream--An ice cream formula having no milk solids which consists of FFSF, coconut oil, sugar, stabilizer (CMC), flavor and water. This product is frozen in bulk or as popsicles.
5. Cookies--Soy fortified cookies.
6. Beverages--A soy-based beverage flavored with chocolate, strawberry or vanilla. The product consists of FFSF (6.5%), sugar (2.5%), coconut oil (3%), flavor and water. The mixture will be homogenized and pasteurized. It is anticipated that it will be packaged and sold in liquid form. CIATECH has purchased equipment to establish a processing and packaging plant in Chihuahua during the next two or three months.
7. Candies and sweets--A caramel nugget candy containing sugar, soy and flavor. The material is boiled to produce the nugget-type candy or spread.

8. Snacks--A granola type snack of oats, raisins and FFSF which is toasted in an oven.
9. Tortilla flour--Fortified tortilla flour which can be used in the conventional manner.
10. Sausage--Sausages produced with 50% of the protein coming from FFSF are juicy and have no detectable soy flavor.

All of the products were very palatable and presented a substantial array of product ideas for the promotion of commercial sales of the FFSF. Retail sales of the flour were uncertain, but also anticipated.

4.4.4 Evaluation of Mexican Soy Sample

A sample of full-fat soy flour extruded in Mexico on a Brady extruder was evaluated for proximate analysis and physical properties. The data are listed in Table 35. The particle size distribution of the ground product is too large, and adjustments are being made to the Alpine mill to correct the problem.

The data are generally consistent with other samples of full-fat soy flour extruded on the Brady at CSU and at INCAP. It is not possible to estimate how much antitrypsin activity was destroyed during extrusion since we did not have raw soybeans available for analysis. The level of antitrypsin activity in the flour following extrusion was somewhat higher than what we have found at CSU but was quite comparable to levels in full-fat soy flour extruded at INCAP in Guatemala.

5.0 TESTING SITES

5.1 Guatemala Workshop

INCAP held a 1 1/2 day workshop on LEC's. The workshop was attended by approximately 50 participants. A demonstration of the Brady was held

Table 35. Evaluation of Mexican full-fat soy sample (dehulled, extruded).

Sample #	2-9-13
Fat, %	22.2
Moisture, %	3.64
Nitrogen, %	5.54
Protein, %	34.6
Ash, %	5.44
Fiber, %	2.85
Viscosity (Pa-s)	1.76[a] 0.227[b]
NSI	20.2
Water absorption, %	125
Trypsin inhibitor activity (TIU/g)[c]	44,000
Density (g/cc)	0.938
Particle size distribution:[d]	
on #30 sieve, %	31.8
on #40 sieve, %	28.1
on #60 sieve, %	36.0
on #80 sieve, %	4.0
on Pan, %	0.0

[a]Uncooked viscosity on Brookfield viscosimeter at 50 rpm, spindle #6.

[b]Cooked viscosity on Brookfield viscosimeter at 50 rpm, spindle #5.

[c]Trypsin inhibitor activity is reported as TIU/g since there is no raw sample for comparison to compute % destruction.

[d]Sieving was done by hand.

where mixtures of soy/rice and corn/rice/soy/gondul were extruded. Precooked corn/soy flour was also formed into pasta and samples of soups, drinks and tortillas were made available.

Interest was expressed by the participants and a good exchange of ideas and information was made.

Harper presented information on worldwide applications of LEC technology as well as cost information. Copies of the LEC Workshop Proceedings (LEC Report 1) and the Annual Report (LEC Report 2) were distributed.

The results of laboratory tests made by CSU and INCAP on soy samples which had been exchanged, were discussed. Results from both laboratories were similar. The Guatemalan soybeans behave differently giving lower fat and trypsin inhibitor values until after extrusion. PER values appear similar. Despite some yet unexplained chemical results, the data indicate that the Brady is doing a satisfactory job at thermally deactivating antinutritional factors in soybeans.

The Brady was examined after extensive use at INCAP. The rotor weldment was showing signs of wear, the beater bars were badly eroded, and the cone and cup needed replacing. Requirements and procedures for these changes were discussed and INCAP is planning to initiate preventive maintenance steps.

It appears that the drive shaft may be slightly bent on the Brady screw. Partial correction may be possible by cup centering techniques. INCAP also intends to order a new rotor weldment.

Harper also spent time with Dr. Molina and representatives of agricultural cooperatives who are interested in agro-industrial development, specifically, concerning application of LEC's to the manufacture of:

1. CSB
2. Soup bases
3. Snack items
4. Drink bases
5. Precooked corn tortilla flour.

5.2 Philippines

Between May 5-23, 1977, a training program was conducted at the Batek Center of the Philippines, Philippine Women's University, which is located 30 km south of Manila in Dasmariñas, Cavite.

Initially, the facility was inspected to determine the best location to install the equipment as it had only been uncrated. After a proper location was determined, installation of equipment was made. The following items were required before the machine was operational.

1. Engine and drive assembly were located.
2. Extruder was attached to drive.
3. Feeding hopper was constructed.
4. Water hook-up was made.
5. Fuels, lubricants, etc., were obtained.
6. Battery filled and charged.

Due to the location of the facility and the distance to stores, approximately one week was required to complete the installation.

5.2.1 Training

The training program was altered to accommodate as many recommendations from the various evaluation teams as possible.

The program was given in the following sequence:

1. Classroom lecture
2. Machine experience
3. Post-extrusion training.

A classroom lecture was given to the trainees to initiate the technology transfer. Extensive information was given regarding the following areas:

1. History of LEC project
2. History of the Brady
3. Principle of operation of the Brady
4. Warm-up procedures
5. Operational procedures
6. Shut-down procedures
7. Indicators of proper functioning during operation--sight, smell, etc.
8. Determining the test and extrusion parameters.

The training associated with operating the machine began with disassembly of the Brady. Important parts were designated and their importance to the extrusion process was explained. The trainees were allowed to reassemble the machine under close supervision with special attention given to the proper sequence of assembly and the correct torque for bolts holding critical parts.

Maintenance was discussed with the trainees. Parts that should be greased frequently were discussed. Maintenance of the diesel engine was also noted.

In an effort to acquaint the trainees with designing a test program, a portable blackboard was made available to plan and record each day's

run, temperatures, and water additions prior to extrusion. The trainees were asked to plan the different runs followed by a discussion on the reasons for temperature selection, water additions, and any other operational logistics. Pitfalls foreseen and possible corrective actions that could be initiated were indicated prior to starting the run.

Following extrusion, discussions were held on problems that occurred during the period of operation. Trainees were asked to respond to the problems they felt they had encountered and how they would solve them if they should occur in the future.

Training was given on the possible ways of determining the degree of cooking. Discussed was the use of taste tests and consistometer tests. A consistometer test on 70/30 corn/soy cooked at different temperatures was demonstrated to show the effects of temperature on viscosity and thus the degree of cooking.

5.2.1.1 Materials for Testing. Also located in the Dasmariñas area is a farm cooperative headed by Rev. John Beran for the Union Theological Seminary. The cooperative has a feed milling operation used for preparation of animal feed. Because some interest was shown in the Brady by the cooperative, the initial problem of obtaining cereals was overcome. The cooperative agreed to loan cereals and other products to the university for the training program. Materials that were extruded would then be returned to the cooperative for feeding their animals.

Items used during the training program included rice bran, a special feed mixture, corn, sorghum and soybeans. Some of the materials were ground in a hammer mill owned by the seminary as the Batek Center

did not have the capacity to grind enough material for the training session.

5.2.1.2 Training Combinations. Although the soybeans were old, they did serve the purposes of warm-up and shut down, etc. A mixture of 70% corn/30% soybeans was used for initial extrusion and polishing the extruder internal surface.

Rice Bran--The rice bran loaned by the theological seminary was extruded in the Brady. The bran was one of three grades (fine) available in the Philippines. It was fresh and approximately 60-80 mesh size.

Three grades of rice bran are available according to particle size:

1. Grade Coarse - This material is a combination of rice bran and hulls or waste from the rice milling.
2. Grade Medium - This material has a large percentage of rice bran and a small percentage of hulls.
3. Grade Fine - 100% rice bran with no hulls present. Mesh size ranges from 60-80 mesh. Generally this product is most frequently used in the Philippines.

A test matrix of four temperatures and two moisture additions was designed. Temperatures of 138°C, 149°C, 160°C and 171°C were selected to give a range of test points. In addition, moisture additions of zero and approximately 1% were used.

Results indicated that the rice bran could be extruded with relative ease. Throughput rates were approximately 295 kg/hr at all temperatures. Because of the large oil content in the rice bran, the cone had to be tightened down to maintain and/or increase the temperature. A temperature of 171°C could not be attained as the cone clearance was too close,

and a feed transition plug resulted. A second attempt produced similar results.

Water addition of 1% was used, however, the maximum temperature reached was only 149°C. Attempts to reach higher temperatures with moisture again resulted in feed transition plugs.

Examination of the screw after extrusion of the rice bran indicated that it was highly polished. These observations indicate that rice bran is quite abrasive and might mean rapid screw wear with extensive extrusion. Only expanded testing would indicate the extent of screw wear with time.

The extruded rice bran took the form of chips approximately 6 mm in diameter. Samples were kept for analysis to be conducted at CSU. These tests will determine the effect of heat treatment on the rice bran and the resulting stabilization of the oil.

Special Formula--A special formula used by Rev. Beran on his research farm was tested on the Brady. The formula consisted of:

30% corn	3% meat and bone
30% rice bran	1% limestone
20% copia	7% corn germ
6% soybean meal (44% protein)	vitamins
3% fish meal (65% protein)	minerals
	antibiotic

This formula was designed to have 7.5% oil content and to be used for an animal feed. The formula extruded quite easily and reacted similarly to a 70% corn/30% soybean combination.

The purpose of using the Brady on this formula was not to cook the mixture, but to form the product into a pellet. The Brady was not capable of pellet forming without some type of heat treatment.

Corn/Coconut/Mung Bean--A mixture of 70% corn/20% dessicated coconut/10% mung bean was blended together and extruded to familiarize the trainees with some of the ingredients they will be working with during the test period.

The formula extruded easily at 160°C with and without water. Chips formed were well cooked with a pleasant aroma and taste. The coconut was the most dominant flavor characteristic of the mixture.

Other materials were extruded such as 100% cereals, etc., to complete the training.

During training, no problems occurred other than a bearing failure in the gear reduction unit of the Caterpillar engine. The failure is most likely due to a factory defective bearing and lubrication problems. Bearing replacements were found in Manila. An upper gear could not be found, therefore, it was taken to a machine shop where one end was built up and machined to fit the bearing. Replacement parts are currently being ordered and shipped.

5.2.2 Demonstration

On Friday, May 20, 1977, a lecture/demonstration was held to acquaint various groups in the Philippines with the LEC technology. Approximately 50 people attended the demonstration. Due to the involvement with the program it was impossible to meet all of the people who were there. Therefore, the groups represented compared to those invited could not be discerned. In talking with one group, Leslie Food Corporation, the interest was mainly centered around snack food items. Their chief concern was in the form of the output from the Brady and how it might be improved.

Feeding programs are being carried on in the Philippines, however, it was impossible to determine if those programs were represented by any organization at the demonstration. Interest generated was quite positive and any individual who was interested in the Brady was to contact Dr. Pablo.

5.3 Guyana - Technical Assistance Visit

5.3.1 Background

During March 1978, the Guyana Pharmaceutical Corporation (GPC) in Georgetown, Guyana, obtained a Brady 206 extruder and electric motor to begin experimental operations to determine potential products for distribution in Guyana. The GPC is interested primarily in manufacturing a weaning food for distribution to malnourished children and an instant pea soup using indigenous black-eyed peas for commercial marketing.

During April, Joe Kellerby and Ron Tribelhorn visited Guyana to provide some initial technical assistance to officials of GPC. The chief objectives of the visit were to assist the staff of GPC in operating the extruder on various materials and to discuss preliminary specifications for the proposed weaning food plant.

5.3.2 Training of GPC Personnel on Brady Operation

The procedure to acquaint the GPC personnel with the mechanics of the extruder and to train them in its operation was performed in the sequence listed below.

1. The flow of material through the extruder was briefly explained.
2. The extruder was disassembled, and the function of each component was described.

3. The GPC personnel reassembled the extruder.
4. The ancillary equipment was set up and the raw materials were prepared for extrusion through a cooperative effort by GPC and CSU personnel.
5. Product cut-off knives were installed on the outlet of the extruder.
6. Proper operation of the Brady on various materials was described, including warm-up and shut down procedures.
7. The extruder was warmed up and operated on whole soybeans, followed by 100% ground rice bran, showing the method of operation to the GPC personnel.
8. The GPC food technologist, Mr. Vic Oditt, was given control of the machine and assisted in operating it on rice bran.
9. Operation of the extruder on 70% corn/30% soy was performed by Mr. Oditt with assistance from Tribelhorn and Kellerby.
10. Mr. Oditt was assisted in operating the extruder on other formulations as electricity became available. (The city of Georgetown experienced numerous blackouts during the week due to power plant failures.) Other GPC personnel were also instructed in the Brady operation throughout the week, and they assisted by collecting and bagging the extruded products.

The following formulations of raw materials were prepared and extruded during the training period:

1. 100% whole soy
2. 100% rice bran
3. 70% corn/30% soy
4. 70% rice/30% soy

5. 100% corn
6. 100% rice
7. 100% black-eyed peas (BEP)
8. 70% corn/30% BEP
9. 80% BEP/10% corn/10% rice
10. 50 parts corn/10 parts rice/7 parts soy oil to be blended following extrusion with 20 parts skim milk/8 parts sugar.

Mixtures 9 and 10 were prepared as initial trial formulations for the instant pea soup and infant weaning food which GPC plans to produce.

5.3.3 Proposed GPC Plant Development

GPC has several objectives for the establishment of a production facility. These objectives are listed below.

1. Manufacture of a weaning food, formulated and developed by GPC.
2. Manufacture of a pea soup-type product which would be sold commercially for various consumer uses.
3. Manufacture of a breakfast-type cereal for commercial sales.
4. Production of a variety of products.
   a. weaning food - 455 metric tons/yr
   b. pea soup - dependent on sale and acceptability
   c. breakfast cereal - unknown.
5. Production of these components using two independent processing lines.

GPC has identified two phases for reaching their ultimate objective--a weaning food plant. The essentials of these phases include:

Phase 1 - The erection and implementation of a pea soup production line that would also be used to manufacture and test various formulations of weaning foods.

Phase 2 - Selection of a weaning food formulation and design, installation and start-up of a separate production line for the manufacture of a weaning food.

GPC has secured essential pieces of equipment that will assist in the implementation of the initial phase. These items include:

1. Brady cooker with 74.6 kW electric motor
2. Hammer mill with 22.4 kW motor
3. Paddle blender with 50 kg capacity
4. Fitz mill comminuter with 5.6 kW motor.

These items would be incorporated with other essential pieces of equipment into a production line capable of manufacturing the pea soup product. Trial weaning food formulations would be manufactured with this line and sent out for acceptability tests in order to select the two best formulas.

The two formulas would be remanufactured on a larger scale for purposes of acceptability, test marketing (or public acceptability) and nutritional analysis. It is expected that this stage would require an outside consultant to assist in the final formula selection.

It is anticipated that phase 2 of the project which deals with plant design and equipment selection may begin after the proposal for funding is approved by USAID/W. This would permit some plant design to proceed prior to selection of the final formula.

A compact time table has been set up by GPC. Essentially, the goal is to have the weaning food plant in operation by the middle of November. Although possible, GPC was briefed on the recent problems that CSU

has experienced in the logistics of equipment purchase and shipment for Costa Rica, Tanzania and Sri Lanka.

5.3.4 Plant Design Discussion

Ideas were exchanged on plant design to gain a better insight into both GPC and CSU by both parties. CSU discussed the plant layouts for Costa Rica, Tanzania and Sri Lanka, describing the constraints and steps that led to the final designs. Equipment specifications for Costa Rica were reviewed briefly and left as reference material for GPC.

GPC discussed their ideas for a production plant. Some important design considerations for this plant were given.

1. The plant should use a minimum amount of floor space.
2. The minimum number of conveyors should be used.
3. Multilevel design to utilize gravity was believed to be a means of reducing the number of onveyors and floor space.

GPC would like to use pneumatic systems for vertical conveying between levels in the proposed plant. Several points were discussed concerning the relative merits of pneumatic and screw conveyors.

The GPC presently has 445 sq m of building space available for a production facility. This space is approximately 25 m by 18 m, constructed of concrete block, with a clear span roof 6 m high at the walls and 9 m at the center. In addition, the floor area might be doubled if necessary by occupying an adjacent room in the same building.

5.3.5 Product Packaging Discussion

A discussion was held to determine GPC's ideas for packaging the final product. Their original idea to use automatic packaging has been abandoned due to the high capital cost. Packaging lines in use or

planned for use in other LDC's were discussed; GPC concurred that a labor-intensive type of line would work for their operation.

Packaging materials are not readily available in Guyana. GPC is presently considering two package types:

1. Polyethylene - printed single color
2. Polypropylene with cellophane laminate for printing.

GPC would prefer a two- or three-color printed bag. The major problem they have is printing the polyethylene bags which apparently require pretreatment (required for bag to accept the ink). The polypropylene/cellophane laminate is a possible choice, but preliminary study has indicated it may be too expensive.

GPC was also concerned that product oils might permeate the bags. CSU has requested the staff of USDA/W to assist in providing packaging advice to GPC to help solve the problem.

6.0 GRANULAR BED ROASTER EVALUATION

6.1 Roaster Designs

Colorado State University has evaluated several roasters for heat treating soybeans during the past year. These roasters have all used a heated agitated granular bed of sand or salt which co-mixed with the soybeans to accomplish the roasting.

One type of roaster tested was designed with a granular bed heated in a separate heating chamber, conveyed into a contacting chamber where beans and granular bed mixed, followed by a separation and recirculation of the granular bed. In this case, heat transfer occurs between the heated granules of salt or sand and the cold beans when the two materials

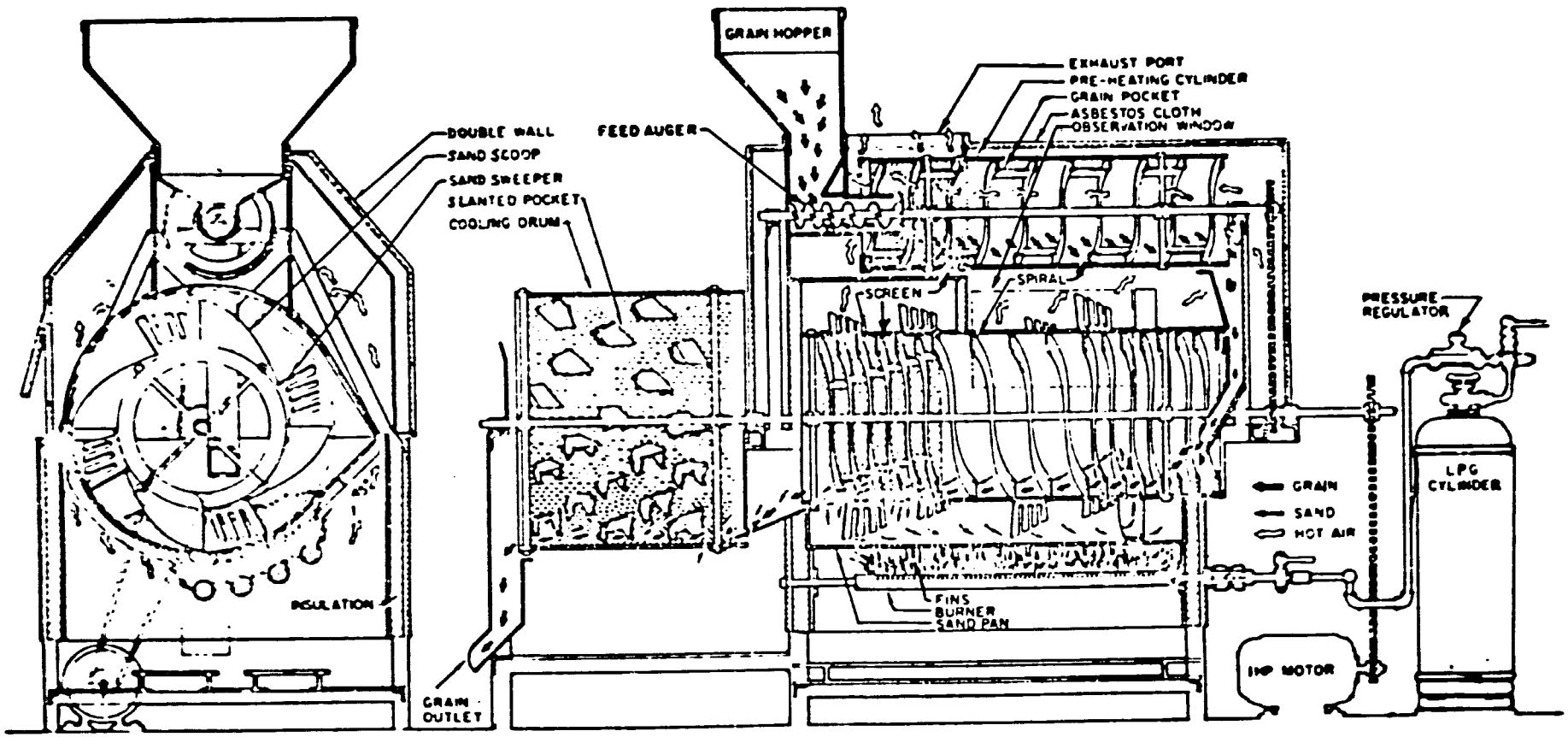
are mixed. Also, the beans are never exposed to direct flames. Typically, these roasters have the following characteristics:

1. A constant quantity of granular bed material exists in the machine which means that the recirculation rate of the bed is constant.
2. Residence time of the beans in the bed is generally fixed by the rotational speed of the contacting chamber which is equipped with an internal helix.
3. Bean throughput is variable, however, as throughput is increased, the volumetric ratio of sand to beans is reduced which can change roast uniformity detrimentally.
4. Temperatures of granular bed can be changed by simple burner control.

One roaster of the type studied at CSU is the heat sand parboiler designed by IRRI, Los Banos, Philippines. The design is shown in Figure 22. Another roaster using a separate chamber for heating the granular bed and then mixing the hot granular bed with the soybeans is the Model 1, Food Processes, Inc. (FPI), Saginaw, Michigan. In this machine, the granular bed is heated through direct contact with combustion gases, then mixed with the soybeans.

Operational characteristics of the roasters with the granular bed heated separately are as follows:

1. The granular bed is heated through contact with a steel plate which is directly heated with propane burners underneath or by direct contact with combustion gases.
2. A single drum with an internal helix is used as the contact chamber between the agitated bed and beans. In the case of



SCHEMATIC DRAWING OF THE CONTINUOUS FLOW HEATED-SAND DRYING AND PARBOILING MACHINE

Figure 22. Heated sand parboiler designed by Dr. Amir U. Khan for the International Rice Research Institute, Los Banos, Philippines.

the IRRI roaster, fins are attached to the outside diameter of the drum which drag the granular bed over the heated plate, conveying it in an opposite direction to the helix in the contacter.

3. The heated bed granules enter the contact chamber through small scoops near the inlet end. A screw conveyor lifts the granular bed from the heating to the contacting chamber on the FPI Model 1 roaster.
4. The last third of the contacting chamber is screen which serves as a separator of granular bed and beans.
5. Throughput is approximately 135 kg/hr for the IRRI roaster and 910 kg/hr for the FPI Model 1 roaster.
6. The FPI Model 1 has improved thermal efficiency because the heat transfer area is the surface area of the particles in the granular bed while the IRRI roaster has a heat transfer surface area limited to the metal pan separating the burner from the heating bed.

A second type of roaster which has been evaluated, is a direct contact type roaster. Here a horizontal cylinder fixed with internal lifting flights is used to mix and convey beans and the granular bed simultaneously. In this roaster, both the granular bed and co-mingled beans cascade through hot air in the same chamber. Such a design improves mixing and thermal efficiency, but reduces residence time control.

Typically, direct contact type roasters have the following characteristics:

1. The quantity of granular bed material in the roaster can be varied, therefore, a constant heated granule-to-bean ratio can be achieved with different roasting rates.
2. Residence time of contact may be varied by changing the slope of the roaster and rotational speed of heat/contacting drum.
3. Temperature can be regulated by changing burner controls.

Figure 23 shows a direct contact type roaster that will be demonstrated in Costa Rica and which has been extensively tested at CSU. The roaster is manufactured by Food Processes, Inc., and is designated as Versatile-100. The roaster body is made using two concentric drums. Between the outside drum and inner drum is a helix which is used to convey the granular bed "S" back to the input end of the roaster. The bed is then scooped up to the inner drum where it comes in contact with the beans. The bean/bed mixture is then conveyed by lifting flights to the output end, and cascades through hot air from a burner firing directly down the center of the drum. Air is moved through the cascade of sand and beans by a discharge blower and heated using a liquid propane burner located at the bean discharge end of the drum. The mixture is screened, with the sand falling through the screen, for recirculation while the beans exit the chamber over the top of the screen.

The granular bed, in the case of the direct contact roaster, is not the total heat transfer medium for the beans, but increases the rate of heat exchange to the beans, improves residence time control and enhances thermal efficiency of the roaster.

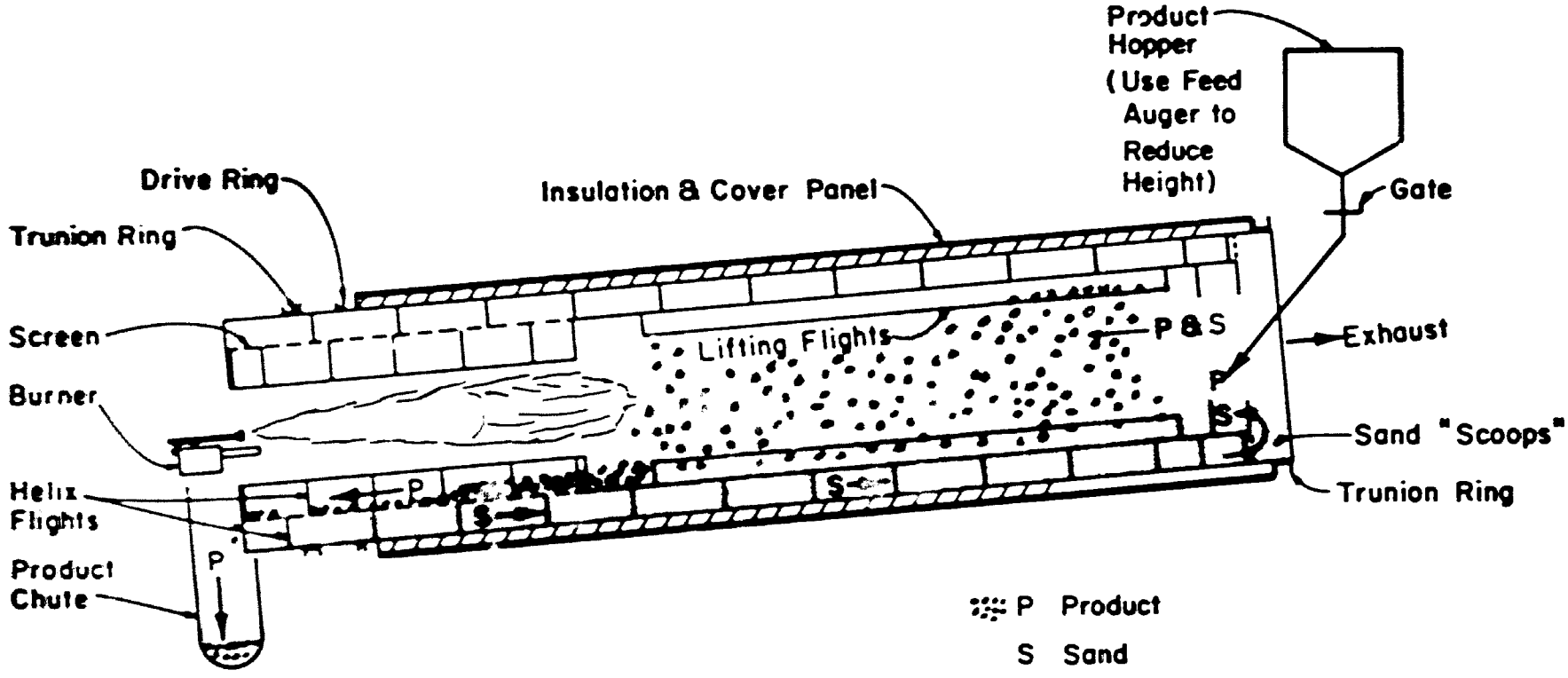


Figure 23. Schematic drawing of Versatile-100 roaster - internal flow.

6.2 Evaluation of Roasters Where Granular Bed is Heated Separately from Contacting Process

Samples of whole raw soybeans were roasted in Model 1, Food Processes, Inc., agitated bed roaster. Roasting was done at temperatures ranging from 175-230°C with residence times ranging from 15-24 seconds.

The results of these trials are very encouraging. The dry roaster technology, where a granular bed is employed to give a uniform temperature and heat treatment, appears to offer substantial processing advantages. It has a simple design, yet gives products with good functional and nutritional characteristics. Its major mechanical drawback is the use of a screw conveyor to recirculate the heated granular bed.

Table 36 shows the conditions of the roasting study. At the low roasting rates, the temperature drop in the agitated granular salt bed was quite low (~16.7°C). Subsequent roasting studies at higher rates (~910 kg/hr) show a substantial temperature drop across the contact bed. This temperature drop can be reduced through the use of sand rather than salt because the heat capacity of sand is higher than salt.

Table 37 shows the results of the proximate analysis. Little difference between samples is noted, as expected. Values for moisture, fat, nitrogen, ash and fiber are similar to those reported in the literature. Approximately 3% moisture was lost from the samples during the roasting process.

The chemical and physical properties of the roasted soy samples are shown in Table 38. These data would indicate that the functionality of the protein decreased [as measured by water-holding capacity, viscosity (uncooked and cooked) and NSI] as the temperature increased and a

Table 36. Data from 5 x 5 temperature/residence time study for agitated sand bed roaster.*

Test point	Sprocket size (number of teeth)	Angular rotation (rpm)	Salt inlet temperature (°C)	Estimated salt outlet temp. drop (°C)	Soybean throughput (kg/hr)	Soybean residence time (sec)	Salt recirculation rate (kg/hr)
1**	35	17.8	178	16.7	189	15.2	2073
2	35	17.8	202	16.1	183	15.2	2073
3	35	17.8	215	15.0	166	15.2	2073
4**	35	17.8	235	17.2	198	15.2	2073
5	35	17.8	246	16.7	192	15.2	2073
6	42	14.9	175	17.2	202	18.1	1978
7	42	14.9	203	17.2	204	18.1	1978
8	42	14.9	217	17.2	202	18.1	1978
9	42	14.9	231	16.7	195	18.1	1978
10	42	14.9	245	16.1	186	18.1	1978
11	48	13.0	181	16.7	192	20.8	2142
12	48	13.0	206	16.1	184	20.8	2142
13**	48	13.0	219	15.6	169	20.8	2142
14	48	13.0	233	15.6	169	20.8	2142
15	48	13.0	247	15.0	172	20.8	2142
16	54	11.6	174	17.8	209	23.3	2122
17**	54	11.6	203	16.7	196	23.3	2122
18	54	11.6	218	16.7	196	23.3	2122
19	54	11.6	231	17.2	197	23.3	2122
20	54	11.6	245	16.7	192	23.3	2122
21**	60	10.5	176	17.2	200	25.8	2068
22	60	10.5	198	17.2	201	25.8	2068
23	60	10.5	214	16.7	195	25.8	2068
24**	60	10.5	226	16.7	192	25.8	2068
25	60	10.5	237	20.0	255	25.8	2068

* FPI, Model 1 roaster was used where salt was heated in a separate chamber from the contacting/roasting device.

**Samples used in chemical, physical and nutritional property analysis.

Table 37. Proximate analysis of roasted soy samples - as is basis.[1]

Sample Code number	Description	Moisture (%)	Fat (%)	Nitrogen (%)	Protein[2] (%)	Ash (%)	Fiber[3] (%)	Carbohydrate, by difference (%)
2-15-7	Dehulled soy - 175°C 15 sec.	6.2	19.1	5.77	36.1	4.2	2.5	31.9
2-15-8	Dehulled soy - 175°C 24 sec.	5.5	20.3	5.85	36.6	4.1	2.5	31.0
2-15-9	Dehulled soy - 205°C 22 sec.	5.2	20.7	5.80	36.3	4.2	2.5	31.1
2-15-10	Dehulled soy - 220°C 20 sec.	4.8	20.8	5.86	36.6	4.3	2.5	31.0
2-15-11	Dehulled soy - 230°C 15 sec.	5.1	20.8	5.79	36.2	4.3	2.5	31.1
2-15-12	Dehulled soy - 230°C 24 sec.	3.9	21.2	6.00	37.5	4.3	2.5	30.6
2-15-27	Whole soy - 205°C 22 sec.	5.3	18.9	5.46	34.1	4.5	5.1	32.1

[1] FPI, Model 1 roaster was used where salt was heated in a separate chamber from the contacting/roasting device.

[2] N x 6.25.

[3] Fiber determination done for sample 2-15-10; used for other dehulled soy samples.

Table 38. Chemical and physical properties of roasted soy samples - as is basis.[1]

Sample[2]	Code[3]	Moisture (%)	Water-holding capacity (%)	Urease activity (increase in pH)	Viscosity uncooked[4] (CPS)	Viscosity cooked[5] (CPS)	Total nitrogen (%)	Water-soluble nitrogen (%)	NSI[6]
18-175	HF	4.70	240	1.83	4400	—	5.88	2.80	47.6
	HM	5.36	229	2.01	1000	25	5.78	2.41	41.7
	HC	5.82	243	1.96	334	15	5.72	1.99	34.8
18-175	DF	4.49	254	2.00	3800	30	6.02	3.42	56.8
	DM	4.97	220	1.99	1000	20	5.85	2.73	46.7
	DC	5.43	237	1.98	734	15	6.09	2.16	35.5
22-220	HF	3.91	184	0.27	1066	80	5.83	0.93	16.0
	HM	4.27	217	0.32	v. low	45	5.79	0.94	16.2
	HC	4.58	214	0.35	66	5	5.70	0.58	10.2
22-220	DF	5.45	193	1.08	400	75	5.78	1.23	21.3
	DM	4.20	195	0.36	v. low	115	5.98	1.07	17.9
	DC	4.61	204	0.28	v. low	15	6.06	0.74	12.2
24-245	HF	3.14	177	0.07	66	—	6.00	0.70	11.7
	HM	3.13	178	-0.02	v. low	25	6.08	0.56	9.21
	HC	3.14	215	-0.02	134	10	6.04	0.41	6.79
24-245	DF	2.81	177	-0.02	66	155	6.33	0.56	8.85
	DM	3.45	182	0.21	400	6	6.23	0.91	14.6
	DC	3.03	218	-0.2	v. low	v. low	6.33	0.42	6.64
Raw whole soy		7.05	273	1.92	1667	25	5.59	3.42	61.2
Raw dehulled soy		6.32	283	1.97	1067	18	5.88	3.38	57.5

[1] FPI, Model 1 roaster was used where salt was heated in a separate chamber from the contacting/roasting device.

[2] First number is residence time in seconds; second number is roasting temperature in °C.

[3] D = dehulled; H = hulled; F = fine; M = medium; C = coarse.

[4] Spindle No. = 7; rpm = 20.

[5] Spindle No. = 3; rpm = 20.

[6] Nitrogen solubility index.

coarser grind was used. Dehulling tended to increase functionality slightly. Using the criteria for properly heat processed full-fat soy flour of a urease value <0.50 and NSI >10, samples heat processed at 205-220°C for approximately 20-25 seconds appear suitable.

At the bottom of Table 38, the values of the functional properties for raw soy are shown where the protein has received no heat treatment. These data can be used as a standard of comparison to see how the functional properties of the soy change with heat treatment.

Table 39 gives the effect of heat treatment of trypsin inhibitor (TIU) levels. The dry granular bed roasting process was very effective at denaturing the trypsin inhibitor activity. All samples at 205°C or above showed 75% or more TIU destroyed, which is very satisfactory. Higher temperatures resulted in greater destruction of trypsin inhibitor activity.

The results of rat growth experiments are shown in Table 40. Excellent results were obtained for all samples roasted at 205°C for approximately 20 seconds or at higher temperatures. The maximum PER of 2.3 was found for soybeans roasted at 230°C for 15 seconds. Excessive heat treatment can reduce the functionality of the protein and should be discouraged. For this reason, roasting temperatures in excess of 220°C appear unwarranted.

These data clearly show that the dry roasting process is an effective means of heat treating legumes. It is interesting to compare the TIU results in Table 39 with the PER's. There appears to be a definite correlation with greater trypsin inhibitor destruction and higher PER's, as would normally be expected.

Table 39. Roasted soy samples - trypsin inhibitor activity.[1]

Sample	Residence time (sec)	Roasting temperature (°C)	TIU/gram	% Inhibitor destroyed
Raw whole soy			59,050	
Raw dehulled soy			75,500	
with hulls	18	175	35,000	40.7
dehulled	18	175	40,500	46.4
with hulls	22	220	3,250	94.5
dehulled	22	220	14,150	81.3
with hulls	24	245	1,000	98.3
dehulled	24	245	2,075	97.3
dehulled	15	175	48,500	35.8
dehulled	24	175	40,250	46.7
dehulled	22	205	19,000	74.8
dehulled	20	220	9,250	87.7
dehulled	15	230	7,150	90.5
dehulled	24	230	9,600	87.3
with hulls	22	205	28,250	52.2
Extruded dehulled		138	36,450	51.8

[1]Samples were defatted and passed through a 100 mesh sieve. Extraction was maximized with a one-hour extraction period for the raw samples and a three-hour extraction period for the roasted samples.

The procedure and calculations are described in AOCS Tentative Method Ba 12-75.

FPI, Model 1 roaster was used where salt was heated in a separate chamber from the contacting/roasting device.

Table 40. Results of rat growth experiment 4 (4 weeks growth) on roasted samples.[1]

Sample code number	Description	Weight gain (g)	PER	Corrected[2] PER	PRE[3]
2-15-7	Soy roasted 175°C, 15 sec, dehulled	59.8 ± 3.8	2.11 ± 0.09	1.67 ± 0.07	51.1 ± 1.7
2-15-8	Soy roasted 175°C, 24 sec, dehulled	66.0 ± 5.9	2.05 ± 0.16	1.62 ± 0.13	49.3 ± 3.3
2-15-9	Soy roasted 205°C, 22 sec, dehulled	102.6 ± 4.2	2.79 ± 0.04	2.20 ± 0.03	61.8 ± 1.2
2-15-10	Soy roasted 220°C, 20 sec, dehulled	113.1 ± 4.6	2.75 ± 0.06	2.17 ± 0.05	60.0 ± 2.5
2-15-11	Soy roasted 230°C, 15 sec, dehulled	108.4 ± 3.3	2.93 ± 0.04	2.31 ± 0.03	65.9 ± 1.5
2-15-12	Soy roasted 230°C, 24 sec, dehulled	104.4 ± 4.7	2.67 ± 0.06	2.11 ± 0.05	60.8 ± 1.6
2-15-12a	Soy roasted 205°C, 22 sec, whole	106.6 ± 5.5	2.53 ± 0.04	2.00 ± 0.03	58.0 ± 1.8
2-15-16	Dehulled soy - Raw	54.1 ± 4.3	1.88 ± 0.07	1.49 ± 0.06	44.1 ± 2.7
2-15-16	Dehulled soy extruded 138°C	103.4 ± 5.2	2.50 ± 0.07	1.98 ± 0.06	58.1 ± 1.1

[1] FPI, Model 1 roasted was used where salt was heated in a separate chamber from the contacting/roasting device.

[2] Corrected to casein = 2.50.

[3] Based on 2 weeks growth.

The roasted soy samples were used to supplement white bread. All six products designated by a ** in Table 36 performed very satisfactorily even at the 10% level of addition. The bread formula used is shown in Table 41.

Farinograph results on the bread doughs are shown in Table 42. Generally, as the amount of soy in the blend increased, Farinograph absorption increased and dough development time decreased. The mixing tolerance index (difference in Brabender units from top of curve at peak to top of curve measured five minutes after peak) did not change. All blends showed good mixing properties with the addition of soy product.

Baking trials using the full-fat soy in white bread showed that it could be substituted for white flour up to 10% with no resulting loaf-depressing effect when SSL was used.

In summary, the studies showed that a very desirable full-fat soy flour could be produced by first dry-roasting the soybeans and then grinding. As the roasting temperature increased, the functional properties of the full-fat soy flour were reduced. Grinding to -100 mesh improved the functional properties. Optimal roasting conditions appeared to be 205-220°C for 20 seconds. At this condition, the resulting product had a water-holding capacity of about 200%, a urease value of 0.3, a nitrogen solubility index of 18% and a corrected PER of 2.2. Such a product would be suitable for incorporation into Title II commodities currently manufactured in the United States.

6.3 Evaluation of Roasters where Granular Bed and Products are Heated Together in a Single Chamber

The roaster for the Costa Rican installation, FPI, Versatile-100, has been tested at CSU to determine the mechanical characteristics of

Table 41. Baking formulation for bread fortified with roasted soy products.[1]

Ingredient	Percent	Grams
Flour[2]	100	500
Yeast	2.5	12.5
Yeast food	0.5	2.5
Salt	2.0	10
Sugar	4.0	20
Shortening (Crisco)	3.0	15
Emplex (SSL)	0.5	2.5
Mycoban	0.3	1.5
Water[2]		

Method

Used Hobart N-50 mixer.
Mixed 10 minutes - 1 min. on low (speed 1) and 9 min. on speed 2.
Fermented dough 1 1/2 hours at 80°F (27°C).
Divided dough into 3 loaves (22C g/loaf).
Rounded and let rest 10 minutes.
Molded into loaves and placed in greased pup-loaf pans.
Proofed to height (1" above pan) at 100°F (38°C).
Baked at 425°F (220°C) for 18 minutes.
Removed from pans and let cool on rack.

Sample		Bread flour, g	Soy product, g	Water, ml[3]
Control		500	--	350
-15-1	(5%)	475	25	350
	(10%)	450	50	360
2-15-2	(5%)	475	25	355
	(10%)	450	50	365
2-15-3	(5%)	475	25	355
	(10%)	450	50	365
2-15-4	(5%)	475	25	355
	(10%)	450	50	365
2-15-5	(5%)	475	25	355
	(10%)	450	50	375
2-15-6	(5%)	475	25	365
	(10%)	475	50	380

[1]FPI, Model 1 roaster was used where salt was heated in a separate chamber from the contacting/roasting device.
[2]See the section of the table below.
[3]Includes 10 ml $KBrO_3$ (potassium bromate).

Table 42. Farinograph results - breads fortified with roasted soy products.[1]

Sample		Absorption (%)	Dough development time (min)	Mix tolerance index (BU)[2]
2-15-1	(5%)	68.0	6.0	20
	(10%)	69.5	5.5	20
2-15-2	(5%)	69.3	7.0	20
	(10%)	70.5	5.5	25
2-15-3	(5%)	68.3	6.5	20
	(10%)	70.5	6.5	30
2-15-4	(5%)	67.6	6.5	25
	(10%)	70.0	6.0	25
2-15-5	(5%)	68.8	6.0	30
	(10%)	72.0	5.5	30
2-15-6	(5%)	71.9	7.0	20
	(10%)	73.9	7.0	20
Control		68.0	7.0	30

[1]FPI, Model 1 roaster was used where salt was heated in a separate chamber from the contacting/roasting device.

[2]BU = Brabender units.

operation. These tests included studies of the uniformity of soybean movement based on the following variables: rotational speed of drum, roaster incline, total sand loading and sand recycling rate. In addition, the energy balance of the roaster system was determined using the ambient and exhaust temperatures, the change in sand temperature, the change in bean temperature, propane gas consumption and amperage for each test. The results of these tests are given in the next section.

Chemical, physical and nutritional analyses of the roasted soybeans have been conducted to finalize the evaluation of the roaster for the purpose of specifying the best operating conditions. When specifying these conditions, an attempt was made to match the optimum product quality with the most efficient mechanical operation.

During the evaluation tests of the roaster, it was possible to recognize and correct some mechanical deficiencies which existed in the original drive mechanism. These modifications should significantly improve the life of the roaster in continuous operation. This "hands-on" experience has contributed greatly toward the preparation of the operation and training manuals for the Costa Rican plant.

A summary of the roaster mechanical characteristics is given in Table 43. A total of four roaster inclines, five rotational speeds, and four sand loading rates were investigated to determine the effects on average bean residence time and sand recycling rate. Table 43 presents selected variables and results that were investigated. Other variables investigated included 1.56 cm/m incline, 22.1 rpm and 24.6 rpm speeds, and 135 kg sand loading.

Several observations were made based upon data presented in Table 43 and on visual analyses of the roaster operation.

Table 43. Versatile-100 direct contact roaster mechanical variables.

Sand Loading (kg)	Speed (rpm)	Incline (cm/m)	Bean Residence Time (min:sec)	Sand Recycling Rate (kg/hr)
0	17.4	3.13	2:51	0
		4.69	2:00	0
		6.25	1.07	0
0	27.3	3.13	2:27	0
		4.69	1:40	0
		6.25	1:18	0
90	17.4	3.13	4:24	1,188
		4.69	2:59	1,494
		6.25	2:16	2,064
90	19.7	3.13	4:30	1,068
		4.69	2:47	1,368
		6.25	2:18	1,854
90	27.3	3.13	4:09	1,260
		4.69	2:36	1,860
		6.25	2:03	2,232
180	17.4	3.13	3:52	2,310
		4.69	2:41	3,006
		6.25	2:13	3,088
180	19.7	3.13	3:40	2,448
		4.69	2:32	3,438
		6.25	1:56	3,906
180	27.3	3.13	3:38	2,580
		4.69	2:21	3,978
		6.25	1:52	4,128

1. Effects of the sand loading into the roaster:

   a. As the sand loading was increased, the residence time of the beans was more narrowly distributed, creating a condition more closely related as "plug flow."

   b. The bean residence time was increased approximately 1 minute between corresponding tests with varying sand loadings. There was little noticeable difference in bean residence times when sand loadings between 90 and 180 kg were used.

   c. Sand spillage into the roaster outlet was noticeably greater with the 180 kg loading than with the 90 kg loading. This was attributed to a doubling of the sand recycling rate.

2. Effects of the roaster rotational speed:

   a. Increases of roaster speed from 17.4 rpm to 27.3 rpm at a constant incline had negligible effects on bean residence time.

   b. Increases of roaster speed by 50% generally caused increases of the sand recycling rate by at least 10%.

   c. Increases of roaster speed from 17.4 rpm to 27.3 rpm produced undesirable mechanical effects--such as large amplitude vibrations in the machine and projected shorter roller bearing life.

3. Effects of the roaster incline:

   a. An increase in roaster incline of 100% produced a 50% decrease in bean residence time for given values of speed and sand loading.

b. For a sand loading of 90 kg, increases in incline of 50% and 100% produced increases in the sand recycling rate of 25% and 70%, respectively. For a sand loading of 180 kg, the corresponding increases in the sand recycling rate were approximately 40% and 60%.

A decision was made, based upon these observations, to fix the speed of the roaster at 17.4 rpm prior to the next phase of testing and for continuous operation in Costa Rica. Operation of the roaster at the lowest speed assured the longest operating life and the minimum operating costs without noticeably affecting its performance. The next phase of testing involved roasting soybeans under controlled conditions for the determination of the roaster energy balance and changes in product characteristics.

A summary of the average roasting conditions is given in Table 44. The following variables were measured for each test: ambient dry-bulb and wet-bulb temperatures, exhaust dry-bulb and wet-bulb temperatures, bean inlet and outlet (cooking) temperatures, exhaust air flow rate, and propane consumption. These variables were dependent on the bean feed rate and the propane input regulator, which were both fixed.

A computer program was developed to process the data and to calculate the energy balance and the efficiency of the system. The efficiency of the roaster was defined as the heat energy taken up by the beans and moisture evaporated divided by the heat energy provided by combustion of the propane. Efficiencies were difficult to determine because propane consumption could not be accurately measured. The percentages shown in Table 44 represent averages of several widely scattered values.

Table 44. Average soybean roasting conditions

Bean feed rate (kg/hr)	Bean cooking temperature (°C)	Number of tests	Ambient temperature (°C)	Ambient relative humidity (%)	Exhaust temperature (°C)	Exhaust relative humidity (%)	Propane consumption (kg/hr)	Efficiency (%)
625	120	6	11	76.8	98	5.1	7.6	51
	135	5	11	73.9	114	5.3	8.8	49
	150	6	12	70.1	118	5.0	9.3	52
865	120	6	12	78.7	72	13.1	8.2	58
	135	7	11	83.3	81	15.7	12.3	51
	150	5	12	78.2	89	11.1	11.4	57

The bean cooking temperature was controlled by adjustment of the propane flow and pressure using the propane regulator system. As the cooking temperature was raised, the propane consumption gradually increased.

The average efficiency for the 865 kg/hr feed rate was higher than that for the 625 kg/hr feed rate which indicated that more of the propane energy was going directly into roasting the soybeans. This result was confirmed by the fact that the exhaust temperatures were lower and the relative humidities were higher in the case of the 865 kg/hr feed rate. Based upon these results, it appears that the roaster should be operated at 850-900 kg/hr bean feed rate for maximum efficiency.

6.4 Evaluation of Roaster Samples

The following determinations were made on the approximately 50 samples involved: antitrypsin activity available lysine, water absorption, viscosity, nitrogen solubility index, particle size distribution and color. In addition, on a smaller subset of nine samples, protein quality evaluation, baking and flavor studies were conducted.

Trypsin inhibitor, available lysine, water absorption, viscosity, NSI and PER data are presented in Table 45. Generally speaking, lower effectiveness of heat treatment was associated with a lower destruction of antitrypsin activity along with increases in viscosity and solubility. Changes in water absorption were considerably less than were the changes in uncooked viscosity as related to heat treatment. As measured by antitrypsin activity and PER, a minimum temperature of 121°C was satisfactory in the presence of 90-kg sand loading and residence time of 4.4 minutes. In this case, 86% of the antitrypsin activity was

Table 45. Evaluation of roasted and extruded soy samples.[1]

FSN Code #	Sample description[2]	% Trypsin inhibitor destroyed	Available lysine[3] (g/100 g protein)	% Water absorption	Uncooked viscosity[4] (centipoise)	NSI	Weight gain (g)	Corrected PER
2-71- 6	140- 90.8-600-4.4-3.0	97.9	5.68	168	200	5.91		
2-71- 4	118- 90.8-600-4.4-3.0	98.2	5.75	178	272	5.98		
2-71- 2	118- 90.8-645-4.4-3.0	86.3	N.A.	160	288	6.28		
2-71- 8	121- 90.9-645-4.4-3.0	80.7	5.32	170	208	0.89		
2-71- 5	138- 90.8-600-2.9-4.4	98.9	6.11	180	224	5.83		
2-71- 3	107- 90.8-625-2.9-4.4	76.8	6.20	176	840	7.66		
2-71- 7	127- 90.8-575-2.9-4.4	95.9	6.05	169	608	4.63		
2-77-21	121- 90.8-875-4.4-3.0	100.0	7.12	190	80	11.95		
2-77-23	127- 90.8-875-4.4-3.0	94.5	5.91	190	36	6.97		
2-77-26	135- 90.8-850-4.4-3.0	98.0	6.51	198	60	7.02	105.1±7.8	1.93±0.07
2-77-20	140- 90.8-860-2.9-4.4	81.6	6.75	195	40	7.40	99.7±7.8	1.94±0.11
2-77-11	129- 90.8-860-2.9-4.4	94.5	5.20	193	60	8.56	117.1±3.5	2.11±0.04
2-77- 1	121- 90.8-875-2.9-4.4	86.2	6.13	234	144	21.93	119.7±5.1	2.25±0.04
2-77- 2	124-181.6-860-2.9-3.9	84.7	5.88	235	132	17.23		
2-77-16	135-181.6-850-2.9-3.9	97.7	5.00	195	80	9.63	120.8±5.6	2.15±0.04
2-77- 3	146-181.6-850-2.9-3.9	100.0	6.56	218	48	7.14		
2-77- 7	135-181.6-850-4.4-2.7	90.4	6.14	218	60	9.74	119.5±5.0	2.09±0.05
2-77-18	149-181.6-850-4.4-2.7	72.6	5.94	191	56	8.26		
2-77-19	124-181.6-850-4.4-2.7	73.9	7.01	219	160	26.12		
2-77-10	121-181.6-625-4.4-2.7	73.6	6.65	219	144	26.07		
2-77-15	127-181.6-635-4.4-2.7	93.9	6.16	198	56	13.14		
2-77-14	146-181.6-625-4.4-2.7	92.6	6.95	206	40	10.88		
2-77- 4	149-181.6-625-2.9-3.9	100.0	5.91	211	64	7.22		
2-77- 5	138-181.6-625-2.9-3.9	83.6	6.58	219	68	13.71		
2-77-24	124-181.6-625-2.9-3.9	73.8	7.09	214	476	36.56		
2-79- 2	163- 0 -625-2.9-2.8	96.8	6.21	188	128	7.21		
2-77- 6	143- 0 -625-2.9-2.8	92.4	5.67	213	52	9.35		
2-77-25	118- 0 -635-2.9-2.8	38.7	6.40	229	4504	50.60		
2-77- 9	135- 0 -860-2.9-2.8	88.7	6.76	205	480	15.68	123.0±4.1	2.18±0.05
2-77-13	122- 0 -860-2.9-2.8	50.1	7.35	220	720	43.40		
2-77-17	149- 0 -860-2.9-2.8	95.8	6.96	188	40	9.14		

Table 45. Evaluation of roasted and extruded soy samples (continued).[1]

FSN Code #	Sample description[2]	% Trypsin inhibitor destroyed	Available lysine[3] (g/100 g protein)	% Water absorption	Uncooked viscosity[4] (centipoise)	NSI	Weight gain (g)	Corrected PER
2-77-22	135- 0 -860-4.4-2.0	91.8	7.81	213	128	22.20	122.7±4.3	2.17±0.03
2-77-12	149- 0 -835-4.4-2.0	88.0	5.12	200	60	10.42		
2-77- 8	121- 0 -860-4.4-2.0	28.4	6.49	230	2088	54.77		
2-77-32	121- 90.8-850-4.4-3.0	78.2	6.69	218	632	28.27		
2-85- 6	121- 90.8-850-4.4-3.0	60.1	6.46	256	612	32.79		
2-85- 3	143- 90.8-880-4.4-3.0	95.3	5.01	235	184	17.08		
2-85- 5	135- 90.8-635-4.4-3.0	85.3	5.50	225	164	12.97		
2-85- 8	143- 90.8-625-4.4-3.0	100.0	6.31	235	108	9.24		
2-85- 7	124- 90.8-625-4.4-3.0	69.3	5.54	238	680	32.03		
2-85-10	149- 90.8-625-2.9-4.4	99.6	5.77	195	224	8.51		
2-77-33	135- 90.8-625-2.9-4.4	82.1	5.96	189	112	11.22	116.3±3.9	2.20±0.05
2-77-31	127- 90.8-625-2.9-4.4	78.4	6.33	203	200	16.75		
2-85- 9	127- 90.8-625-2.9-4.4	98.8	5.64	225	256	19.97		
2-85- 4	135- 0 -625-4.4-2.0	75.8	6.82	230	252	21.49		
2-85- 1	149- 0 -625-4.4-2.0	93.5	6.37	233	116	10.11		
2-85- 2	121- 0 -625-4.4-2.0	95.8	5.70	225	200	17.23		
2-77-30	143- 90.8-625-4.4-3.0	98.9	N.A.	228	116	9.32		
2-77-29	124- 90.8-625-4.4-3.0	78.6	7.08	224	728	27.04		
2-81-10	Extruded dehulled soy, 138°C	64.4	6.36				120.7±5.6	2.17±0.07
2-81-11	Extruded dehulled soy, 143°C	55.0	6.68				106.6±5.6	2.14±0.03
2-81-12	Extruded dehulled soy, 149°C	67.8	6.55				120.5±3.5	2.20±0.06
2-81- 9	Raw soy, dehulled	--	6.69				51.0±7.9	1.24±0.18

[1] Samples roasted on FPI, Versatile-100 roaster where sand, mixed with soybeans, was heated with combustion gases in a single chamber.

[2] Bean outlet temperature, °C-Sand loading (kg)-Bean throughput (kg/hr)-Roaster slope (cm/m)-Average residence time (min)

[3] Samples were defatted and ground to 200 mesh for analysis. N.A. - no sample available for analysis.

[4] Viscosity measurements were made on a Brookfield viscosimeter using a #5 spindle at 50 rpm. The samples retained on a 60 mesh screen were evaluated.

destroyed and the corrected PER was 2.25, which is quite good for soy. However, reduction of the sand load to zero pounds along with a decrease in residence time to 2.8 minutes resulted in a considerable decrease in destruction of antitrypsin activity and large increase in nitrogen solubility. Raising the temperature to 135°C, however, resulted in an 89% reduction in antitrypsin activity and a corrected PER of 2.18, even in the absence of sand and a decrease in residence time to 2.8 minutes. This probably represents close to a minimum amount of effective heat treatment to make full-fat soy flour in this process. Although the data showed sand was not absolutely essential in the heat treatment, the sand provided more operating latitude for the equipment and reduced the residence time variability for the product to pass through the roaster. Both of these results are beneficial and are sufficient reason to use the sand as heat transfer medium.

Examining the PER's for the nine samples separately, corrected PER's ranged from 1.93 to 2.25. Although the outlying values may approach statistical significance, it would not appear likely that any of these small differences are of practical significance and none appear related to roasting conditions.

Available lysine as a percentage of protein ranged from approximately 5 to 7.8. Out of the 50 samples, only six gave available lysines in excess of 7%. These higher values might be questioned on the basis that they represent more lysine than has been determined by column chromatography. Although one might expect an inverse relationship between percent trypsin inhibitor destroyed and available lysine, there are many limitations to available lysine data as determined by the TNP

method, and it will probably be necessary to determine lysine availability in the rat in order to make certain that full-fat soy flour produced by the roasting process is a good supplement to cereal grain.

Particle size data are presented in Table 46. Because of the amount of fat in the sample, sieving the samples was extremely difficult and, in fact, had to be done by hand, rather than on a mechanical shaker. Although there were fairly large differences observed in particle size distribution, because of the difficulties in sieving, it is questionable that these were of practical importance at the time. The major function of evaluating the particle size distribution was to obtain a uniform sample which was used for the viscosity determinations.

Table 46. Particle size distribution for roasted samples.[1]

FSN Code	% on #20 Sieve	% on #30 Sieve	% on #40 Sieve	% on #60 Sieve	% on #80 Sieve	% in Pan
			Samples sieved on mechanical shake			
2-71-10	21.3	26.3	--	39.5	1.73	9.14
2-71-16	19.9	25.9	--	48.5	0.4	3.7
2-71-12	13.7	22.9	--	55.6	0.5	3.7
2-71-15	15.4	26.2	--	3[illegible].4	7.7	5.5
2-71-14	19.3	24.3	--	46.4	6.7	1.1
2-71-13	14.2	26.9	--	48.2	1.2	6.1
2-71-11	16.2	26.5	--	52.6	0.4	1.62
			Samples sieved by hand			
2-77-21	--	1.2	6.0	36.3	20.8	26.2
2-77-23	--	5.9	4.5	43.1	31.8	7.8
2-77-26	--	14.0	20.0	44.0	13.0	5.0
2-77-20	--	3.5	5.0	32.2	22.0	32.0
2-77-11	--	3.1	7.0	31.6	10.7	41.0
2-77- 1	--	1.1	13.7	70.0	7.2	1.2
2-77- 2	--	1.1	14.4	67.3	9.9	2.0

Table 46. Particle size distribution for roasted samples (continued).[1]

FSN Code	% on #20 Sieve	% on #30 Sieve	% on #40 Sieve	% on #60 Sieve	% on #80 Sieve	% on Pan
2-77-16	--	1.0	12.0	57.6	1.8	15.9
2-77- 3	--	1.2	14.2	66.8	12.1	1.7
2-77- 7	--	2.4	10.5	33.5	26.1	20.1
2-77-18	--	0.1	4.1	36.3	23.0	28.1
2-77-19	--	0.2	7.8	36.8	16.8	32.0
2-77-10	--	2.2	15.6	41.1	17.8	16.3
2-77-15	--	1.0	7.8	43.0	30.0	14.7
2-77-14	--	0.2	8.2	38.5	38.2	9.2
2-77- 4	--	2.2	17.4	45.5	22.4	6.0
2-77- 5	--	2.0	12.7	56.5	13.0	9.2
2-77-24	--	3.9	5.9	58.0	22.0	2.8
2-79- 2	--	5.0	46.0	46.0	2.0	1.0
2-77- 6	--	0.4	12.5	71.9	4.8	5.2
2-77-25	--	2.0	3.0	43.0	24.0	19.0
2-77- 9	--	4.2	9.0	33.0	38.2	8.2
2-77-13	--	0.5	5.5	34.5	38.0	14.0
2-77-17	--	0.3	3.1	35.6	18.0	35.5
2-77-22	--	1.0	8.2	37.0	25.3	24.0
2-77-12	--	0.1	2.5	32.3	21.3	36.9
2-77- 8	--	0.9	11.5	37.8	32.0	11.0
2-77-32	--	8.0	12.0	60.0	10.0	4.0
2-85- 6	--	12.0	23.0	45.0	13.0	5.0
2-85- 3	--	13.0	24.0	45.0	11.0	3.0
2-85- 5	--	7.0	27.0	56.0	8.0	4.0
2-85- 8	--	5.0	23.0	51.0	16.0	5.0
2-77-30	--	2.0	27.0	46.0	15.0	6.0
2-85- 7	--	10.0	19.0	54.0	11.0	5.0
2-77-29	--	1.0	18.0	54.0	18.0	6.0
2-85-10	--	1.0	35.0	53.0	7.0	2.0
2-77-33	--	8.0	65.0	20.0	4.0	1.0
2-77-31	--	12.0	23.0	38.0	14.0	7.0
2-85- 9	--	7.0	17.0	56.0	13.0	6.0
2-85- 4	--	8.0	20.0	46.0	14.0	3.0
2-85- 1	--	15.0	11.0	54.0	11.0	4.0
2-85- 2	--	6.0	18.0	58.0	8.0	4.0

[1]Some sample was lost in the sieves and into the air, so the percentages for a given sample may not total 100%. Initial sample size was 100 gms. Samples were roasted on FPI, Versatile-100 roaster where sand, mixed with soybeans, was heated with combustion gases in a single chamber.

Data on the color measurement of roasted soy samples are presented in Table 47. These data were obtained using a Hunter Color Difference Meter. Differences in total lightness ascribed to processing conditions were quite minimal, with all samples as light as, if not lighter than, raw ground soybeans. Differences in hue were also quite minimal as related from a color standpoint.

A flavor profile analysis of the nine roasted soy samples evaluated in the rat study is presented in Table 48. Samples with the overall highest aroma intensities were 2-77-20, 2-77-16 and 2-77-9 or samples roasted above 135°C. The highest overall flavor intensity was associated with sample 2-77-9. Burnt aroma and flavor notes were detected in sample 2-77-26. All samples, with the possible exception of 2-77-26 were quite acceptable to the trained panel. This particular sample was roasted at 135°C with a sand loading of 90 kg, a throughput of 850 kg/hr, a slope of 4.4 cm/m and a residence time of 3.0 minutes. Although these conditions appear to be well within the range of acceptable roasting conditions, this particular sample gave the lowest corrected PER of 1.93 and also a 98% reduction of antitrypsin activity. It would appear that the heat treatment actually received by this particular sample was in excess of that which would be considered desirable from either a nutritional or a flavor standpoint, although the differences are of borderline statistical significance. Apparently the sample represented some anomalous result rather than the expected properties for that processing condition. Only a retest could confirm this hypothesis.

A baking study was carried out using the full-fat soy flours that were evaluated in the protein quality evaluation. Roasted FFSF samples

Table 47. Color measurement of roasted soy samples.[1]

FSN Code	L[2]	a[3]	b[4]
2-77- 1	78.9	-2.0	22.0
2-77- 7	77.8	-1.7	19.2
2-77- 9	78.4	-2.3	19.4
2-77-11	76.6	-1.6	19.0
2-77-16	77.8	-1.8	19.0
2-77-20	75.5	-1.6	19.1
2-77-22	79.3	-2.9	19.9
2-77-26	76.3	-1.2	19.4
2-77-33	79.7	-1.7	20.7
2-81- 9[5]	77.5	-2.1	21.6
The above samples were used in the rat study for PER.			
2-77- 8	81.3	-3.0	21.8
2-77- 9	79.6	-1.6	20.9
2-77-10	80.7	-2.6	21.3
2-77-11	77.1	-0.5	20.3
2-77-12	77.8	-0.5	20.9
2-77-13	81.2	-2.6	21.7
2-77-14	78.6	-1.2	21.2
2-77-15	79.5	-1.6	21.0
2-77-17	76.8	-0.5	20.7
2-77-18	76.4	-0.2	20.9
2-77-19	80.6	-2.7	21.3
2-77-21	79.1	-1.6	20.9
2-77-23	76.8	-0.4	20.8
2-77-24	81.6	-2.9	21.8
2-77-25	81.8	-2.8	21.9
2-77-31	80.5	-2.0	20.1
2-77-32	82.6	-3.0	20.1
2-77-33	79.9	-1.5	19.9
2-85- 1	77.2	-1.5	19.4
2-85- 2	79.7	-1.7	19.0
2-85- 3	80.2	-2.1	19.5
2-85- 4	81.1	-2.2	19.5
2-85- 5	80.3	-1.8	19.2
2-85- 6	82.3	-2.8	19.5
2-85- 7	81.7	-2.6	19.2
2-85- 8	80.0	-1.5	19.5
2-85-10	78.6	-0.9	19.9

[1] Samples were roasted on FPI, Versatile-100 roaster where sand, mixed with soybeans, was heated with combustion gases in a single chamber.
[2] L = total lightness; 100 = white, 0 = black.
[3] a = the more negative, the more green.
[4] b = the larger the number, the more yellow.
[5] Raw soy sample.

Table 48. Flavor Profile analysis of roasted soy samples.[1]

FSN Code	Aroma Intensity	Flavor Intensity
2-77-20	1+ 1+ toasted	1 1 sweet)(green)(astringent)(soy)(bitter
2-77-11	)(+ 1 toasted	1)(+ sweet 1 roasted)(starchy)(bitter
2-77-16	1+ 1 toasted)(soy	)(+ 1 sweet)(toasted)(starchy)(bitter
2-77- 1	1)(+ soy)(+ toasted	)(+ 1 sweet)(toasted)(soy)(bitter
2-77-33	1 1 green 1 toasted)(soy	)(+)(+ sweet)(+ toasted)(soy)(bitter
2-77-22	1)(+ toasted)(soy)(starchy	)(+)(+ sweet)(toasted 1 starchy)(bitter
2-77- 9	1+ 1 green)(soy)(toasted	1+ 1+ sweet 1 starchy)(toasted 1 bitter

Table 48. Flavor profile analysis of roasted soy samples (continued).[1]

FSN Code	Aroma Intensity	Flavor Intensity
2-77-26	1 1 burnt)(toasted)(soy	1 1+ sweet 1 toasted)(burnt)(bitter
2-77- 7	1 1+ toasted)(soy)(starchy	1)(sweet)(toasted)(bitter

[1]Samples were roasted on FPI, Versatile-100 roaster where sand, mixed with soybeans, was heated with combustion gases in a single chamber.

1 = slight
1+ = slight to moderate
)(= detected at threshold

were baked into a bread at a 12% level (14% based on flour weight). The results are presented in Table 49 for the dough and Table 50 for the bread scores. The roaster samples were compared to a fresh commercial sample of full-fat soy flour referred to as Nutrisoy 220. Compared to the commercial sample, all roaster samples performed rather well. Only three of the samples produced breads of lower volume than the Nutrisoy 220. A slightly lower volume as compared to the co ol was expected at a 12% substitution level. Except for the bread volume there were no differences in external bread characteristics. The longer proof time due to soy substitution was expected. The higher total score of the control was due mainly to a slightly higher volume and a lighter crumb color. Total scores of all soy breads ranged from 80 to 85, indicating

Table 49. Evaluation of dough using FFSF produced by roasting process.[1]

Dough	Blend Composition	Absorption (%)	Mixing Time min.[2]	Dough Temperature, °C	Proof Time min.
1	Wheat flour (100%)	72	4	28	32
2	Wheat flour (88%) + Nutri-soy[3] (12%)	76	3 3/4	28	33
3	Wheat flour (88%) + 2-77-20[4] (12%)	76	3 3/4	28	34
4	Wheat flour (88%) + 2-77-26 (12%)	76	3 3/4	29	35
5	Wheat flour (88%) + 2-77-22 (12%)	76	3 3/4	28	39
6	Wheat flour (88%) + 2-77-16 (12%)	76	3 3/4	29	40
7	Wheat flour (88%) + 2-77-11 (12%)	76	3 3/4	28	41
8	Wheat flour (88%) + 2-77-33 (12%)	76	3 3/4	29	37
9	Wheat flour (88%) + 2-77- 7 (12%)	76	3 3/4	29	39
10	Wheat flour (88%) + 2-77- 1 (12%)	76	3 3/4	29	42
11	Wheat flour (88%) + 2-77- 9 (12%)	76	3 3/4	29	42

[1] Samples were roasted on FPI, Versatile-100 roaster where sand, mixed with soybeans, was heated with combustion gases in a single chamber.

[2] National Manufacturing Company mixer.

[3] Commercial sample.

[4] FSN Code.

Table 50. Bread scores[1] using FFSF produced by roasting process.[2]

Dough	Specific Volume (cc)	Crust Color (7)	Symmetry (7)	Break (6)	Crumb Color (10)	Flavor (15)	Grain (20)	Texture (20)	Volume (15)	Total Score (100)	Bread Color[3] (ΔE)
1	4.40	7	7	6	10	14	18	18	13	93	24.1
2	4.08	6	7	6	8	14	16	17	11	85	29.4
3	4.14	6	6	6	5	14	16	17	11	81	36.3
4	3.91	6	6	6	5	14	16	17	10	80	36.5
5	4.03	6	6	6	7	14	17	18	11	85	29.3
6	4.19	6	6	6	7	14	16	18	11	84	31.1
7	4.37	6	7	6	6	14	15	17	12	83	31.9
8	4.02	6	7	6	7	14	13	16	11	80	29.1
9	4.30	6	7	6	6	14	15	16	12	82	31.4
10	4.28	6	7	6	8	14	15	16	12	84	29.7
11	4.42	6	7	6	8	14	14	16	13	84	30.5

[1] Numbers in parentheses under each bread characteristic indicate maximum points.

[2] Samples were roasted on FPI, Versatile-100 roaster where sand, mixed with soybeans, was heated with combustion gases in a single chamber.

[3] $\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$; L = 94.65; a = 0.6; b = 0.1 (Hunter Color System).

that breads of satisfactory quality can be produced with most of the full-fat soy flours without the use of improvers such as SSL. Crumb colors were darker due to the use of soy, as expected. However, some of the samples produced a darker crumb than others as indicated by the crumb color scores and the total crumb color differences. Products 2-77-20, 2-77-26, 2-77-11 and 2-77-7 (roasting temperature <135°C) produced breads with darker crumb color in comparison with the commercial full-fat soy sample. It may be significant that the first two of these samples gave the lowest PER's and had the strongest flavors, indicating higher heat treatment. The PER's of the latter two samples were over 2.1, although they did, in fact, represent the next two PER's, but they are consistent with the changes in the bread scores. In summary, all of the samples produced a pleasant bread flavor with samples 2-77-16 and 2-77-22 appearing to perform best overall.

6.4.1 Roaster Operating Parameters

Based on the extensive testing on the roaster, it is concluded that a FFSF can be produced using the low-cost roasting technology. Although no single set of roasting conditions can conclusively be classified as optimal, because of some scatter in the data, the following conditions are recommended for roasting whole soybeans for the production of FFSF using the Versatile-100 roaster.

Bean exit temperature	129°C
Internal sand loading	90 kg
Feed rate	910 kg/hr
Slope	3.9 cm/m

Under such conditions, a FFSF product should result having the following characteristics:

Trypsin inhibitor destroyed	>80%
Available lysine	> 5 g/100 g protein
Water absorption	200%
Uncooked viscosity	80 cps
NSI	12-20%
PER	2.1-2.2

The roasted, dehulled FFSF can be ground in a hamme- mill to approximately 70 mesh with 20% being -80 mesh. A high quality hammer mill with internal air classification would further reduce particle sizes. Bread baked with FFSF samples ground to the above specification were judged equivalent to bread baked with a commercial FFSF. Pin milling of the roasted whole soybeans would reduce particle size to -100 mesh and should result in greater functionality of the protein supplement.

6.4.2 Cookability of Roasted Navy and Pinto Beans

In an experiment, 50 grams of each sample, roasted in the FPI, Versatile-100, were placed in 100 ml of water at room temperature and permitted to soak for two and five hours. At the end of each respective time period, 10 beans were removed and smashed with a fork. The ease of crushing was subjectively rated on a 10-point scale with 1 being very hard and difficult to 10 being soft and easy. The other part of the experiment involved putting 50 grams of each sample into 100 ml of water and simmering in a beaker covered with a watch glass for 1 hour. After cooking, 10 beans from each treatment were removed and evaluated as described above. The data obtained in this experiment are summarized in Table 51. In cold water, there were considerable differences in hardness as related to processing conditions, with samples 2-79-19 and

Table 51. Cookability of roasted navy and pinto beans[1]

FSN Code	Sample Description	2-hour Soak	5-hour Soak	1-hour Simmer
2-79- 5	pinto, 118°C, 4.4 minutes	5[2]	7[2]	8[2]
2-79-18	navy, 74°C, 4.4 minutes	1	3	5
2-79-19	navy, 135°C, 4.4 minutes	7	8	8
2-79-16	pinto, 107°C, 4.4 minutes	2	5	5
2-79- 9	pinto, 129°C, 4.4 minutes	5	6	8
2-79-20	navy, 113°C, 4.4 minutes	2	4	5
2-79- 1	navy, raw whole	1	2	5
	navy, raw	1	1	2
	pinto, raw	1	2	3

[1]Samples were roasted on FPI, Versatile-100 roaster where sand, mixed with soybeans, was heated with combustion gases in a single chamber.

[2]10 = soft and easy to smash; 1 = hard and difficult to smash.

2-79-5 being the most effectively cooked beans by this method. Considering these limited tests, precooking of pinto beans at ~120°C exit temperature for 4.4 minutes and navy beans at ~135°C exit temperature for 4.4 minutes appears to be about optimal. The cookability of the two samples again proved to be the most satisfactory, although all beans were considerably more cookable than were the raw navy or raw pinto beans.

The roasting process looks like an interesting approach to making an instant or quick cook bean.

6.5 Storage Studies

Storage studies were undertaken on hammer milled, roasted (143°C) full-fat soy. The storage conditions utilized were:

1. 29°C at 40% relative humidity
2. 31°C at 50% relative humidity
3. 48°C at 60% relative humidity
4. Frozen storage which served as a control.

Roasted whole soy was stored at the above conditions for three months with a flavor profile analysis being performed initially and then at monthly intervals. The samples were packaged in either 4 mil polyethylene or 2 mil polyethylene/Kraft paper. Preliminary studies had indicated that 2 mil packaging may present a problem due to free-fat leakage, especially at high (>38°C) storage temperatures with full-fat products. This observation was not apparent when 4 mil thick polyethylene packaging material was utilized.

Another potential problem that cannot be effectively evaluated under simulated storage conditions is the potential effect of weight

during storage. If product is stacked, the material near the bottom may display more of a tendency to leak fat through the packaging material.

The flavor profile panel consisted of three individuals well versed in the technique. Gruels (11.75%) were prepared and served hot to the panel. Overall aroma and flavor intensities were obtained using a four-point scale [)(= threshold; 1 = slight; 2 = moderate; 3 = strong]. In addition, individual aroma and flavor sensations, along with their intensities using the same scale as described above, were recorded.

The key observation in these storage studies is the fact that no signs of rancidity were detected in any product/packaging material/ storage condition evaluated. Also, storage conditions and time did not alter overall aroma and flavor intensities. They were in the slight to moderate range. The major aroma notes were toasted at a level of 1, and starch at 1 with green at)(. Their intensities also did not change during the study.

In the case of flavor, a sweet sensation was found to decrease with time from an original level of 1 to)(. Other notes that did not change include cooked/toasted at a level of 1 and bitter at a level of)(. The samples remain in storage and it is planned to evaluate their condition at the end of six months of storage.

Thus, these data would indicate that roasted soy can be stored under conditions approaching 49°C and 60% relative humidity for periods up to three months without any detectable differences occurring in the aroma and flavor properties of these products. Since no apparent change has been detected in three months, it would appear that little change can be anticipated at the end of six months.

No sensory differences were noted as influenced by packaging, although the 4 mil polyethylene would be preferred over the 2 mil/Kraft paper system due to the potential free-fat leakage problem associated with the latter material.

7.0 VITAMIN AND MINERAL SUPPLIERS

A list of vitamin and/or mineral supplements suppliers and prices (as of 10-15-77), where available, are given. The list is representative of suppliers but may not include all potential suppliers. Naming suppliers does not imply endorsement by CSU, USDA/ERS or AID. Prices are subject to change, and price quotations are required prior to ordering.

7.1 Vitamins Only

American Roche International Inc. 555 Madison Avenue New York, NY 10022 Phone: (212) 752-5550 Attention: Mr. David Petrillo	Price: $9.90/kg Delivery: approximately 4-6 weeks after receipt of order - FOB
Vitex-American 1016 Trenton Avenue St. Louis, Missouri 63132 Phone: (314) 426-2611 Attention: Mr. Jay Thaman	Price: $10.30/kg Delivery: 10-12 days FOB - St. Louis, MO Linden, NJ Fresno, CA

7.2 Minerals Only

Roland Industries, Inc. 2280 Chaffee Drive St. Louis, Missouri 63141 Phone: (314) 567-3800 Attention: Mr. Charles Becker	Price: $0.80/kg Delivery: Immediate FOB - Factory, St. Louis, MO (Export packaging)
Stauffer Chemical Company Westport, Connecticut 06880 Phone: (203) 222-4054 Cable Code: STAUFCHEM Attention: Mr. John Rush	Price: $0.63/kg (in bags) Delivery: Immediate FOB - Chicago Heights, IL

M. D. Canterbury
P. O. Box 88
Grayslake, Illinois 60030
Phone: (312) 223-4281
Attention: Mr. Canterbury

Price: $0.64/kg in 24.5-kg paper bags
Delivery: Immediate FOB - Chicago area
Observation: Overseas shipments must be packaged in light drums--not paper bags to avoid product loss

7.3 Vitamins and Minerals

Thompson-Hayward Chemical Company
2 East Madison
Waukegan, Illinois 60085
Phone: (312) 623-1600
Attention: Dr. John Burbeck

Price: Vitamins - $10.35/kg
Minerals - $ 0.68/kg
Delivery: One week FOB - Waukegan, IL

With the exception of American Roche International, most of the companies can deliver the product within two weeks after receipt of the order.

8.0 SUMMARY

The past three years of project work have resulted in a considerable amount of data and experience with the LEC technology. This information has been used to determine the capabilities and limitations of two LEC's. The original tests as outlined in the first Annual Report (LEC-2) were expanded to include some of the ingredients which are available in LDC's. Such ingredients as cottonseed, chickpea, rice bran, mung bean and coconut have been tested successfully and increased the scope of the LEC's capabilities.

Products which have been extruded and nutritionally tested have proved suitable for weaning foods or other food uses. As a part of the overall testing, and to further expand the CSB test file, preclinical tests are being conducted to assure the suitability of these products for their intended use as a weaning food or nutritious food supplement.

To further define limitations of the LEC concept, mechanical evaluations on the processing have been conducted. These evaluations have proved helpful in changing and improving the LEC for production.

Demonstration sites in Guatemala, India, Indonesia, Costa Rica and East Africa have been conducting programs to determine applications for LEC's in LDC's. The Philippines, Guyana and Thailand have started testing programs. In each case, formulations have been developed using local ingredients. Problems associated with limitations of the LEC have been minimal, making their application to a variety of situations very promising.

Processing plants which are centered around the LEC technology have shown that the LEC is suitable for continuous production, provided an adequate supply of spare parts are available, the operators are competent in operation of the equipment (usually attained through training), and a good maintenance program is established. Sri Lanka, Bolivia, Tanzania and Chihuahua, Mexico, are presently operating complete processing lines based on the LEC technology.

Consultants and evaluators have been asked to evaluate the LEC concept, LEC program and LEC plants. These evaluations have concluded that the LEC technology is a viable and appropriate intermediate technology. Recommendations for minor changes or additions to the present equipment and systems should further refine the technology that is suitable for LDC's. Recommendations given by the evaluators have been used in design of new LEC systems. Tanzania, Costa Rica and an expansion plant for Sri Lanka have benefited from these recommendations. It is felt that each demonstration system is improved because of the experience gained and the evaluation efforts that have occurred. The latest state of the art is summarized in this, the second Annual Report.