SUMMARY REPORT

NUTRITIOUS FOODS PRODUCED BY LOW-COST TECHNOLOGY

Departments of Agricultural and Chemical Engineering
and Food Science and Nutrition
Colorado State University
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NUTRITIOUS FOODS PRODUCED BY LOW-COST TECHNOLOGY

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LIST OF ABBREVIATIONS

AID	Agency for International Development
ANRC	Animal Nutrition Research Council
AOAS	American Oil Chemists Society
CARE	Cooperative for American Relief Everywhere, Inc.
CR	Costa Rica
CSB	Corn/Soy Blend
CSM	Corn/Soy/Milk
CSU	Colorado State University
dc	degermed corn
ds	dehulled soy
FFA	Free Fatty Acid
FFSF	Full-Fat Soy Flour
GPC	Guyana Pharmaceutical Corpcration, Ltd.
ICSM	Instant Corn/Soy/Milk
LDC	Less Developed Country
LEC	Low-cost Extrusion Cooker
LEC-CSB	Low-cost extrusion cooked-corn/soy blend
LEC-CSM	Low-cost extrusion cooked-corn/soy/milk
M.T.	Metric Ton
NFDM	Non-Fat Dry Milk
NSI	Nitrogen Solubility Index
PER	Protein Efficiency Ratio
PVO	Private Voluntary Organization
RTE	Ready-To-Eat
SSL	Sodium Steroyl-Lactalate
TIU	Trypsin Inhibitor Unit
U.S.	United States
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
wc	whole corn
ws	whole soy
WSB	Wheat/Soy Blend

SUMMARY

Interest has grown in less developed countries (LDC's) for information concerning the manufacture of precooked nutritious foods from cereals and legumes or oil seeds. The cooking extruder is ideally suited to these application for in one continuous operation it combines, heats and precooks food blends increasing their nutritional value, palatability, and utility.

To capitalize on this technology, relatively small low-cost extrusion cookers (LEC's), having the ability to process a wide variety of ingredients, needed to be evaluated and demonstrated. The Brady (#2106), Insta-Pro (#500 and #2000), and the Anderson (4.5") extruders were specifically evaluated for these applications. Although their individual characteristics and capabilities differ, all have the potential to produce nutritious foods. Their relatively low capital and operating costs allow the manufacture of precooked food products at the lowest possible costs so that they can effectively reach the most vulnerable segments of LDC populations.

The principal focus of this work has been the production of blended foods similar to Title II Food For Peace products such as corn/soy blends (CSB), instant corn/soy/milk (ICSM), etc. These studies showed that instant products could be produced having a high caloric density, protein quality similar to milk, good shelf life when packaged in simple packages, and low bacterial counts. Foods of this type can be manufactured using the LEC for about 20% more than the raw ingredient costs.

Demonstration plants using the LEC technology have been designed, constructed and operated in Sri Lanka, Tanzania, Costa Rica, and Guyana. Most plants produce between 500 to 1,000 kg/hr. These plants have served as pilot projects for the technology as well as a method to document actual costs and experiences in the LDC environment. Complete records of the capital and operating costs have been kept which indicate the relatively low cost of the systems and the foods they produce.

A variety of publications, reports and documents are available to the potential users of the technology. All of these findings point to the broad range of applications possible and the potential for the LEC technology to produce nutritious food products in LDC's.

Finally, Colorado State University (CSU) is prepared to provide technical assistance to those interested in evaluating or applying the LEC technology to a variety of projects.

1.0 INTRODUCTION

Starting in the 1960's, food aid supplied under Title II of the Food For Peace Program, PL480, moved in the direction of centrally processed cereal/legume blends fortified with vitamins and minerals. The first such product was corn/soy/milk (CSM), but this was soon followed by others including instant corn/soy/milk (ICSM), wheat/soy blend (WSB), and corn/soy blend (CSB).

These blended foods were designed as supplementary foods to meet special nutritional needs in less developed countries (LDC's), especially among vulnerable groups such as infants, preschool children, and pregnant women or nursing mothers. For this reason they were formulated to contain a high level of high quality protein as well as generous quantities of a broad spectrum of vitamins and minerals. These Title II blended foods have been used successfully in many feeding programs throughout the world.

1.1 Need to Augment the Supply of Title II Blended Foods

For a number of economic reasons in the mid-1970's, it became apparent to both recipients of Title II commodities in LDC's and the Food For Peace Program in the United States government that it was desirable to explore ways that the supply of these commodities might be augmented through local manufacture. Large United States agricultural surpluses were being depleted, as was the world grain reserve, making the production of Title II products more difficult. Also, because of a balance of payments deficit from the need to import large amounts of oil, the demand for United States agricultural products around the world was seen as an important source of foreign exchange useful in balancing the trade deficit making them less available for commodity production. Finally, local manufacture of blended foods offered the opportunity to develop a market for locally grown food crops in contrast to the depressing effect on local agricultural production alleged to occur with imported food aid.

During the 1960's and 1970's, the food extruder was found useful in cooking cereal-type foods including Title II blended foods. However, large capital costs, high throughput requirements, and a necessity for a high degree of technical capability were seen as obstacles to the use of large food extruders in making blended foods in LDC's. In contrast, several simple extruders designed for cooking soybeans on the farm for use as livestock feed were seen as alternatives, to the large commercial extruders used in the United States, for use in developing countries. These simple machines will henceforth be referred to as low-cost extrusion cookers (LEC's) whose characteristics will be defined in section 3.0.

In 1974, the Office of International Cooperation and Development Staff of the U. S. Department of Agriculture (USDA) signed a cooperative agreement with Colorado State University to evaluate the utility of these machines and to determine their value in developing countries to manufacture blended foods. The funding of these activities was provided by the Office of Nutrition, Agency for International Development (AID). The project ended in October 1980, and this report is a summary for the activities during this period.

1.2 Benefits of Centrally Processed Foods

Before outlining the broad scope of the LEC project at Colorado State University, it is desirable to discuss the benefits of centrally processed foods.

It is well known that protein-energy malnutrition of infants and preschool children continues to be one of the most serious public health problems in most LDC's. The most obvious indicators of the seriousness of the problem are high mortality and morbidity rates for infants and preschool children and poor growth and retarded mental development of the survivors. Many social and economic factors are involved, but from a nutritional standpoint the diet consumed by infants and preschool children as well as pregnant or lactating women in many cases is inadequate in quantity and quality.

Many of the problems revolve around the adequancy of breast feeding and the weaning practices followed. Inadequate nutrition of pregnant women and nursing mothers can result in low birth weights and partial-to-complete failure of lactation. In many LDC's, solid foods are not introduced soon enough into the diet of infants. These foods generally are poor in nutritional quality and low in calorie density.

Centrally processed cereal/legume blends manufactured by extrusion cooking in an LEC plant offer many advantages and can prove useful in helping to alleviate the nutritional problems described above.

- The blends can easily be fortified with a broad range of vitamins and minerals.
- By virtue of protein complementation, the extruded blends have been demonstrated to be of high protein quality and well digested.

- The use of precooked blends is energy efficient, particularly in situations where firewood is scare and most cooking is done over an open fire.
- Extrusion increases the calorie and nutritive density of gruels made from the blends.
- Central processing facilities allow use of suitable packaging to protect the nutritious products.
- Extrusion combined with suitable packaging increases shelf life of the products by reducing water activity and inactivating enzymes.
- Central processing allows consistency of formulation and product quality.

1.3 Project Scope

The scope of the LEC project at CSU has been very broad and interdisciplinary in nature. The central focus has been plant design and technical engineering assistance at plant sites during construction, start-up, and production. Laboratory support in product analysis, nutritional evaluation and studies on storage stability has come from nutritionists and food scientists at CSU. The project has also interacted extensively in LDC's with private voluntary agencies (PVO's), various government agencies, private business and research and development institutions.

The unifying project objective has been to assist in the implementation of LEC technology in LDC's for the purpose of local manufacture of nutritious foods from indigenous food crops useful in alleviating nutritional problems. As LEC plants have gone into production, they also have created other benefits:

- Enhanced the utilization of locally grown protein and carbohydrate food resources.
- Served as a focus for the development of small-scale industry and development in the LDC.
- Reduced transportation costs associated with movement of manufactured goods over long distances.
- Allowed formulation and processing of products to meet local tastes and customs.
- Minimized packaging costs required, since products will be consumed locally in a relatively short time.

All of these point to the connection between nutritional improvement and development in LDC's.

2.0 OBJECTIVES

During the project's six years of existence, the following were its specific objectives.

- Evaluate and compare alternative low-cost cooking technologies for legumes alone or in combination with cereals.
- Provide technical assistance to LDC sites where low-cost cooking equipment is being evaluated.
- Design and assist LDC processing plants utilizing low-cost extrusion technology, to manufacture nutritious foods using local ingredients.
- Document actual operation of demonstration plants so that others interested in the technology might accurately assess its potential.

- Develop and assist with the transfer of the low-cost extrusion technology to interested parties.

3.0 ALTERNATIVE LOW-COST COOKING METHODS

3.1 Characteristics of Low-cost Methods

In order for low-cost cooking systems to be effectively applied to solving food and nutrition problems in LDC's, they must have the following characteristics.

- Low-cost--Processing systems must cost less than $250,000/ton/hour capacity. To achieve these costs, the extruder needs to cost less than $50,000/ton/hour capacity.
- Moderate Production Rate--Production rates ranging between 250 to 1,000 kg/hour.
- Simple Operation--Require little sophisticated technical capability to operate and maintain.
- Minimal Auxiliary Equipment--To the greatest possible extent, the system should not require auxiliary boilers, dryers, or pre- or post-processing/conditioning equipment that can increase cost and lead to product contamination.
- Versatile--Process should handle a wide variety of cereals in combination with protein-rich legumes or oil seeds.
- Maintenance--System should be easily maintained and utilize locally available parts and equipment to the greatest possible extent.
- Sanitary--Equipment must be cleanable and suitable for producing human food products.

Several types of low-cost processing systems are potentially capable of achieving these characteristics and the project has specifically evaluated a number of extruders and roasters. In developed countries, drum dryers also find utilitv for making precooked blended foods but were rejected as not being low-cost cooking technology because of high initial capital cost, costly and technically complex maintenance and their ability to only process high moisture slurries.

3.2 Extruders

There is a wide variety of commercially available extrusion equipment differing in mechanical features and product capabilities. The moisture content of feed ingredients is a useful way to differentiate between various extruder types. Table 1 shows such a classification for extrusion equipment.

The low-moisture extruders are normally characterized by lower capital cost, high electrical energy inputs to supply heat by friction, higher maintenance costs, little or no-product drying requirements, and limited product capabilities. The exception to the above statements would be the collet extruders used to manufacture expanded cereal-based snacks such as corn curls. These systems are characterized by high capital costs and were not considered in the project's evaluation of alternatives.

In all cases, the characteristics of high-moisture extruders can be found to be opposite of those given for most low-moisture extruders. Consequently, low-moisture extrusion cookers are appropriate choices to manufacture centrally processed nutritious foods on a low to moderate

Table 1. Classification of extrusion equipment on the basis of the moisture content of the feed ingredients.

Feature	Low Moisture	Intermediate Moisture	High Moisture
1. Ingredient moisture	$M \leq 20\%$	$28\% > M > 20\%$	$M \geq 28\%$
2. Source of input energy	All energy input from viscous dissipation of mechanical energy input.	About half of energy input comes from viscous dissipation of mechanical energy input, other half comes from steam injection.	Majority of energy comes from steam injection with very little energy coming from the conversion of mechanical energy to heat.
3. Mechanical energy	$0.10 \frac{kW - hr}{kg}$	$0.04 \frac{kW - hr}{kg}$	$< 0.02 \frac{kW - hr}{kg}$
4. Product drying	None required. Product cooling results in 6% moisture loss.	Some product drying required to remove moisture in excess of 12% in finished product.	Extensive product drying is required to reduce finished product moisture.
5. Product shape	Minimal number of shapes available beyond highly expanded pieces or flakes.	Many product shapes available.	Maximum flexibility of product shapes and textures.
6. Product density	Low density, expanded	Moderate density	Range of densities
7. Ingredients	Feed blends should contain > 7% fat.	Few limitations	Few limitations
8. Capital cost	Low to high	Moderate to low	Moderate to high
9. Maintenance costs	High - $1.20/M.T.	Moderate - $0.50-0.60/M.T.	Low to moderate $0.40-0.50/M.T.
10. Manufacturers	Brady, MFM, Insta-Pro; Collet extruders: Manley Dorsey-McComb, and Adams	Anderson and Wenger	Anderson, Bonnot, Sprout-Waldron, and Wenger

scale (500-200 ton/year) in LDC's. These systems can have total energy and maintenance costs nearly equivalent to larger high-moisture extrusion systems and lower total operating costs compared to alternative small-scale systems. Processes requiring large capacity (10,000 ton/year) or products with relatively sophisticated shapes and textures should consider the use of high capacity high-moisture extrusion systems.

3.3 Roasters

Roasting equipment has been developed and used for grains and legumes. The roasted products are heated by several different mechanisms.

- o Contact with a heated metal surface
- o Heated with infared radiant heat
- o Contact with heated granular media such as salt or sand

The basic difference in these techniques besides equipment cost lies in the speed, uniformity, and the thermal efficiency of the heat treating process. The systems which use heated air or hot surfaces normally have the lowest capital cost, but the poorest uniformity and low thermal efficiency leading to high operating costs. Radiant roasters have high capital costs and poor thermal efficiency, but process the product rapidly and effectively. Granular bed roasters do a fast and uniform roasting job but have somewhat higher capital costs.

4.0 CAPABILITIES AND LIMITATIONS OF LEC'S

Over the course of the project, a number of extruders meeting the criteria listed in section 3.1 have been tested and evaluated to better determine their capabilities and limitations. The characteristics of each machine are summarized below:

4.1 <u>Brady Extruder</u> (Fig. 1)

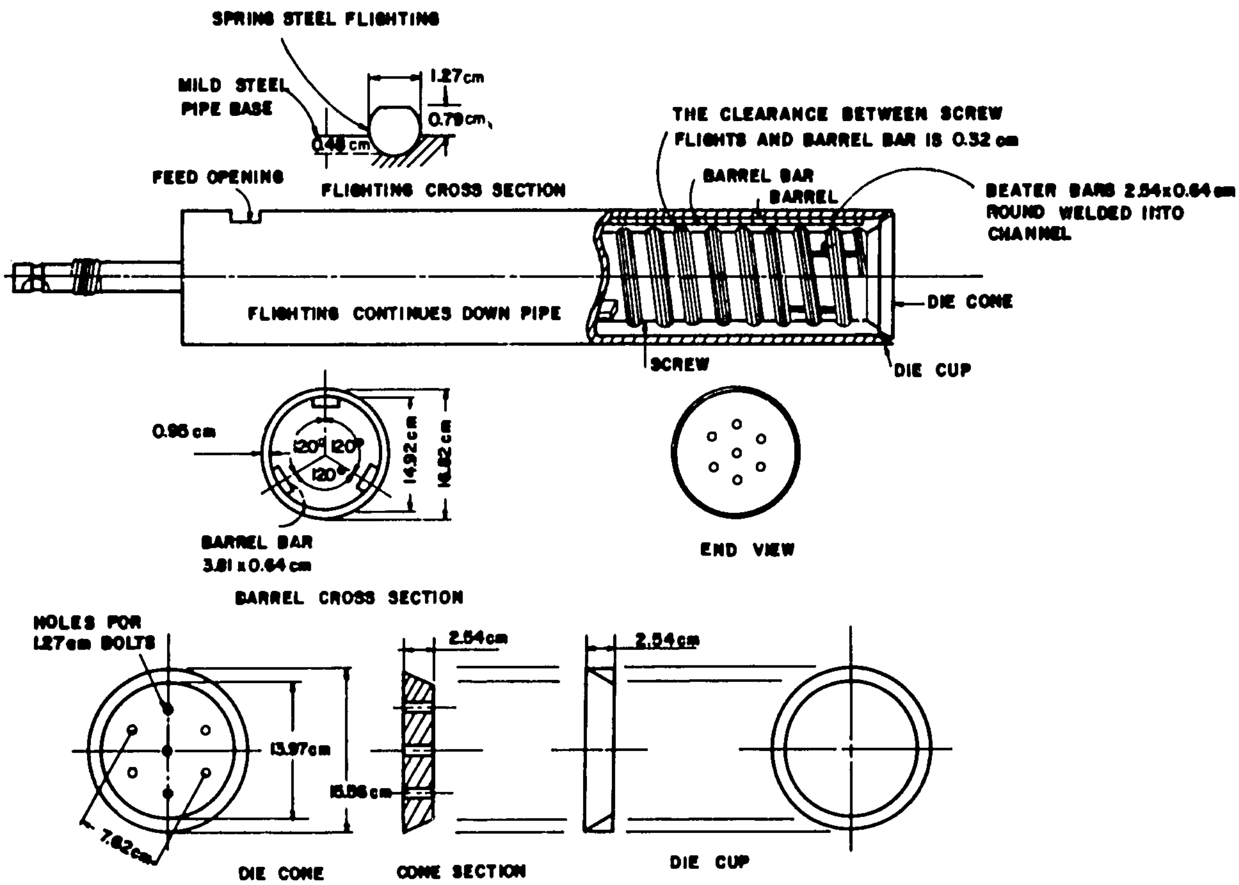

Figure 1. Schematic of Brady extruder.

4.1.1 Manufacturer:

Koehring Farm Division
P. O. Box 1279
Appleton, Wisconsin 54911

Contact: Mr. Elroy Kalies (Phone: 414-739-3631)

Model #206--powered by power take-off from stationary engine at 540 rpm

Model #2106--powered by 100 hp electric motor at 900-1,000 rpm

4.1.2 Physical Characteristics

Extruder consists of fixed configuration screw and barrel. The die is a conical annulus with continuously variable clearances which are adjustable during extruder operation. Feeder consists of a hydraulically driven auger. Parts are easily replaceable or rebuildable in the field. Modification of bearings to improve lubrication allow operation for eight-hour shifts.

4.1.3 Capacity

The Brady operates between 340 and 450 kg/hr with most cereal/legume feed ingredients.

4.1.4 Ingredients

The extruder can handle cereals such as corn (flint and dent), rice, wheat, sorghum with oil seeds such as soy, cottonseed, sesame and cocnut or pulses such as chickpeas. Whole soy can also be extruded alone. All ingredients must be clean and fee of infestation. Dehulling is not necessary for extrusion, but gives a superior and more uniform product with reduced fiber. All formulations extruded must have a minimum of 5% fat, but should have no more than 25% fat.

4.1.5 Product Shape or Type

The Brady extruder does not produce a uniformly shaped cooked product because the die consists of an annular opening which cannot be precisely centered. The typical product is irregular flat slightly expanded flakes with 40-50% fines. The material can be ground to produce a nutritious precooked composite flour suitable for making an instant gruels, drinks, soups, or fortified baked products.

4.1.6 Durability

The design of the feed auger drive shaft with universal joints, hydraulic drive and bearings limits mechanical durability of the extruder. Minor mechanical modifications eliminate these deficiencies and allow operations on an eight-hour shift basis. With proper modification and preventive maintenance, operation for 10,000 hours between major overhauls can be accomplished.

4.1.7 Operational Adjustments

Pregrinding of ingredients improves extrusion operation and product uniformity. Addition of 3-5% water to dry feed ($\sim$ 12-18% feed moisture) aids extrusion. Maximum feed moistures are 20%. Under these conditions product cooling will result in finished products having moistures $<$ 14% which are safe for storage. Extrusion temperatures for cereal-based products range between 160-170°C while soy is extruded at 138-143°C to denature antinutritional factors. Adjustments of die clearance, feed rate and moisture additions control extrusion temperature.

4.2 <u>Insta-Pro Extruder</u> (Fig. 2)

4.2.1 Manufacturer:

Triple "F", Inc.
P. O. Box 3600
Urbandale Branch
Des Moines, Iowa 50322

Contact: Mr. Wayne Fox (Phone: 515-276-5406)

Model 500--powered by 50 hp electrical engine at 540 rpm

Model 2000--powered by 150 hp electrical engine at 540 rpm

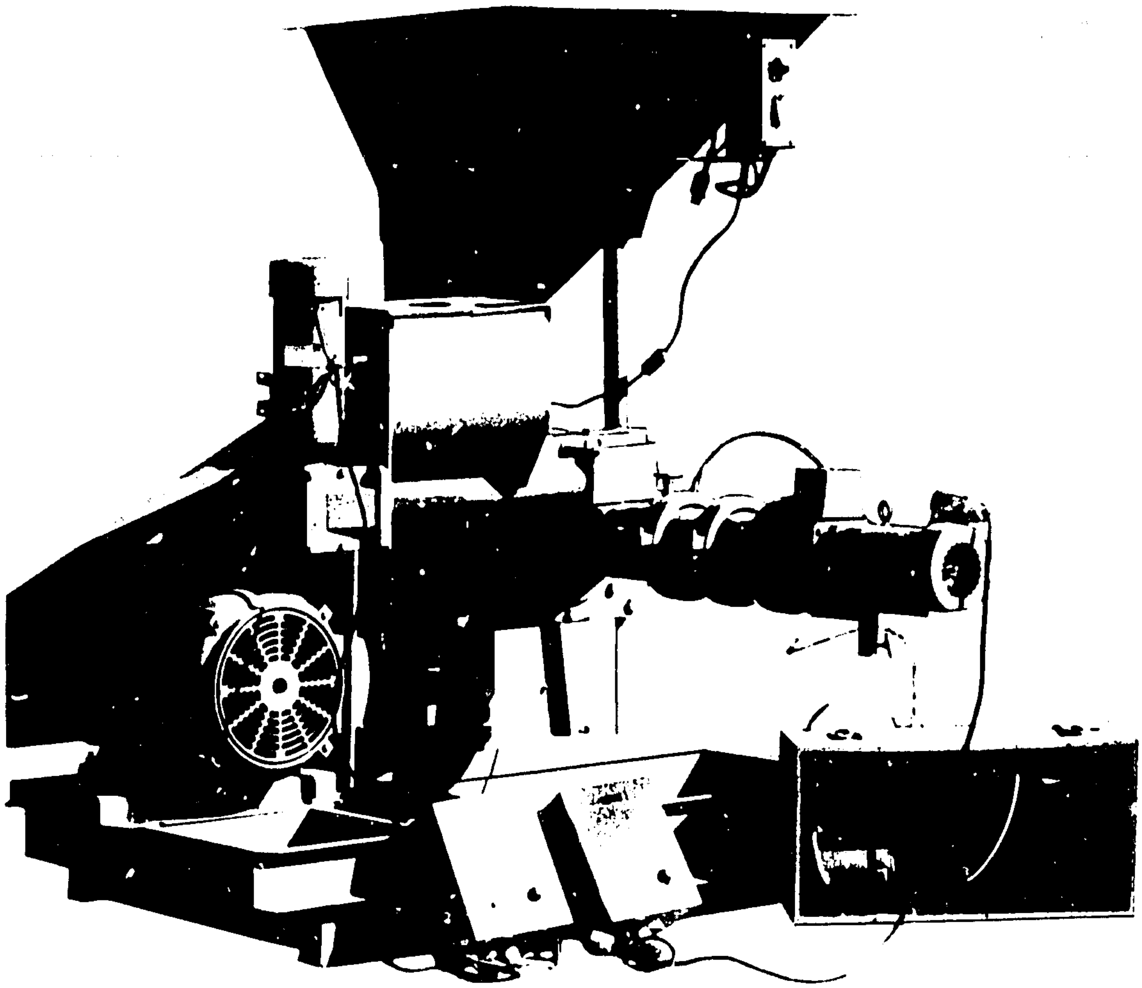

Figure 2. Insta-Pro Model 2000 extruder.

4.2.2 Physical Characteristics

The extruder consists of cast barrel and screw segments. Screw segments slip over a central keyed shaft with steam locks (ring-like restrictions) placed between screw segments. Different screw configurations can be achieved by the order of assembly of screw segments and steam locks. Barrel segments are clamped together to form a continuous barrel. Internal wear rings in barrel segments can be easily replaced when wear occurs. The die is either a single hole with adjustable clearance or a multiple-hole die with a variable speed face cutter. A variable speed injection auger or vibrating pan feeds the extruder.

4.2.3 Capacity

The capacity of the Insta-Pro extruder varies with the model. Model 500 has a production rate between 200 and 300 kg/hr at 540 rpm for mixtures of cereals with oil seeds and pulses. The Model 2000 has a production rate between 450-750 kg/hr at 540 rpm.

4.2.4 Ingredients

Ingredient mixtures with less than 10% fat require 5-15% water addition with the Model 500 and 3-7% water addition with the Model 2000. At the higher moisture levels required for the Model 500, some product drying may be necessary.

4.2.5 Product Shapes and Types

The Insta-Pro extruder with the multiple-orifice die and face cutter can make expanded cylindrical products of varying lengths. Because these extruders are fed coarse grits and operate at moisture contents above 14% with oil content above 7%, most expanded products are relatively dense and hard. In addition to the multi-holed die, a single-hole die with adjustable clearance at the end of screw can be used to make an expanded rope-like product. Extruded products can be ground to produce a precooked composite from suitable for soups, gruels, beverages, and baked goods.

4.2.6 Durability

No specific evaluation of the Insta-Pro extruders durability has been made. Both machines can be operated continuously. Preventive maintenance will have to be done every 500-1,000 hours of operation. Some wear has been noted on rifling in barrel sections due to direct contact with screws.

Disassembly of the extruder is done by removing the barrel segments and then disassembling the screw. Under plugged conditions, this can be difficult if additional water or soybeans were not provided to the machine during the onset of plugging.

4.2.7 Operational Adjustments

Primary operation adjustments of the Insta-Pro extruder involves the correct configuration of the stream locks which are placed between the screw sections. These restrictions control the temperature profile along the barrel measured with bimetallic thermometers located in each barrel section. On line control of the extrusion temperature involves feed rate control, water addition, and granulation of feed ingredients.

Extrusion temperatures for cereal-based products range between 150 and 170°C. Extrusion of soy to denature antigrowth factors can be accomplished at 138-143°C.

4.3 <u>Anderson Extruder</u> (Fig. 3)

4.3.1 Manufacturer:

Anderson-International Corporation
19699 Progress Drive
Strongsville, Ohio 44136

Contact: Mr. R. W. Olsson (Phone: 216-238-5800)

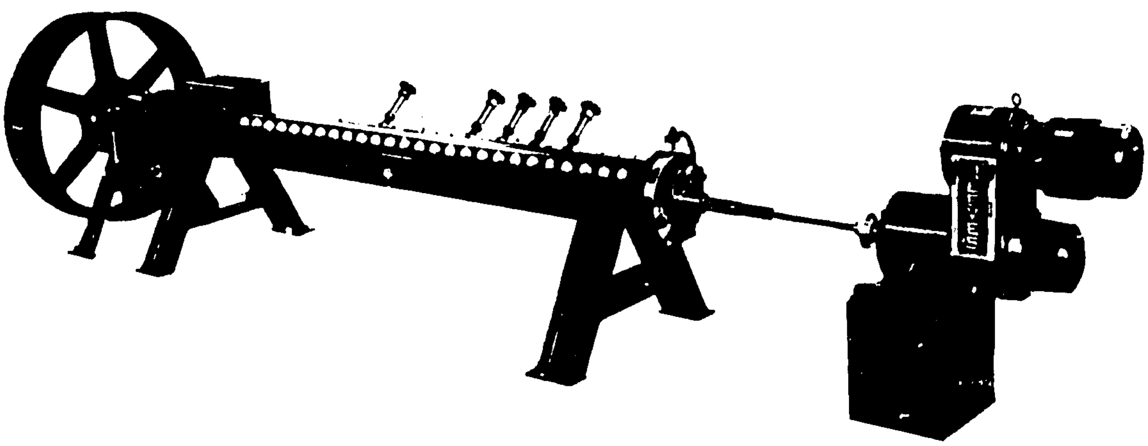

Figure 3. Anderson extruder.

4.3.2 Physical Characteristics

The extruder consists of a single piece barrel and segmented screw with single-turn screw sections slipping over a keyed shaft. When assembled, screws have cut flights which allow a series of breaker bolts to be inserted through the sides of the barrel. The number, length and location of the breaker bolts control the amount of energy input to the product. Certain bolts are hollow and allow injection of water and/or steam. Screw segments and barrel liner sleeves can be replaced when wear occurs.

4.3.3 Capacity

Anderson extruders come in a variety of sizes ranging from a 4.5-inch diameter barrel to an 8-inch diameter barrel. These machines can be run dry with no steam and their capacity ranges from 200 kg/hr to 1,000 kg/hr. When steam is added, increasing operating moistures to 20%, capacities of 2 M.T./hr can be reached with the 8-inch machine.

4.3.4 Ingredients

The Anderson extruder can handle cereals such as corn, rice, wheat, sorghum with or without the addition of soy. Whole soy cannot be extruded without extensive modification of the extruder screw because the necessary extrusion temperatures cannot be reached. Ingredients are normally ground flour fine so that the resulting products are more homogeneous than those which can be made on either the Brady or Insta-Pro extruders. Low-fat (<3%) products can be made on the Anderson because water can be added and serves as an effective lubricant.

4.3.5 Product Shapes and Types

The Anderson extruder comes with a die plate which accepts various shaped die inserts. A variable speed cutter gives significant flexibility in producing a variety of product shapes. The ability of the Anderson to handle finely ground ingredients with low fat extends the capability of the extruder to produce expanded snack or breakfast cereal items in addition to the less expanded and homogenous products produced on the Insta-Pro.

4.3.6 Durability

The Anderson extruder is designed as a heavy-duty machine for continuous operations. Replacement of extruder screw and barrel parts will be required from between 1,000 and 3,000 hours of operation. Major overhauls would occur at about 10,000 hours.

4.3.7 Operation Adjustments

Discharge temperature on the Anderson is controlled primarily by the size and number of die openings. Fine adjustment of temperature is accomplished through water and steam additions and feed rate changes. Once operating at steady state, the extruder runs with little operator attention. Clean-up of the Anderson requires a wet shutdown. Water/steam can be added to a plugged extruder to achieve relatively easy clean-up. Some very wet feed ingredients resulting from start-up and shutdown procedures may have to be discarded.

4.4 Summary of Extruder Characteristics

The capabilities and limitations on the operation of the LEC's tested vary over a considerable range. The Brady is best suited to small-scale operations producing a ground precooked composite flour suitable for gruels, weaning foods, beverages, soups, etc. The Brady is the lowest cost LEC available.

The Insta-Pro extruders have the capability to manufacture a relatively dense product from mixtures of cereal and oil seed with simple shapes. The Insta-Pro requires ingredients having higher fat and/or water content than either the Brady or Anderson. Both the Insta-Pro and Brady can effectively heat treat whole raw soybeans.

The Anderson extruder has the broadest range of ingredient and product capabilities. It can manufacture expanded/shaped products suitable for snacks and/or ready-to-eat (RTE) cereals. The machine was designed for continuous duty. The cost of an Anderson exceeds both the Brady and the Insta-Pro, but it becomes cost competitive at production requirements exceeding 2 M.T./hour.

5.0 LEC PRODUCT EVALUATION AND SPECIFICATIONS

In the product evaluation area most of the work has been directed toward evaluating nutritional and functional characteristics of cereal/legume blends, especially corn/soy blend. The effectiveness of the LEC process in making full-fat soy flour has also been evaluated. In addition, full-fat soy flour made using a sand or salt bed roaster has also been evaluated.

5.1 Cereal/Legume Blends

5.1.1 Preclinical Evaluation of CSB

Initial effort was directed toward determining whether corn/soy blends made on an LEC (LEC-CSB) would have protein values comparable to that of Title II CSB. One of the first questions that needed answering was whether the corn and soybeans required separate processing, as done in making Title II CSB, or whether they could be processed together by metering a 70/30 mixture of corn and soybeans into the extruder. Rat growth evaluation confirmed that the protein quality of CSB was as high when the grains were extruded together as when they were extruded separately, thus, simplifying the process for LDC operations.

Since LEC-CSB was demonstrated to contain protein comparable in quality to casein (milk protein), and since neither the ingredients nor extrusion cooking represented significant departures from the "state of the art" used in making blended foods, it would not have been necessary to do a clinical evaluation. However, since LEC-CSB was the first product made totally on a Brady or Insta-Pro extruder intended to be used in feeding young children, the CSU team recommended that the product be subjected to clinical evaluation in the laboratories of Drs. Graham and McLean. It was also recommended that the effect of dehulling the ingredients on nitrogen absorption and retention in infants be evaluated. These recommendations were supported by USDA/AID.

Prior to submitting samples to Drs. Graham and McLean, a preclinical study was carried out on three samples of LEC-CSB: 1) degerminated corn grits and dehulled soy (dc/ds), 2) whole corn and dehulled soy (wc/ds), and 3) whole corn and whole soy (wc/ws). All were blends of 70 parts corn and 30 parts soy by weight. Following extrusion on a Brady extruder at 163°C, all samples were ground in a Fitz Mill and fortified with 0.7% vitamin and antioxidant premix and 2.7% mineral premix according to specifications for Title II CSB.

As shown in Table 2, all samples exceeded Title II specifications for protein and fat. Only the blend made from whole corn and whole soy exceeded the 2.0% specification for crude fiber of 2.0%. A four-week protein efficiency ratio (PER) study in rats confirmed that all blends were equal to or better than casein in protein quality (Table 3). Microbiological analysis demonstrated that all samples were free of *E. coli*, coagulase positive staphylococci, and salmonella with aerobic plate counts of < 1,000/g compared to the Title II specification of < 50,000/g.

Table 2. Proximate analysis of 70/30 samples extruded at 163°C in the Brady.

Sample Description	Moisture %	Fat %	Nitrogen %	Protein[1] %	Ash %	Fiber %	Carbohydrate[2] %
dc/ds[3]	2.82	6.75	2.72	17.00	4.25	0.8	68.38
wc/ws[4]	3.58	8.63	2.84	17.75	5.07	2.3	62.67
wc/ds[5]	3.27	9.22	2.97	18.56	5.09	1.9	61.96

[1](N x 6.25)

[2](By difference)

[3]dc/ds = degerminated corn grits/dehulled soybeans

[4]wc/ws = whole corn/whole soybeans

[5]wc/ds = whole corn/dehulled soybeans

Table 3. Rat growth evaluation of 70/30 samples extruded at 163°C in the Brady.

Sample Description	Weight Gain (g)	PER	Corrected PER[1]
dc/ds[2]	129.9 ± 6.4[3]	3.02 ± 0.06	2.63 ± 0.05
wc/ws[4]	137.5 ± 5.6	3.04 ± 0.08	2.46 ± 0.07
wc/ds[5]	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]dc/ds = degerminated corn grits/dehulled soybeans

[3]Mean ± standard error

[4]wc/ws = whole corn/whole soybeans

[5]wc/ds = whole corn/dehulled soybeans

Rat growth studies have also been carried out with LEC-CSB made in Sri Lanka, Tanzania and Costa Rica although in the latter case 10% non-fat dry milk was also added. The resulting PER's were all in the range 2.0-2.3 (casein = 2.5) confirming that these blends made locally also would be expected to contain protein of high enough quality to be satisfactory for a weaning food.

5.1.2 Clinical Evaluation of LEC-CSB

The clinical evaluation had two major objectives. One was to confirm in human infants the high protein nutritional value of these blends predicted from the animal study. The other was to study the effect of dehulling ingredients on nitrogen absorption and retention.

Sample 1, dc/ds, was evaluated in nine infants 5-20 months of age with protein fed at 6.4% of calories. In addition all three blends were evaluated with protein fed at 8.5% of calories. This second phase of the evaluation was designed primarily to evaluate digestibility since protein quality differences are less apparent at the higher protein level.

Nitrogen absorption values, as a percentage of intake, were 76.7 ± 9.0 for LEC-CSB #1 and 84.1 ± 4.0 for casein when fed with protein at 6.4% of calories. Nitrogen retention, as a percentage of intake, was 28.9 ± 12.5 and 34.5 ± 7.3 for LEC-CSB #1 and casein, respectively.

In the second phase of the study, with protein fed at 8.5% of calories, nitrogen absorption was 81.8 ± 4.8, 74.7 ± 7.8, and 77.1 ± 7.6 for LEC-CSB blends dc/ds, wc/ds, and wc/ws, respectively. Corresponding nitrogen retention values, as a percentage of intake, were 35.3 ± 6.6 and 25.3 ± 7.7, and 27.9 ± 4.8. These results suggest that nitrogen retention in infants fed with the two higher fiber products was approximately 75% of that in infants fed LEC-CSB made from dc/ds. Differences between the blends made from wc/ds or wc/ws were undetectable.

These results indicate that the LEC-CSB made on a Brady extruder from dc/ds has a protein nutritional value comparable to ICSM. In addition, the results indicated that all three products were satisfactory for child feeding. A reasonable inference from this clinical evaluation is that LEC-CSB or LEC-CSM meeting the finished product specifications established contain dietary protein and energy that can be utilized by infants and preschool children as well as the protein and energy in blended foods such as ICSM, CSM and WSB. These later commodities are Title II foods which have been distributed for many years under PL 480 and they have been used with apparent success in many child feeding programs.

5.1.3 Nutritional Evaluation of Other Blends

Although major attention has been directed at blends of corn and soy, nutritional studies also were carried out with blends of chickpeas or cottonseed with various cereals.

Blends (50/50) of chickpeas with wheat, sorghum or rice supplemented after extrusion with 10% non-fat dry milk all exhibited PER's equal or greater to that of casein.

A major factor influencing the protein nutritional value of cottonseed flour is gossypol, a toxic polyphenolic compound. The effect of extrusion on the protein quality of corn or sorghum blends with glanded (gossypol containing) and glandless cottonseed was evaluated along with glanded cottonseed flour extruded alone. In addition, levels of free and total (free plus bound) gossypol were measured chemically. It is generally acknowledged that the adverse effects from gossypol are associated with consumption of free, not bound, gossypol.

The results of the protein quality studies are summarized in Table 4. Cottonseed blends with any cereal generally had significantly lower PER's than observed previously for soy/cereal blends. Since cottonseed contains less lysine than soy and during heating free gossypol is known to react with lysine making it unavailable, it was surmised that the low PER's were caused by lysine deficiency in the blend. This was shown to be the case since lysine addition increased the PER of a corn/glanded cottonseed blends from 1.51 ± 0.08 to 2.21 ± 0.06.

Extruded glanded cottonseed flour had a corrected PER of 1.97 ± 0.04. The raw glanded cottonseed flour when fed to the rats resulted in weight loss and death. Extrusion of glanded cottonseed reduced free gossypol levels from 0.65% to 0.21% (Table 5). Although the resulting PER was quite good, the free gossypol level was much higher than the current allowable standard of 0.06% for defatted cottonseed flour. However, free gossypol levels of the blends were all below 0.06%.

These preliminary studies with glanded cottonseed flours strongly suggest that the LEC process has considerable potential for the utilization of glanded cottonseed as an ingredient in blended foods processed locally in LDC's. More research is needed if this potential is to be realized, however.

5.1.4 Vitamin Stability During Extrusion

Addition of vitamins and minerals prior to actual extrusion could result in some operational advantages for the LEC process. Potential

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

Sample Description	Extruder and Temperature °C	Weight Gain (g)[1]	PER	Corrected PER[2]	PRE[3]
100% glandless cottonseed	Raw	124.2 ± 6.5	2.88 ± 0.08	2.50 ± 0.07	60.2 ± 1.3
100% glandless cottonseed	Brady, 132	116.0 ± 5.6	2.74 ± 0.07	2.38 ± 0.06	59.6 ± 0.9
100% glanded cottonseed	Brady, 139	96.5 ± 3.7	2.26 ± 0.05	1.97 ± 0.04	49.6 ± 1.2
100% glanded cottonseed	Insta-Pro, 140	73.2 ± 3.7	2.07 ± 0.09	1.80 ± 0.08	47.9 ± 1.5
70% corn/ 30% glanded cottonseed	Brady, 171	50.4 ± 3.8	1.73 ± 0.09	1.51 ± 0.08	46.6 ± 2.4
70% corn/ 30% glanded cottonseed[4]	Brady, 171	94.9 ± 4.8	2.54 ± 0.07	2.21 ± 0.06	57.1 ± 1.1
70% corn/ 30% glanded cottonseed	Brady, 139	70.9 ± 4.4	2.12 ± 0.05	1.84 ± 0.04	49.1 ± 0.8
70% sorghum/ 30% glandless cottonseed	Brady, 174	65.4 ± 3.4	1.98 ± 0.08	1.72 ± 0.07	48.4 ± 2.0
70% corn/ 30% glanded cottonseed	Insta-Pro, 149	93.6 ± 5.8	2.55 ± 0.08	2.22 ± 0.07	55.8 ± 1.9
70% sorghum/ 30% glanded cottonseed	Insta-Pro, 138	65.5 ± 5.6	2.01 ± 0.10	1.75 ± 0.09	45.2 ± 1.8
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% L-lysine • HCl was added to mixture.

Table 5. Free and total gossypol content of raw cottonseed and cottonseed blends extruded on the Brady.

Sample Description	Total Gossypol[1] %	Free Gossypol[2] %
Glanded cottonseed, extruded, 138°C	0.831	0.209
Glanded cottonseed, not extruded	0.863	0.653
Glandless cottonseed, not extruded	0.088	0.032
70% corn/30% glanded cottonseed, 141°C	0.258	0.053
70% corn/30% glanded cottonseed, 160°C	0.264	0.034
70% corn/30% glanded cottonseed, 169°C	0.262	0.024
70% sorghum/30% glandless cottonseed, 169°C	0.005	0.004
70% sorghum/30% glandless cottonseed, 163°C	0.003	0.003
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 spectrophotometer range, and should perhaps be defined as "less than 0.01%."

adverse effects of this procedure include vitamin loss and lowered mineral availability. Several studies were carried out to determine the loss of vitamins during extrusion. Vitamin-antioxidant and mineral premixes were added before or after extrusion to both wc/ws (70/30) and dc/ds (70/30) at 120% of Title II levels. In the first experiment, the extrusion temperature was 171°C and in the second 163°C. Samples for analysis were coded and sent to Hoffman LaRoche for analysis[1]. Thiamin, riboflavin, vitamin B_6, folic acid, reduced vitamin C, and vitamin A levels were measured in both experiments, and vitamin E in experiment 2.

The results are summarized in Table 6. In experiment 1, retention of all vitamins was 80% or better. However, in experiment 2, thiamin retention dropped to 48-75% and vitamin C was 70 to 80%. The reason for the lability of thiamin in the second experiment is not known. Since the extrusion temperature in the second experiment was lower, it does not appear that temperature was responsible.

An additional experiment was carried out on the storage stability of thiamin and vitamin C in the blended foods as a function of time of addition. Thiamin appeared to be as stable in storage up to a month when added before or after extrusion. However, as shown in Table 7, vitamin C was much less stable when added before extrusion, being almost totally lost after one month of storage at 49°C and 61% relative humidity.

The very poor stability of vitamin C during storage when the vitamin mix was added prior to extrusion combined with the variability of thiamin recovery indicate that vitamin mixes should be added following extrusion. Since there is no advantage in adding vitamins and minerals at different times, it is highly recommended that both vitamin and mineral fortification be done after extrusion.

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[1]We are indebted to Mr. Howard Gordon and Hoffman LaRoche for conducting these determinations.

Table 6. Retention of vitamins during extrusion of corn/soy blends.

Vitamin	% Retained Experiment 1[1]	Experiment 2[2]
	Whole Corn/Whole Soy (70/30)	
Thiamin	90.2	48.3
Riboflavin	95.3	92.2
Vitamin B_6	110.2	129.7
Folic acid	100.3	103.6
Vitamin C	83.1	80.4
Vitamin A	89.3	86.5
Vitamin E	--[3]	113.1
	Degermed Corn/Dehulled Soy (70/30)	
Thiamin	97.8	75.4
Riboflavin	98.3	100.0
Vitamin B_6	91.3	128.2
Folic acid	101.2	122.1
Vitamin C	110.7	78.9
Vitamin A	104.0	94.1
Vitamin E	--[3]	126.9

[1]Extruded in Brady at 171°C

[2]Extruded in Brady at 163°C

[3]Not determined

5.1.5 Viscosity and Calorie Density Studies

In the earliest studies carried out with LEC-CSB, it was observed that uncooked viscosities and water absorption values were much higher than observed for Title II CSB or CSM. These observations strongly suggested that the starch was gelatinized in the LEC cooked cereal product

Table 7. Storage stability of vitamin C added to corn/soy blend before or after extrusion[1] (one month's storage).

Sample Description	Storage Condition	Time of Addition	Retention %
wc/ws[2]	-32°C, freezer	before extrusion	71.0
wc/ws	-32°C, freezer	after extrusion	101.1
wc/ws	31°C, 48% R.H.	before extrusion	43.4
wc/ws	31°C, 48% R.H.	after extrusion	86.3
wc/ws	49°C, 60% R.H.	before extrusion	8.6
wc/ws	49°C, 60% R.H.	after extrusion	65.3
dc/ds[3]	-32°C, freezer	before extrusion	84.9
dc/ds	-32°C, freezer	after extrusion	89.7
dc/ds	31°C, 48% R.H.	before extrusion	34.0
dc/ds	31°C, 48% R.H.	after extrusion	80.2
dc/ds	49°C, 60% R.H.	before extrusion	2.2
dc/ds	49°C, 60% R.H.	after extrusion	64.5

[1] Extruded with Brady at 163°

[2] wc/ws = whole corn/whole soybeans

[3] dc/ds = degermed corn/dehulled soybeans

making it more similar to ICSM than CSB or CSM. A comparison of the viscosity properties of LEC-CSB with Title II CSM and ICSM was conducted[2]. In addition, in view of the importance of calorie deficits in LDC's, the effect of extrusion conditions and fat, sugar, non-fat dry milk and amylase additions on the calorie densities of gruels made from these blends was measured.

[2] Title II CSB was unavailable.

All blends were made from dc/ds (70/30). All additions, except water were made following extrusion. Viscosity was measured using the Bostwick procedure recommended for evaluation of Title II blends. These results are listed in Table 8. In the Bostwick procedure, high values represent low gelatinization and viscosity and low numbers indicate more gelatinization and high viscosity. The data in Table 8 suggest that LEC-CSB is closer to Title II ICSM than Title II CSM or CSB based on viscosity.

To determine calorie densities, "instant" and "cooking" procedures were followed for making gruels. In the instant procedure, samples were added to water at 70°C with viscosity measured at 50°C. In the cooking procedure, the gruels were boiled for 10 minutes with the viscosity also measured at 50°C. The standard of reference was the viscosity of a commercial sample of baby cereal as prepared and judged by experienced mothers suitable for feeding by spoon to six-month-old infants. From viscosity-concentration curves and the proximate analysis of the blends, the calorie densities of the gruels were calculated assuming 4 kcal/g for protein and carbohydrate and 9 kcal/g for fat.

The calorie densities of all gruels, as measured under these defined conditions, are listed in Table 9. Under the "instant" gruel procedure increasing extrusion temperature lowered calorie density slightly. Adding oil increased calorie density, but only slightly. However, the most effective way to increase calorie density of the precooked gruel was the addition of an amylase[3] with 0.01% increasing calorie density from 84 to 124 kcal/100 ml. Also effective was adding either sugar or non-fat dry milk.

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[3]Recommended International Standards for Foods for Infants and Children, Codex Alimentarius Commission CAC/RS 72/74-1976, by Food and Agriculture Organization of the United Nations and the World Health Organization.

Table 8. Bostwick viscosity values[1].

Sample Description	Uncooked	Cooked
70/30 dc/ds[2]	>24	8.6
70/30 dc/ds (raw) 2% oil	>24	11.3
70/30 dc/ds (raw) 4% oil	>24	11.4
70/30 dc/ds (raw) 10% sugar	>24	11.6
70/30 dc(raw)/ds 143°C	>24	8.0
70/30 dc(149°C)/ds(143°C)	4.2	>24
70/30 dc(171°C)/ds(143°C)	2.8	>24
70/30 dc(149°C, 9% H_2O)/ds(143°C)	2.9	>24
70/30 dc/ds (149°C)	8.3	20.5
70/30 dc/ds (149°C) 2% oil	9.0	22.6
70/30 dc/ds (149°C) 4% oil	9.8	23.5
70/30 dc/ds (194°C) 10% sugar	9.9	>24
70/30 dc/ds (171°C)	4.3	>24
70/30 dc/ds (171°C) 2% oil	5.6	>24
70/30 dc/ds (171°C) 4% oil	4.8	>24
70/30 dc/ds (171°C) 10% sugar	5.6	>24
70/30 dc/ds (149°C) 9% H_2O	2.5	>24
70/30 dc/ds (171°C) 9% H_2O	4.9	>24
dc (149°C)	1.0	19.6
dc (171°C)	< 0.1	>24
dc (149°C, 9% H_2O)	< 0.1	>24
dc (raw)	>24	2.5
Title II-CSM	23.5	16.3
Title II-ICSM	10.2	15.2

[1]Title II Standards

	Uncooked (37 g + 100 ml H_2O)		Cooked (23 g + 177 ml H_2O	
	Minimum	Maximum	Minimum	Maximum
CSB	--	20	9	21
CSM	--	20	10	22
ICSM	9	--	--	--

[2]degermed corn/dehulled soy.

Table 9. Calorie densities of gruels.

Sample Description	Fat kcal/ 100 g	Protein kcal/ 100 g	Carbohydrates kcal/ 100 g	Total kcal per 1 g	"Instant" Procedure		Cooking Procedures	
					Calorie Density kcal 100 g gruel	Calorie Density kcal/100 ml gruel	Calorie Density kcal/100 g gruel	Calorie Density kcal/100 ml gruel
70/30 dc/ds (raw)	83.3	72.4	234	3.89	138.5	153.7	40.8	43.3
70/30 dc/ds (raw) 2% soy oil	98.1	70.4	232	4.01	152.4	169.2	45.7	47.1
70/30 dc/ds (raw) 4% soy oil	114.1	69.2	225	4.09	155.4	174.0	51.9	54.5
70/30 dc/ds (raw) 10% sugar	74.1	64.4	252	3.91	148.6	164.9	54.7	58.0
70/30 dc (raw)/ds (143°C)	82.2	74.8	237	3.94	98.5	106.4	36.6	37.7
70/30 dc (149°C)/ds (143°C)	71.6	76.0	254	4.02	76.4	82.5	68.7	72.1
70/30 dc (171°C)/ds (143°C)	70.1	76.8	259	4.06	81.2	86.1	77.5	80.6
70/30 dc (149°C) 9% H_2O/ds (143°C)	67.6	75.2	254	3.97	67.5	70.9	74.6	78.3
70/30 dc/ds (149°C)	75.2	75.2	254	4.04	76.8	84.4	61.4	64.5
70/30 dc/ds (149°C) 2% soy oil	93.6	74.4	248	4.16	72.0	83.7	71.6	75.9
70/30 dc/ds (149°C) 4% soy oil	108.9	74.4	240	4.23	80.4	84.4	71.9	76.2
70/30 dc/ds (149°C) 10% sugar	68.0	68.4	264	4.00	82.0	86.1	68.8	72.9
70/30 dc/ds (171°C)	66.0	76.0	264	4.06	73.1	76.0	72.3	75.2
70/30 dc/ds (171°C) 2% soy oil	82.6	73.6	259	4.15	87.2	91.6	73.0	76.7
70/30 dc/ds (171°C) 4% soy oil	99.1	71.6	255	4.26	80.9	84.9	77.5	82.2
70/30 dc/ds (171°C) 10% sugar	59.0	67.2	279	4.06	79.2	82.9	82.4	87.3
70/30 dc/ds (149°C) 9% H_2O	56.9	77.6	252	3.87	69.7	73.9	72.4	76.0
70/30 dc/ds (171°C) 9% H_2O	51.4	76.4	256	3.84	71.2	75.5	73.7	77.4
70/30 dc/ds (149°C) 15% NFDM	63.0	80.8	246	3.90	88.1	91.6	73.5	77.9
70/30 dc/ds (171°C) 15% NFDM	55.4	76.8	257	3.89	81.3	84.6	80.8	84.8
dc (149°C)	25.8	38.8	316	3.81	59.8	62.2	57.2	60.6
dc (171°C)	25.1	39.8	322	3.87	60.0	61.2	60.0	63.0
dc (149°C) 9% H_2O	17.0	38.0	309	3.64	51.0	53.0	61.9	65.6
dc (raw)	43.8	37.0	286	3.67	135.8	149.4	29.7	30.3
Gerber® rice cereal	9.54	32.2	330	3.72	46.9	52.6	62.5	66.3
Gerber® mixed cereal	15.6	65.6	291	3.72	55.8	62.5	55.8	59.1
Title II-CSM				3.80	115.9	121.6	54.0	56.1
Title II-ICSM				3.80	76.0	84.1	49.0	51.0
(0.025% K4814) dc/ds (149°C) [1]	75.2	75.2	254	4.04	109.0	115.5	66.3	69.6
(0.010% H 39) dc/ds (149°C) [2]	75.2	75.2	254	4.04	113.0	123.6	76.2	80.1

[1] ENZECO® fungal amylase obtained from Enzyme Development Corporation, 2 Penn Plaza, New York, New York 10001.

[2] Rhozyme H-39 obtained from Rohm-Haas Company, Independence Mall West, Philadelphia, Pennsylvania 19105.

Using the "cooked" gruel procedure increased the calorie density of LEC-CSB from 43 kcal/100 ml for the raw blend to 75 kcal/100 ml for the sample extruded at 171°C. Addition of oil, sugar or non-fat dry milk further increased calorie density.

The results of these studies indicate that LEC-CSB or LEC-CSM are precooked cereal blends with calorie density properties closer to Title II ICSM than CSB or CSM. These precooked cereals have the advantage of not requiring further cooking thus saving home fuel. In applications where they are cooked in water for either aesthetic of sanitary reasons, they produce gruels with substantially increased calorie density as compared to gruels made from CSB containing raw corn.

5.1.6 Storage Stability

An evaluation of storage stability of LEC-CSB at elevated temperatures and humidities was made. First, CSB samples were stored at two temperatures and two humidities for four months in 3 mil polyethylene bags. In this study the corn and soy were either raw or extruded on a Brady extruder at two different temperatures. Reduced vitamin C and free fatty acids (FFA) were measured as indicators of vitamin stability and hydrolytic rancidity. The results of this experiment clearly demonstrated that extrusion of the corn component greatly reduced both the loss of vitamin C and formation of FFA during storage, especially at elevated temperature and relative humidity.

In a second experiment, LEC-CSB samples extruded in an Insta-Pro 2000 extruder were stored, up to six months, at two temperatures and humidities and in the freezer. Two types of bags were used: (1) 2 mil polyethylene/nylon/polyethylene laminate (Cerex bags--Guyana) and

(2) 3 mil polyethylene (Thriposha bags--Sri Lanka). The samples were analyzed for rancidity by odor evaluation at the end of the storage period.

As expected, extrusion reduced sample moisture levels which remained low even when stored at elevated humidity. Thiamin retention in LEC-CSB after six months averaged 87% and did not appear to be much affected by extrusion temperature or storage temperature and humidity.

As in the first experiment, vitamin C and FFA changes during storage were strongly influenced by extrusion. Changes in FFA levels are summarized in Table 10. As observed in the first experiment, FFA levels increased rapidly to high levels in the raw CSB. In the Cerex bags, FFA levels in LEC-CSB remained $\leq$ 1.5% even after 6 months storage. In Thriposha bags after 6 months of storage at 38°C and 40% relative humidity, FFA levels increased to 20-30%. This did not occur at 38°C and 70% relative humidity. The reason for this unexpected result is not known but might have been caused by deterioration of the bag or plasticizers in the plastic film.

Data pertaining to the stability of vitamin C in LEC-CSB during storage are summarized in Table 11. As observed in the first study, the loss of vitamin C in raw CSB during storage was very high with only 3.5% retained at 38°C and 70% relative humidity. The stability of vitamin C in the extruded blends was much higher with no consistent effect related to package observed. In the LEC-CSB samples, retention ranged from 60 to 100% depending on extrusion and storage temperature, humidity or packaging.

Based on the data obtained in the second study, vitamin C loss in extruded CSB would be predicted to be 1.5% per month at 28°C and 40%

Table 10. Free fatty acid change in cereal/soy (70/30) blends during storage (% of fat).

Sample Description	Storage Condition	Zero Time	Cerex Bags--Storage Time (mo) 2	4	6	Thriposha Bags--Storage Time (mo) 2	4	6
dc/ds[1], raw	38°C, 40% R.H.	6.12	34.1	46.9	45.3	39.9	55.8	44.4
	38°C, 70% R.H.		39.5	66.7	75.4	38.7	71.3	80.0
	22°C, 50% R.H.		30.4	39.5	42.2	31.2	41.9	43.5
	22°C, 70% R.H.		30.8	42.8	56.1	29.6	43.5	50.8
	Freezer, -18°C		5.83	6.20	8.59	6.46	6.01	8.09
dc/ds, 155°C, 1.72% H_2O, Insta-Pro	38°C, 40% R.H.	0.549	0.651	0.655	1.46	1.06	0.836	27.8
	38°C, 70% R.H.		0.667	1.04	1.16	0.567	0.899	5.97
	22°C, 50% R.H.		0.651	0.474	0.716	0.468	0.474	0.832
	22°C, 70% R.H.		0.581	0.644	1.19	0.756	0.517	1.10
	Freezer, -18°C		0.624	0.705	0.714	0.540	0.326	0.938
dc/ds, 177°C, 1.72% H_2O, Insta-Pro	38°C, 40% R.H.	0.631	1.17	1.13	1.33	1.07	0.617	20.1
	38°C, 70% R.H.		1.63	1.61	1.53	0.933	1.40	1.81
	22°C, 50% R.H.		0.799	0.419	0.842	0.557	0.562	0.936
	22°C, 70% R.H.		0.905	0.759	1.40	0.989	1.20	1.37
	Freezer, -18°C		0.530	0.662	1.30	0.774	0.557	1.13

[1]dc/ds = degermed corn/dehulled soy

Table 11. Stability of vitamin C in cereal/soy (70/30) blends during storage (mg/100 g, dry weight).

Sample Description	Storage Conditions	Time	Cerex Bags--Storage Time (mo) 2	4	6	% Retained	Thriposha Bags--Storage Time (mo) 2	4	6	% Retained	Average % Retained
dc/ds[1], raw	38°C, 40% R.H.	44.0	23.5	21.4	28.1	63.9	15.6	15.3	14.8	33.6	48.7
	38°C, 70% R.H.		12.0	3.3	0.98	2.2	8.7	4.2	2.1	4.8	3.5
	22°C, 50% R.H.		38.8	31.6	24.1	54.8	41.5	31.4	21.3	48.4	51.6
	22°C, 70% R.H.		35.5	16.8	11.2	25.5	34.9	16.7	8.1	18.4	22.0
	Freezer, -18°C		48.5	46.3	46.2	105.0	50.5	46.5	46.9	106.6	105.8
dc/ds, 155°C, 1.72% H_2O, Insta-Pro	38°C, 40% R.H.	45.6	40.0	36.4	37.9	83.1	39.6	38.9	40.2	88.2	85.6
	38°C, 70% R.H.		42.1	35.3	29.5	64.7	41.4	31.6	28.0	61.4	63.0
	22°C, 50% R.H.		42.0	42.4	43.7	95.8	42.6	42.1	35.3	77.4	86.6
	22°C, 70% R.H.		41.9	40.1	36.8	80.7	41.0	39.1	40.6	89.0	84.8
	Freezer, -18°C		45.0	44.6	46.2	101.3	47.3	43.3	44.0	96.5	98.8
dc/ds, 177°C, 1.72% H_2O, Insta-Pro	38°C, 40% R.H.	56.1	48.9	43.7	40.9	72.9	50.1	52.4	47.9	85.4	79.2
	38°C, 70% R.H.		46.7	44.2	39.2	69.9	48.2	37.4	37.8	67.4	68.6
	22°C, 50% R.H.		52.2	51.7	57.5	102.5	51.3	50.6	54.0	96.3	99.4
	22°C, 70% R.H.		51.2	48.1	47.3	84.3	51.9	47.6	50.0	89.1	86.7
	Freezer, -18°C		52.6	56.1	52.1	92.9	59.2	57.6	55.6	99.1	96.0

[1] dc/ds = degermed corn/dehull soy

relative humidity and 2.4% per month at 28°C and 70% relative humidity, losses which are consistent with other studies. The beneficial effect of extrusion on the stability of vitamin C is probably related to the lower moisture (water activity) of the extruded samples. To what extent the increased stability of vitamin C resulted from enzyme inactivation during extrusion cannot be determined from the data obtained in this study. Regardless of the mechanism, the beneficial effects of the LEC process on the storage stability of thiamin and vitamin C are apparent.

The results of the storage studies suggest the following conclusions. The LEC process results in cereal/legume blends which when fortified with the AID vitamin, antioxidant and mineral premixes have the following desirable properties. Moisture levels are reduced, and remain low even during storage under conditions of high relative humidity. Controlling moisture levels in this way is a desirable way to produce shelf-stable products. Although not evaluated in this study, the LEC process may have an advantage over intermediate and high moisture extrusion processes, unless the latter products are dried to similar low moisture levels. Conversely, drying the high moisture extruded blends to the low levels observed for the LEC blends would add significantly to cost, thus increasing the potential cost advantage of the LEC process. Although not measured in this experiment the lower moisture levels in these LEC blends should reduce microbial growth as well.

Extruding CSB on an LEC greatly reduces the increase in FFA levels and the destruction of vitamin C during storage, especially under conditions of high temperature and high humidity, as compared to raw CSB. It is clearly necessary to extrude the cereal component in order to see these beneficial effects. All three LEC's (Brady, Insta-Pro 2000, and Anderson) evaluated were effective in preventing the increase in FFA levels and in reducing vitamin C loss during storage. These results may have applicability for home and village processed blended foods as well as those centrally processed. The development of some rancidity during high moisture accelerated storage conditions suggest that the product should be used some time prior to a year's storage at 28°C and 70% relative humidity. However, even though slight to moderate rancidity scores were recorded by the panel for several of the extruded blends, none were judged by the panel to be unacceptable.

5.2 Extruded Full-fat Soy Flour

The low-cost Brady and Insta-Pro extruders were originally designed to cook whole soybeans for use as animal feed. Work on extrusion of soybeans at Colorado State University has been directed toward confirming the effectiveness of heat treatment in inactivating antinutritional factors, evaluating the resulting full-fat soy flour (FFSF) as a bread ingredient, and determining the storage stability of FFSF made in this way.

5.2.1 Effectiveness of Heat Treatment

In order to determine the extrusion temperature needed for effective heat treatment, dehulled soybeans (ds) were extruded in the Brady at temperatures ranging from 121° to 149°C. The extruded products were ground into flour with a pin mill and evaluated for antitrypsin activity, urease activity, protein quality and nitrogen solubility index (NSI). The results are summarized in Table 12. The maximum corrected PER 1.94 $\pm$ 0.05 was obtained with an extrusion temperature of 143°C. At this temperature, NSI was 21.6, urease activity 0.02 and 56.7% of antitrypsin activity was destroyed.

Table 12. Effect of temperature on extrusion of soybeans[1] (Brady).

Temperature °C	Nitrogen Solubility Index	Urease pH Units	Trypsin Inhibitor TIU/mg	Trypsin Inhibitor % Destroyed	Corrected PER[2,3]
Unextruded	55.6	2.07	64.5	--	1.01 ± 0.08
121	41.9	1.96	64.8	0.0	1.35 ± 0.04
127	56.1	1.82	57.2	11.2	1.42 ± 0.05
132	44.3	1.46	45.5	29.5	1.41 ± 0.04
138	47.1	0.34	47.2	26.7	1.55 ± 0.04
143	21.6	0.02	28.0	56.7	1.94 ± 0.05
149	16.6	0.01	16.8	74.0	1.78 ± 0.08

[1]Composition of dehulled soybeans: protein 39.2 ± 0.03, fat 21.0 ± 0.02, ash 5.9 ± 0.1, fiber 2.4 ± 0.1, and moisture 5.9 ± 0.5.

[2]Protein efficiency ratios corrected relative to casein = 2.50.

[3]Mean ± standard error.

Another experiment was carried out with the Insta-Pro 2000 extruder where dehulled soy was extruded at varying temperatures and moisture levels. Following grinding on a pin mill, the resulting flours were evaluated as described in the first experiment. In addition, pancreas weights were determined in the rat feeding study as an additional indicator of antitrypsin activity.

The effect of extrusion on NSI, urease and antitrypsin activity is summarized in Table 13. Extruding with the Insta-Pro at 138°C and 2.0% added moisture or 143°C with no added moisture totally destroyed urease activity. Antiptrypsin activity was reduced 67 to 91% and NSI's ranged from 9 to 11 over the conditions evaluated. The results of the rat growth study summarized in Table 14 showed that the Insta-Pro extrusion conditions evaluated resulted in PER's not significantly different from one another and all prevented pancreatic hypertrophy caused by antitrypsin activity.

Table 13. Effect of extrusion on nitrogen solubility, urease and antitrypsin activity in soy[1] (Insta-Pro).

Extrusion Temperature °C	% H_2O Added	Urease Activity[2]	TIU[3]/mg	% Trypsin Inhibitor Destroyed	NSI[4]
not extruded	--	2.20	55.3	--	52.8
139	0.0	-0.11	17.6	68.2	10.7
138	2.0	0.0	18.4	66.8	11.4
137	3.3	-0.02	15.9	71.3	11.2
143	0.0	-0.05	15.6	71.8	11.0
143	2.0	-0.04	14.4	73.9	9.8
143	3.3	-0.02	9.6	82.7	9.7
149	0.0	-0.05	4.9	91.1	8.7
149	2.0	0.0	8.3	85.0	10.0
150	3.3	0.01	9.5	82.8	8.8

[1]All soybeans were dehulled on a Sturtevant scourer-aspirator.

[2]Change in pH units.

[3]Trypsin inhibitor units.

[4]Nitrogen Solubility Index

Table 14. Protein quality evaluation of full-fat soy flour with Insta-Pro 2000.

Sample Description	Weight Gain (g)	Protein Efficiency (PER)	Corrected PER[1]	Pancreas Weight (mg/100 g B.W.)
ds, raw	34.3 ± 3.8[2]	1.34 ± 0.13	1.03 ± 10	416 ± 29
ds, 139°C, 0.0% H_2O	96.0 ± 3.4	2.53 ± 0.06	1.94 ± 0.05	279 ± 17
ds, 137°C, 3.3% H_2O	102.8 ± 5.9	2.67 ± 0.08	2.05 ± 0.06	270 ± 12
ds, 143°C, 0.0% H_2O	113.6 ± 4.3	2.72 ± 0.05	2.09 ± 0.04	274 ± 6
ds, 143°C, 2.0% H_2O	104.1 ± 4.9	2.72 ± 0.06	2.09 ± 0.05	263 ± 16
ds, 149°C, 0.0% H_2O	112.3 ± 6.9	2.78 ± 0.07	2.13 ± 0.05	263 ± 12
ds, 150°C, 3.3% H_2O	107.1 ± 7.7	2.69 ± 0.07	2.06 ± 0.02	273 ± 17
ANRC casein	121.9 ± 5.7	3.26 ± 0.07	2.50	330 ± 16

[1]Corrected relative to casein = 2.50

[2]Mean ± standard error

In summary, the Brady and Insta-Pro extruders were effective in inactivating sufficient antitrypsin and urease activity, and producing corrected PER's not significantly different than 2.0.

5.2.2 Baking Study

FFSF made from dehulled soy extruded on a Brady cooker at 138-140°C and ground with a pin mill was incorporated into standard white bread at 5%, 10% and 15% levels. Comparison was made with commercial Nutrisoy 220 (defatted soy flour) at the 5% level. Breads were baked without added improvers such as calcium or sodium steroyl-lactalate (CSL and SSL).

The results are summarized in Table 15. Bread volumes did not change when replacing up to 15% of the flour with soy flour, although, as expected, crust and crumb color were slightly darker and the grain more open at the highest level. The flavor of all breads was satisfactory and the experimental sample performed as well as Nutrisoy at 5% addition. This baking study indicated the extruded and pin milled FFSF was satisfactory for use in bread baking. Additional studies are needed to evaluate fully the potential of this product as a bread ingredient.

Table 15. Effects of defatted soy and pin milled full-fat soy flour added to bread[1].

Flour Replaced	Specific Volume cc	Crust Color (7)	Symmetry (7)	Break (6)	Crumb Color (10)
0%	3.97	7	7	6	9
5% defatted soy	3.92	6	7	6	8
5% FFSF[2]	4.18	6	7	6	8
10% FFSF	4.06	5	7	6	7
15% FFSF	3.90	5	7	5	7

Flour Replaced	Flavor (15)	Grain (20)	Texture (20)	Volume (15)	Total Score (100)
0%	14	17	19	10	89
5% defatted soy	14	15	17	10	83
5% FFSF	14	15	19	11	86
10% FFSF	14	15	18	11	83
15% FFSF	14	13	17	10	78

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

[2]Extruded on Brady at 138-140°C

5.2.3 Storage Stability

Dehulled soybeans were extruded on the Insta-Pro 2000 extruder at temperatures ranging from 139° to 150°C. Following grinding in a pin mill they were placed in Cerex and Thriposha bags and stored up to six months at two temperatures and two humidities and in the freezer as described in section 5.1.6. Moisture and FFA levels were measured during storage and at the end of the storage period samples were evaluated for rancid odor by a semi-trained panel.

As expected, moisture levels were reduced by extrusion and remained low during storage, even at 70% humidity. In contrast to the results with cereal blends, FFA levels remained low during storage on both the extruded and raw samples.

After six months of storage, rancidity scores ranged from "slight" to "moderate" for all soy flours. It was surprising and unexpected that unextruded raw dehulled soybeans stored at 38°C and up to 70% relative humidity exhibited such a low degree of rancidity ranging from "none" to less than "moderate."

The highest rancidity scores of 1.9 to 2.4 (2 = moderate) were observed for FFSF extruded in the Insta-Pro at 139°C with no added moisture and stored in Cerex bags. However, because of the large standard errors it is doubtful if any effects attributable to extrusion conditions or type of packaging would be significant. A higher storage temperature also appeared to increase rancidity development but because of the variability encountered, the temperature effect also was not consistent. The low rancidity scores observed for raw dehulled and ground soybeans stored six months at an elevated temperature and high relative humidity were unexpected. Previous work on FFSF made by high moisture extrusion processes indicated that stability toward oxidative rancidity of extruded soy flours came about through inactivation of lipoxygenase. The low rancidity scores for the unextruded samples would appear to have come about because the samples were ground dry at the relatively low moisture ambient conditions typical of eastern Colorado. During storage, even under conditions of high relative humidity, moisture levels at 38°C did not exceed 9% and at 22°C moisture levels did not exceed 11%.

5.3 Roasted Full-fat Soy Flour

Full-fat soy flour made with a roaster using hot agitated salt or sand to cook soybeans was evaluated for effectiveness of heat treatment. Whole soybeans were roasted at temperatures ranging from 178° to 234°C and residence times of 15 to 24 seconds. Dehulling was accomplished by cracking the beans with a roller mill and winnowing the cracked hulls following roasting. Grinding was carried out with a Fitz Mill.

5.3.1 Effectiveness of Heat Treatment

The results of the nutritional evaluation of the roasted beans are presented in Table 16. Roasting soybeans at 178°C for 15-24 seconds only slightly increased their corrected PER compared to raw beans. However, roasting at 206°C for 22 seconds gave a corrected PER of 2.20 and roasting at 234°C for 15 seconds gave a corrected PER of 2.31. A reasonable relationship was observed between PER and antitrypsin activity in the roasted soybeans. This work is generally consistent with the earlier work at the Northern Regional USDA laboratory in which it was observed that if at least 55% destruction of the antitrypsin activity was achieved, no pancreatic hypertrophy occurred. The relationship between protein utilization and enzyme inhibition is not completely clear, however. Our work on FFSF made on a low-cost extrusion cooker gave a corrected PER of 2.0 with a 52% loss of antitrypsin activity. It is well known that antitrypsin activity does not account for all anti-nutritional properties of legumes and more work is needed to better understand the differences between the effectivenss of the roasting and extrusion processes.

Table 16. Nutritional evaluation of roasted soy flours.

Roasting Conditions[1]	Weight Gain, g[2]	PER[3]	Corrected PER[4]	TIU[5]/ mg	% Loss of TIU
Raw	54.1 ± 4.3[6]	1.88 ± 0.07	1.49 ± 0.06	75.5	--
Roasted 178°C, 15 sec	59.8 ± 3.8	2.11 ± 0.09	1.67 ± 0.07	48.5	36
Roasted 178°C, 24 sec	66.0 ± 5.9	2.05 ± 0.06	1.62 ± 0.13	40.2	47
Roasted 206°C, 22 sec	102.6 ± 4.2	2.79 ± 0.07	2.20 ± 0.03	19.0	75
Roasted 220°C, 20 sec	113.1 ± 4.6	2.75 ± 0.06	2.17 ± 0.05	9.2	88
Roasted 234°C, 15 sec	108.4 ± 3.3	2.93 ± 0.04	2.31 ± 0.03	7.2	90
Roasted 234°C, 24 sec	104.5 ± 4.7	2.67 ± 0.06	2.11 ± 0.05	9.6	87
Casein control	119.0 ± 4.8	3.16 ± 0.09	2.50	--	--

[1]Temperature of salt bed and exposure time

[2]Least significant difference $P < 0.05$, 14.3; $P < 0.01$, 18.7

[3]g wt gained/g protein consumed; Least significant difference $P < 0.05$, 0.19; $P < 0.01$, 0.25

[4]Corrected relative to an assigned value of 2.50 for ANRC casein; Least significant difference $P < 0.05$, 0.19; $P < 0.01$, 0.25

[5]TIU = trypsin inhibition units

[6]Mean ± standard error

The data demonstrate that it is possible to produce FFSF with a high protein quality using a dry heat process and beans with initial moisture levels of approximately 5%. Our results suggest that it is the effectiveness of heat penetration that is important in the inactivation of antigrowth factors in soybeans, rather than the moisture level. It has been previously reported that a hot salt bed roasting process is also effective in destroying antitrypsin activity in raw navy beans.

The potential applicability of the roasting process in developing countries is related to its simplicity and low cost. Since no water is required in processing, no drying is necessary. In addition, FFSF made by the roasting process is much easier to mill to a particle size suitable for bread baking than is the case with the extrusion process, because of a considerable difference in the distribution of the oil within the product. The roasting process greatly simplified the dehulling process since roasting partially cracked the hulls which, after light rolling, were easily winnowed away in a stream of air.

5.3.2 Baking Studies

The samples described in section 5.3.1 were baked into bread at a 12% level. Compared with commercial Nutrisoy 220, all roaster samples performed well. As expected volume was slightly reduced as compared to the control but only three of the nine samples evaluated produced lower volumes than the Nutrisoy. All samples produced a pleasant bread flavor. Total scores of all soy breads ranged from 80 to 85 indicating that breads of satisfactory quality can be produced with most of these soy flours without SSL.

5.4 Specifications for Blended Foods

To determine the feasibility and potential of LEC's for the production of blended foods in LDC's that could augment the supply of blended foods supplied in the Title II program, specifications for blended foods needed to be developed. The starting point in developing specifications for LEC-blended foods has been the specifications for various Title II blended foods that are well established. In order to assess the suitability of Title II specifications in LEC applications the following activities were carred out: 1) evaluation of nutritional specifications with outside consultants, 2) development of product specifications for LEC-CSB and LEC-CSM, 3) consideration of allowable fiber levels and dehulling requirements, and 4) development of a food approval procedure for possible use by AID.

5.4.1 Outside Nutritional Specifications

An *ad hoc* panel of outside consultants[4] was assembled to evaluate the appropriateness of specifications for Title II CSB for use in LEC applications. The specific sites considered included Sri Lanka, Tanzania and Costa Rica, but the discussion centered around the concept of generalized recommendations appropriate in most LDC's where significant nutritional problems are present.

The panel came to the unanimous opinion that, without specific evidence to the contrary, the Title II specifications are appropriate as they stand for general use in LEC programs with the specific applications considered as special cases. Several possible changes were considered

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[4]Dr. George Graham, Johns Hopkins University; Dr. Samuel Foman, University of Iowa; and Dr. Gerald Combs, National Institutes of Health.

to be appropriate minor variations from the Title II specifications. It would be desirable to double the vitamin C level to increase absorption of dietary iron. To help recover this added cost, halving the level of vitamin B_{12} added appeared appropriate. Also because of the possible adverse effect of high levels of tricalcium phospate on zinc and iron absorption, and because LEC products would have an expected shorter storage requirement than Title II blends, it was suggested that an alternative formulation of calcium carbonate and dibasic calcium phosphate be used.

5.4.2 Overall Product Specifications

Product specifications for LEC-CSB and LEC-CSM were developed for applications in Sri Lanka, Tanzania and Costa Rica. These specifications are suggested guidelines only, since those responsible for any specific LEC application have the authority to establish their own specifications.

The specifications developed included the Title II CSB or CSM nutritional specifications, with the modifications discussed in section 5.4.1. The Title II microbiological standard of 50,000 bacteria/g and free of salmonella, *E. coli*, and coagulase positive staphylococci was retained and an upper limit of 20 ppb of aflatoxin proposed. Particle size and sample description guidelines followed the Title II specifications.

After further consideration of allowable fiber levels and dehulling requirements of LEC-blended foods, it is now recommended that use of whole corn be allowed while retaining the requirement for partial dehulling of the soybeans. In addition, it is recommended that microencapsulated vitamin C be used to enhance storage stability, and stability of this nutrient during cooking.

5.4.3 Allowable Fiber Levels in Weaning Foods

The specification of allowable fiber levels is a particular concern in the LEC program. The lower-cost technology being used has some significant limitations in dehulling efficiency, particularly of cereal grains such as corn. A requirement to dehull corn to the same extent, as is done in producing commercial degerminated corn grits, would have at least four potentially undesirable consequences for the LEC concept: 1) The capital costs of degerming equipment are much higher than a scourer-aspirator currently being used, thus adding to the cost of an LEC Plant, 2) the equipment available to make degerminated corn grits is of large capacity not compatible with many LEC systems, 3) the technical expertise required to operate and maintain milling equipment of this nature is at a higher level than is typical in LEC plants, and 4) to dehull corn to achieve the very low fiber levels present in degerminated corn results in a rela tively low extraction rate of 65-75%. This means that a large amount of grain intended for human food would need to be converted to animal feed. Although degerminated corn grits are available at some locations, this is not generally true. Also, even if degerminated corn grits are available at a production site, economic factors may preclude their purchase.

For these reasons, a position paper[5] was written dealing with allowable fiber levels in cereal/legume blends to be used as weaning

[5]Jansen, G. R. A consideration of allowable fiber levels in weaning foods. U.N. University Food and Nutrition Bulletin 2(4):38-47 (1980).

foods in developing countries. The review included a definition of dietary fiber, methods of fiber analysis, and analytical data on corn/soy blends made using an LEC system. After outlining potentially beneficial and undesirable attributes of fiber in human nutrition, studies carried out in infants were reviewed. Finally, the position paper makes some conclusions relative to allowable fiber levels in LEC-blended foods.

Considering all of the data reviewed, there does not appear to be any reason to lower the Title II crude fiber specification for CSB or CSM below the 2.0% currently specified. This fiber level can be achieved in LEC-CSB made from 70% wc and 30% ds. In view of the difficulty of dehulling corn in an LEC factory and the considerable cost savings that will result from using whole corn, it is concluded that it is acceptable to use whole corn as an ingredient for making extruded blended corn/soy blends in an LEC plant. Use of whole corn has the additional advantage of retaining germ protein and oil in the final product. It should be noted that if whole corn is to be used, the cleaning operation needs to be of high quality.

The above recommendation is made only for use of whole corn. Since soy is easier to dehull and there is less experience in consuming whole soy by infants and young children, then is the case for whole corn, it is recommended that soybeans continue to be dehulled. Minerals can be added to these blended foods in ample amounts after extrusion so use of whole corn should not pose a particular problem for mineral availability. However, it would be desirable to conduct studies in experimental animals and infants confirming this point. It is possible that somewhat more iron and zinc in the fortification mixture should be specified if whole corn were used. Other cereal grains have not been investigated specifically. It would appear whole wheat or whole rice also would be acceptable for many applications. However, because of the presence of antinutritional tannins in the sorghum hulls, it is strongly recommended that any sorghum used in an LEC plant be adequately dehulled using pearling equipment specifically designed for this purpose.

5.4.4 Food Approval Procedure for AID

In the LEC Program, weaning foods are being manufactured from local ingredients with in-country processing using an LEC system. It is necessary that these products be safe and wholesome if used as directed. CSU has provided guidelines for nutritional and quality control specifications for these products. In addition, CSU has conducted pre-clinical evaluation of many of these products and arranged for the clinical evaluation of others. AID because of its support of the LEC program, also has an interest in making certain that the new foods are safe and wholesome as well as adequately tested.

CSU in collaboration with USDA took the initiative to help AID develop a food review procedure, not only for LEC-produced products, but for all foods and food grains for which AID has a degree of responsibility. After a meeting at AID, CSU drafted a suggested procedure. The technical issues that are considered by the suggested AID Food Approval Committee include: 1) food composition issues (protein, fat, energy, fiber, vitamins and minerals); 2) food safety issues (microbiological levels, aflatoxin levels, pesticide levels, insect infestation levels, and gossypol levels); and 3) evaluation issues (pre-clinical, clinical and field evaluation).

The procedure developed was, in principle, accepted by the Office of Nutrition, AID. At the present time the administrative mechanisms by which AID would implement the review procedure are under study by the agency.

6.0 LEC EXTRUSION PLANTS

All food processing facilities utilizing extruders require equipment in addition to the extruder. A diagram of a typical LEC plant is shown in Figure 4. Raw ingredients are cleaned, destoned and dehulled and then they go through a proportioner mill prior to extrusion. In the case of blended food, extrusion is followed by cooling, and grinding are typical steps. Vitamins, minerals and antioxidants, and in some cases, non-fat dry milk solids are added and blended prior to packaging. Systems for making breakfast cereals, snacks, instant soup mixes, beverage bases and soybean flours include the same extrusion equipment but somewhat different auxiliary equipment.

A complete operations and training manual[6] was developed by CSU to assist LEC plant installations. The two-part manual details the operations of plant equipment, maintenance, quality control, cost and inventory control procedures, and other items associated with plant operation.

6.1 Typical LEC Plant Costs

LEC processes can fit into existing grain handling and processing plants or be constructed as a new facility. The capital cost required

[6] Cummings, D. A., J. M. Harper, J. D. Kellerby and R. E. Tribelhorn. 1979. LEC Manual, Parts I and II. Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, CO. March.

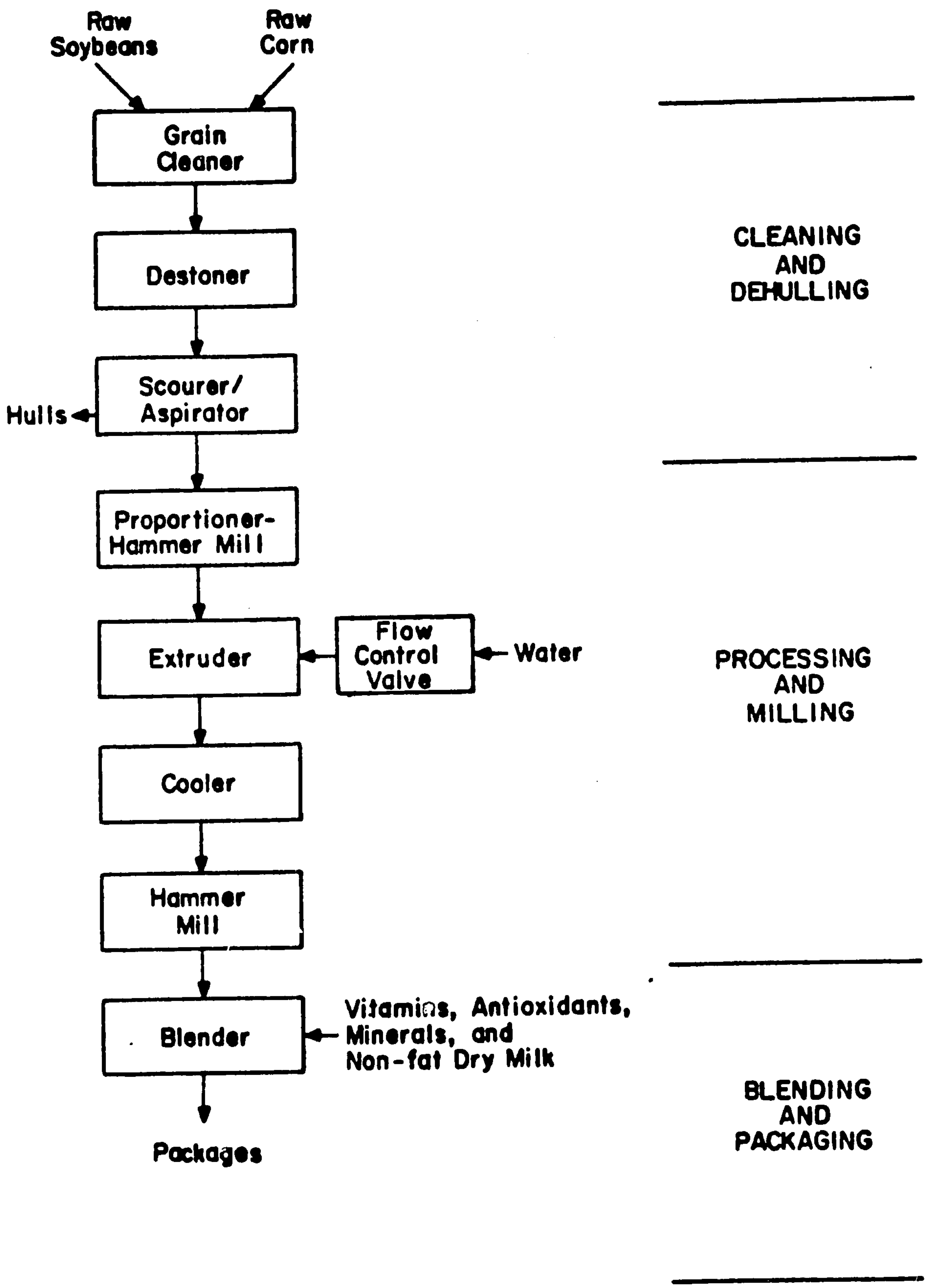

Figure 4. Process flow chart for manufacturing blended food(s) with LEC.

will depend on existing facilities, the type of products to be produced and the form of packaging.

Typical capital costs are shown in Table 17. Since some of the equipment is oversized for a single extruder, it would be possible to expand the plant's capacity by adding a second or larger extruder with a relatively small incremental cost.

6.2 Typical Manufacturing Costs

Table 18 gives some typical manufacturing costs for a blended food product and full-fat soy flour. Since the finished products are relatively dry, their production cost of about 45¢/kg provides a very good value to potential consumers. The raw grains and packaging materials represent about 80% of the finished product costs. This fact remains approximately true regardless of the product being manufactured. The exception would be the production of products which are packaged in very small single-serve packages where the relative cost of packaging would increase.

7.0 LEC PRODUCTS

The principal emphasis of operating LEC plants has been the production of precooked blended foods made from mixtures of cereals and legumes or oil seeds fortified with vitamins, minerals, and in some cases non-fat dry milk.

7.1 Blended Foods

Products produced have been developed to meet local tastes and utilize raw ingredients which are grown in the region surrounding the

Table 17. Capital costs (US $) for LEC systems (500 kg/hr).

Item	Blended Food (precooked fortified flour)	FFSF
1. Purchased Equipment[1]		
Scalper	3,000	3,000
Destoner	6,000	6,000
Dehuller	8,500	3,000
Aspirator	--	1,500
Bucket elevators (2)	4,000	4,000
Bulk tanks	2,800	1,400
Incoming conveyors	1,200	600
Proportioner mill	3,800	--
Conveyor	--	600
Extruder with motor	8,000	8,000
Water application	250	--
Belt conveyor	3,000	3,000
Product cooler	7,800	3,000
Product grinder and air relief system	8,500	40,000
Packaging equipment (bulk)	650	600
Blending equipment	10,000	--
Conveyor	3,500	600
Electrical equipment	10,000	8,500
2. Equipment Transport Costs		
Crating	2,000	1,500
Freight	2,400	4,700
Shipping	6,100	1,400
3. Installation Costs		
Labor	4,000	4,000
Supplies	750	1,125
4. Utilities	existing	existing
5. Building	40,000	40,000
6. Land	5,000	5,000
7. Contingency (20% total costs)	28,250	28,305
8. Total	$169,500	$169,830

[1]Not all equipment listed is used in each system.

Table 18. Manufacturing costs[1] of the two LEC systems.

	Blended Food (precooked fortified flour)	FFSF
1. Direct Product Costs		
A. Raw Materials & Ingredients		
Grains	108.90	167.00
Vitamins	5.94	--
Minerals	11.79	--
Credit for dehulling waste	-2.48	-1.80
B. Packaging Materials (bulk)	37.96	27.50
C. Labor	10.75	6.00
D. Electricity @ 6¢/kW-hr	6.00	6.60
E. Maintenance	2.46	3.08
F. General Supplies	0.27	0.27
G. Product Shipping Costs	4.50	5.50
2. Direct Manufacturing Costs		
A. Payroll Overhead (15% payroll)	1.61	0.90
B. Laboratory Costs	0.28	0.28
3. Indirect Manufacturing Costs		
A. Depreciation[2]	4.09	4.22
B. Repayment of Borrowed Capital[3]	12.54	12.56
4. Total Manufacturing Costs	$204.61	$232.11
Assumed production rate (kg/hr)	450	550
Product value ($/kg)	0.46	0.42

[1]Values given in $/hr

[2]Building depreciation = [(Building cost)]/[(50 years)(2,200 hr/yr)]
Equipment depreciation = [(Equipment cost)]/[(10 years)(2,200 hr/yr)]

[3]Calculated using Capital Recovery Factor for loan at 10% interest for 10 years.

plant. These products typically contain 5% moisture, 8% fat, 17% protein, 4% ash and 1% fiber. The protein is balanced having a PER equivalent to casein (milk) and cooking renders it digestible and utilizable by small children. Blended foods are used as the basis for gruels for infant feeding but also have found important alternate uses in soups, breads, drinks, sauces, main dishes and desserts.

7.2 Full-fat Soy Flour

The extrusion process is an effective means of heat treating whole soybeans and producing a high-energy FFSF as previously discussed. These products typically contain about 40% protein (PER of 2.0) and 20% fat. The heat treatment leaves the product stable to storage and has effectively inactivated antigrowth factors occurring in the raw bean. Full-fat soy is used in baked goods, as an egg and milk solids replacer and food fortifier.

7.3 Drink Bases

Precooked flavored and presweetened instant drink bases can be extruded from cereal and some soy.

7.4 Soup Bases

Instant soup bases containing legumes (peas), soy, cereal and flavor can be easily prepared.

7.5 Snacks

Under the proper conditions, expanded nutritious cereal/soy based snack items can be manufactured. Flavors can be added to the surface of these products.

7.6 RTE Cereals

Some sugar or sodium bicarbonate addition before extrusion increases flavor development in the production of RTE cereals.

8.0 DEMONSTRATION PLANTS

Colorado State University, under the cooperative agreement has demonstrated LEC systems. These are summarized below.

8.1 Sri Lanka

CARE/Sri Lanka initially developed a plan to incorporate locally grown and processed cereals into imported wheat/soy blend (WSB) with the long-range goal of eventually replacing the imported commodity totally with a locally manufactured food product. Engineers from Colorado State University designed an LEC plant which was installed near Kandy in 1976. Since that time, this plant has processed a variety of cereal/legume blends which have been used to extend the imported blended food distributed in the Thriposha program.

To reach additional consumers, CARE decided to relocate the LEC plant closer to Colombo and greatly expand its capacity. The new plant includes two electrically powered Brady extruders. The 750 gram packages cost $0.31 to make which includes $0.06/kg for processing. During the first year of operation, the new plant will process 4,400 M.T. of LEC-CSB to blend with 6,300 M.T. of imported ICSM, enough for 600,000 recipients. By 1984, the long-range plan is to increase production to 8,800 M.T. of LEC-CSB and reduce the requirement for imported ICSM to 3,600 M.T. Extensive marketing plans have been developed to capture a significant commercial market. Examples of this commercial package and promotional materials are shown in Figure 5.

Figure 5. Thriposha packaging and promotional materials.

8.2 Costa Rica

In 1976, the Government of Costa Rica, CARE-Costa Rica and USAID signed an agreement to construct an LEC food processing plant to produce low-cost food products for use in feeding programs in Costa Rica. The processing system includes a Brady extruder for making blended foods and full-fat soy flours.

The plant went into production in 1979. CARE and USAID shared the cost of the new building (Figure 6) and equipment which cost approximately (U.S.) $210,000. A significant part of this capital cost is associated with the Alpine pin mill needed to grind extruded FFSF, but not needed for grinding LEC-CSB. The government of Costa Rica pays for all costs to purchase raw materials and the processing of the food products totaling $0.65/kg. Design capacity is 455 kg/hr for LEC-CSB or FFSF. The anticipated 275 M.T./year FFSF production is sufficient to fortify 6 million pounds of bread at a 10% level.

Figure 6. Nutrisoy plant located near San Jose, Costa Rica.

The blended food (Nutrisoy) being made in Costa Rica is LEC-CSM made by adding 10% non-fat dry milk and vitamins/minerals to extruded CSB. The daily production should be adequate to feed 50,000 children a 300 kilocalorie food supplement every day for a year.

The Department of Nutrition of the Ministry of Health conducted acceptability tests in school lunchrooms and preschool nutrition centers. The locally made product was compared to CSM from the United States through the Food For Peace Program. Both products were acceptable, but the locally made product was preferred. CARE/Costa Rica is currently working to enlarge product lines for drinks (Horchata) consisting of presweetened, precooked cereals.

8.3 Tanzania

Because of the low capital cost of the LEC system, the Tanzanian Government decided to locate a weaning food plant at the National Milling Corporation in Dar es Salaam based on the system. With assistance from Colorado State University, an LEC plant went into production in May 1978 and continuously made LEC-CSM by extruding a corn/soy mixture and blending in milk solids, vitamins and minerals until June 1979. The product has the name "Lisha" and it is distributed to Maternal and Child Health (MCH) centers under the auspices of the Ministry of Health. It is intended to augment imported CSM under the Food For Peace Program. Because the cost of the locally made weaning food is less than the cost of imported commercial cereal based weaning foods, NMC has expressed interest in the possibility of the commercial marketing of "Lisha." The plant is currently idle because of management changes at the production site and interagency funding difficulties which prevent purchase and distribution of the product indicating the importance of developing an integrated implementation program, but is scheduled to reopen soon.

8.4 Guyana

The emphasis of the LEC program in Guyana is on production of a weaning food that is being sold at low cost through 1,200 retail outlets and distributed free through Maternal and Child Health Clinics with priority given to the mothers of malnourished children. The weaning food was developed by the government-owned Guyana Pharmaceutical Corporation (GPC) for the primary target group consisting of weaning age children. The product is being marketed as a baby cereal with the name Cerex. Samples of the package and promotional materials are displayed in Figure 7.

Figure 7. Cerex packaging and promotional materials.

The ingredients and the process being used to make Cerex are somewhat different from other LEC projects. In Guyana, they extrude a mixture of local rice, imported cornmeal and soy oil, and then blend in defatted soy flour, sugar, skim milk powder and vitamin, antioxidant and mineral premixes. The food is being packaged in one-half pound laminated plastic bags.

The LEC plant was made possible by a grant from USAID and is similar in design to those installed elsewhere using the Brady extruder. Because of the large quantity of blended ingredients, its design capacity is 818 kg/hr. GPC has built a second LEC plant to make breakfast cereal, an instant cornmeal, and other blended foods.

8.5 Other Commercial Applications

In addition to the LEC demonstrations described previously, several commercial installations have been installed and operated. The LEC has been successfully used to precook green peas in combination with a small quantity of whole soybeans to serve as the base for a dry soup base. Once precooked, these ingredients are ground and mixed with small quantities of NFDM, CSM and a spice mixture. More than 1,000 M.T. of the product have been manufactured by PRO-NUTRE in San Jose, Costa Rica, and distributed to schools by CARE/CR.

MAISOY in Santa Cruz, Bolivia, makes a series of products from blends of corn and soybeans using the Brady extruder. A partially expanded flake has been produced and sold as a RTE breakfast cereal. To achieve the proper flavor, sugar was added to the dry ingredients prior to extrusion to create the browning characteristic of a toasted breakfast cereal. The product is packaged in boxes with a polypropylene liner and sold in competition with imported products but at a substantially reduced cost. Additionally, beverage bases are being marketed.

CIATECH of Chihuahua, Mexico, has designed an LEC-FFSF processing plant at Delicias, Mexico, an agricultural cooperative. The product is being sold commercially to bakeries as an egg solids replacer, in small bags through retail grocer channels and as a major ingredient in a frozen ice cream-like product. Recipes have been developed and made available to consumers to help them use the soy flour in local dishes.

9.0 TECHNOLOGY TRANSFER

9.1 International Workshops

During the course of the project, two international workshops were convened on the role of low-cost extrusion cookers in producing nutritious food products from local ingredients in LDC's. The first one was held in Fort Collins, June 2-5, 1976. Fifty-three participants from around the world heard of the capabilities and limitations of the low-cost extrusion technology and the potential for this technique for areas of the developing world. The workshop ended with the participants developing priorities for future work on LEC's in the areas of: 1) product evaluation--nutritional and physical properties; 2) improvements in manufacturing operations, and 3) program assistance.

The Second International Workshop was held January 15-18, 1979, in Dar es Salaam, Tanzania, hosted by the National Milling Corporation and CSU. Forty-three participants related their first-hand experience with the LEC systems in LDC's. The extent of the utilization and experience with LEC's was a striking contrast to the first workshop where the focus had been on the potential. Following presentations by the participants, working groups identified a number of future LEC activities. These were categorized in the areas of: 1) process, 2) product, and 3) marketing.

The workshops served a vital role in the evaluation, information dissemination and transfer of the LEC technology. The project's activities were directed by inputs given by the potential user community. The complete proceedings of these workshops were published as LEC Reports 1 and 7 and over 1,200 copies of each were distributed throughout the world.

9.2 Technology Transfer Center

Over the duration of the LEC project, considerable experience and expertise has been developed with LEC applications. These experiences clearly point to the fact that successful project implementation requires the strong interest of an individual, organization or governmental agency in the LDC. Once a potential project has been identified, work is required to establish project management, material suppliers, product acceptability, product specifications, financing, plant design and construction, plant operations, etc.

Much of the expertise to perform these necessary functions exists in the LDC's. Successful transfer of technology requires that interested parties have access to technical assistance to provide any missing ingredients to assure a successful project. This could be done with a Technology Transfer Center for LEC applications. Numerous alternatives were considered for the organization and operation of such a center. Attempts to find initial start-up money to develop an operating base for the center were made. Currently, support for existing LEC installations and new applications is being provided by CSU under a new cooperative agreement between the USDA's Office of International Cooperation and Development with funds provided by the Office of Nutrition, AID, and cost recovery income from new LEC project assistance contracts.

Under this arrangement, Colorado State University stands prepared to assist others to apply the LEC technology to the production of nutritious foods in developing countries. Such services are available to all potential users including governmental agencies, PVO's, entrepreneurs and others on a cost-recovery basis. The extent of the technology transfer services required will depend on the needs of the intended consumer. Some of the technical services would include feasibility studies, nutritional consultation and evaluation, comparison of alternative processing systems, product development and evaluation, plant and process design, equipment specification and/or purchase, installation, training, start-up, and backstopping. Marketing and other commercialization advice could also be made available through CSU.

9.3 Modular Plant Design

To reduce plant design, equipment specification and construction costs, CSU has developed a modular plant design. Four basic modules have been designed including: 1) grain cleaning and dehulling, 2) processing, 3) cooling and grinding, and 4) packaging. The purpose of the modular approach was to facilitate the application of the technology into existing systems by making it easily adaptable to a variety of circumstances, to increase the flexibility of processing systems to manufacture a variety of products which would be suitable and acceptable in developing countries and to incorporate the best features of LEC plant designs tested to date.

The modular plant design includes the layout of equipment, equipment specifications, a general description of plant operations and pro forma plant economics. Using this design along with experience with LEC products, applications and operations, CSU is well prepared to provide technical assistance to interested parties throughout the world.

10.0 ADDITIONAL INFORMATION

10.1 Special Reports and Publications

LEC Report 1 -- Low-cost Extrusion Cookers International Workshop Proceedings, June 2-5, 1976

LEC Report 2 -- Evaluation of Low-cost Extrusion Cookers for Use in LDC's (Annual Report), April 1977

LEC Report 4 -- Evaluation of Low-cost Extrusion Cookers for Use in LDC's (Annual Report), July 1978

LEC Report 5 -- Mechanical Evaluation of Brady Crop Cooker #206 (Special Report), July 1978

LEC Report 6 -- Evaluation of Low-cost Extrusion Cookers for Use in LDC's (Annual Report), July 1979

LEC Report 7 -- Low-cost Extrusion Cookers Second International Workshop Proceedings, January 15-18, 1979

LEC Report 8 -- Effects of Extrusion on Calorie Density of Cereal and Cereal/Legume Blends (Special Report), May 1980

LEC Report 9 -- Evaluation of Low-cost Extrusion Cookers for Use in LDC's (Annual Report), December 1980

LEC Report 10 -- Nutritious Foods Produced by Low-cost Technology (Summary Report), April 1981

LEC Manual -- Part I, Management and Operation; and Part II, Equipment Operations; March 1979

10.2 Papers and Presentations

Tribelhorn, R. E., J. M. Harper and M. L. Stone. 1975. Use of simple cooker extruder to produce low-cost foods in LDC's. Presented at CSU Extension Conference, Colorado State University, Fort Collins, Colorado. April. Also presented at the Rocky Mountain Region Meeting of the American Society of Agricultural Engineers. Logan, Utah. April.

Tribelhorn, R. E., J. M. Harper and M. L. Stone. 1975. Evaluation of simple cooker extruders for use in LDC's. Paper No. 75-6522. Presented at the Winter Meeting of the American Society of Agricultural Engineers. Chicago, Illinois. December 15-18.

Stone, M. L., J. M. Harper and R. E. Tribelhorn. 1976. Costs associated with simple extrusion systems. Paper No. 13-06. Presented at the First International Congress on Engineering and Food. Boston, Massachusetts. August 9-13.

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Harper, J. M. and G. R. Jansen. 1977. Application of low-cost extrusion cookers to the production of blended foods. Presented at the Western Hemisphere Nutrition Congress. Quebec, Canada. August 15-18.

Jansen, G. R., J. M. Harper and L. A. O'Deen. 1977. Evaluation of full fat soy flour produced by dry heat processing. Presented at the Western Hemisphere Nutrition Congress. Quebec, Canada. August 15-18.

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Harper, J. M. 1980. The existing availability and capacity of cooker extruders including price, types of products and production cost. Proceedings of the ASEAN Workshop on Extruder Technology, Kasetsart University, Bangkok, Thailand. January 15-17.

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Information and/or publications are available by writing:

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