NASA-CR-167626

Final Report

For the Period February 1, 1980 to March 1, 1982

Contract NAS 9-16008

EVALUATION OF ENGINEERING FOODS FOR CLOSED ECOLOGICAL LIFE SUPPORT SYSTEM (CELSS)

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A. Introduction

The present contract is part of two phase effort to develop a system of conversion of locally regenerated raw materials and of resupplied freeze-dried foods and ingredients into acceptable, safe and nutritious engineered foods.

The First Phase of the proposed research lasted two years and had the following objectives:

1) Evaluation of feasibility of developing acceptable and reliable engineered foods from a limited selection of plants grown in the GBCD, supplemented by microbially produced nutrients and a minimum of dehydrated nutrient sources (especially those of animal origin).

2) Evaluation of research tasks and specifications of research projects to adapt present technology and food science to expected space conditions. In particular, problems arising from unusal gravity conditions, problems of limited size and the isolation of the food production system, and the opportunities of space conditions are to be considered.

3) Development of scenaria of agricultural production of plant and microbial systems, including the specifications of processing wastes to be recycled.

The Second Phase of the proposed work, if approved, would last three years, initiate upon the completion of the first phase, and include experimental production of engineered foods from specified ingredients.

To accomplish the objectives of the first phase of this research project, we have evaluated and developed a nutritionally adequate and acceptable diet for scenario II of Partially Closed Ecological Life Support System (PCELSS). In the most recent work we have concentrated on developing a design for a multipurpose food plant to perform the necessary food operations within the constraints of the proposed scenario for PCELSS.

Based on the assumptions we developed from previous work and frequent contacts with other workers involved in the CELSS program, we proposed the types and calculated the amounts of foods needed to be regenerated in PCELSS and/or resupplied from earth. We also considered, in detail, all steps of food processes to be utilized in the multipurpose food plant of PCELSS. Considering the mass balance of above processes, we chose appropriate, currently commercially available equipment. Specifications for above equipment were evaluated and analyzed.

As the next step we evaluated the potential simplification of the proposed processes. We finally evaluated and analyzed the food-waste treatment under the assumed conditions. The assumptions for the proposed space station were constantly modified and improved. It is important to realize that change of one assumption results in re-evaluation of most, if not all, of the proposed food-pilot plant. The work was reported in part in previous program reports sent to NASA Johnson Space center, as follows:

Progress	Report	#1	(7/1/80)	For	Period	of	2/1/80 to 5/1/80
"	"	#2	(10/7/80)	"	"	"	5/1/80 to 8/31/80
"	"	#3	(12/2/80)	"	"	"	9/1/80 to 11/30/80
"	"	#4	(2/26/81)	"	"	"	12/1/80 to 1/31/81
"	"	#5	(4/27/81)	"	"	"	2/1/81 to 4/30/81
"	"	#6	(7/31/81)	"	"	"	5/1/81 to 7/31/81
"	"	#7	(11/23/81)	"	"	"	8/1/81 to 11/15/81

The report on "Engineered Foods in PCELSS" which was submitted previously is also being enclosed as Appendix II to the present Final Report. During the first phase of this project, the principal investigator attended and presented lectures in two NASA-sponsored CELSS scientific conferences, held on May 3-6, 1981 in Durham, New Hampshire, and on January 24-27, 1981 in Moffett Field, California.

B. Background

Many food elements are needed to make up a diet which is nutritionally adequate. No single natural food supplied them all. Moreover, the nutritional requirements are different for the two sexes. They change with age; they vary with weight, activity, and environment. Individual differences in metabolism have a profound effect upon the utilization of various food elements. Hence, good nutrition is largely a matter of selecting those foods which together add up to meet the requirements of the individual in all the essential food elements. Important to good nutrition is also proper processing, preparation, and cooking foods so as to conserve their nutritive values.

For nutritional requirements of space habitats, we accepted the recommendation of the Food and Nutrition Board, National Academy of Sciences, National Research Council (Table 1, Ref. 9). For selection of quality and quantity of food items to provide such nutritional needs, we used the USDA "thrifty diet" (Table 2, Ref. 38) as the primary guideline. However, on the basis of recent review of probable Partially Closed Ecological Life Support System (PCELSS) directions, we greatly modified this food plan to meet our criteria. According to the Revised Scenario II of PCELSS, all of the plant food products (except tree fruits) are regenerated hydroponically in the space habitat.

All foods derived from animals are freeze-dried and periodically resupplied from earth. All present calculations are based on the assumptions listed below. As the knowledge of actual possibilities and constraints of the space habitat improves, so will the precision of such calculations.

Table 1. Recommended daily dietary allowances (for a normal healthy man aged 23-50 years with an average weight of 70 kg and average height of 178 cm) by Food and Nutrition Board, National Academy of Sciences, National Research Council (Ref. 9).

Energy	2700 Kcal
Protein	56 g
Vitamin A	1000 μg RE[a]
Vitamin D	5 μg[b]
Vitamin E	10 mg α-TE[c]
Ascorbic Acid (Vitamin C)	60 mg
Folacin	400 μg
Niacin	18 mg
Riboflavin (Vitamin B_2)	1.6 mg
Thiamin (Vitamin B_1)	1.4 mg
Vitamin B_6	2.2 mg
Vitamin B_{12}	3 μg
Calcium	800 mg
Phosphorus	800 mg
Iodine	150 μg
Iron	10 mg
Magnesium	350 mg
Zinc	15 mg

[a]Retinol equivalents. 1 retinol equivalent = 1 μg or 6 μg beta-carotene.

[b]As cholecalciferol. 10 μg cholecalciferol = 400 IU vitamin D.

[c]α-Tocopherol equivalents. 1 mg d-α-tocopherol = 1 mg α-TE.

TABLE 2--Thrifty Food Plan (Ref. 38)

Family member	Amounts of food for a week [1]													
	Milk, cheese, ice cream [2]	Meat, poultry, fish [3]	Eggs	Dry beans and peas, nuts [4]	Dark-green, deep-yellow vegetables	Citrus fruit, tomatoes	Potatoes	Other vegetables, fruit	Cereal	Flour	Bread	Other bakery products	Fats, oils	Sugar, sweets
	Qt	*Lb*	*No*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*
Child:														
7 months to 1 year	5.0	0.39	1.2	0.15	0.41	0.55	0.09	2.49	[5] 1.02	0.02	0.08	0.04	0.04	0.19
1-2 years	3.3	.83	3.3	.17	.22	.89	.65	2.26	[5] 1.02	.31	.78	.24	.11	.30
3-5 years	3.5	.95	2.5	.28	.20	.92	.88	2.28	1.03	.37	.94	.53	.38	.74
6-8 years	4.2	1.27	2.4	.49	.22	1.10	1.23	2.50	1.12	.62	1.42	.79	.51	.94
9-11 years	4.9	1.61	3.4	.53	.28	1.52	1.48	3.38	1.34	.81	1.82	1.10	.60	1.20
Male:														
12-14 years	5.2	1.79	3.6	.67	.23	1.45	1.59	3.30	1.22	.81	2.07	1.13	.77	1.21
15-19 years	5.1	2.35	4.0	.43	.32	1.70	2.10	3.43	.98	.99	2.36	1.46	1.00	1.05
20-54 years	2.6	3.03	4.0	.44	.39	1.80	2.02	3.69	.89	.92	2.29	1.33	.95	.86
55 years and over	2.4	2.45	4.0	.25	.51	1.85	1.75	3.77	1.09	.80	1.90	1.12	.79	.91
Female:														
12-19 years	5.4	1.80	3.8	.28	.42	1.74	1.22	3.61	.72	.76	1.49	.84	.51	.74
20-54 years	2.8	2.41	4.0	.27	.52	1.86	1.51	3.39	.90	.67	1.11	.67	.57	.57
55 years and over	2.8	1.84	4.0	.19	.60	2.02	1.26	3.73	1.12	.68	1.30	.58	.37	.45
Pregnant	[6] 5.2	2.69	4.0	.42	.56	2.17	1.89	4.03	1.13	.58	1.41	.66	.59	.58
Nursing	[6] 5.2	3.00	4.0	.38	.57	2.36	1.92	4.27	.98	.63	1.56	.82	.80	.75
Total														

[1] Amounts are for food as purchased or brought into the kitchen from garden or farm. Amounts allow for a discard of about 5 percent of the *edible* food as plate waste, spoilage, etc. For general use, round the total amount of food groups for the family to the nearest tenth or quarter of a pound. In addition to groups shown, most families use some other foods: coffee, tea, cocoa, soft drinks, punches, ades, leavening agents, and seasonings.

[2] Fluid milk and beverage made from dry or evaporated milk. Cheese and ice cream may replace some milk. Count as equivalent to a quart of fluid milk: natural or processed Cheddar-type cheese, 6 ounces; cottage cheese, 2½ pounds, ice cream or ice milk, 1½ quarts; unflavored yogurt, 4 cups.

[3] Bacon and salt pork should not exceed ⅓ pound for each 5 pounds of this group.

[4] Weight in terms of dry beans and peas, shelled nuts, and peanut butter. Count 1 pound of canned dry beans, such as pork and beans or kidney beans, as .33 pound

[5] Cereal fortified with iron is recommended.

[6] For pregnant and nursing teenagers, 7 quarts is recommended.

C. Assumptions

1) Food products for the space habitants are presented in Table 3. To minimize the amount of animal-derived foods to be resupplied from the Earth, we accepted half of the thrifty diet values. This, however, does not impair the quality of diet since 34.7 g (see Table 4) or 62% of the minimum daily protein requirement, i.e., 56 g (Table 1) is secured from the highest quality animal sources (milk products, meat products, and eggs). Soy and single-cell protein, generated in PCELSS, also present high quality protein, and the total daily dietary protein is much higher than the recommended values.

2) Dry beans, peas, and nuts in thrifty diet are substituted by soy protein isolate produced by aqueous extraction method. Flour consumption was assumed to be 300 g per person per day. Values for tomatoes, fats and oils were accepted as in the thrifty diet. Sugar consumption was doubled and that of potatoes increased by 50% to meet the energy requirement. A portion of dietary protein is planned to be supplied by non-conventional protein sources such as single-cell protein (SCP). Fruits and vegetables, though limited in varieties, are considered adequate for the nutritional quality of the diet.

3) Calculations of energy and protein of the revised diet ingredients, shown in Table 3 are presented in Table 4. The minimum nutritional requirements for a healthy 23-50 year-old man are met. Most of the required vitamins and minerals are provided

by consumption of the suggested food items. However, extra requirements due to environmental stresses will be supplied from Earth. The revised diet together with resupplied vitamin and mineral supplementary pills (see miscellaneous item, Table 3) presents a nutritionally adequate and acceptable diet under the PCELSS conditions.

4) The total population of the space habitat is 20. For diet calculations a normal, healthy man (23-50 years old with an average weight of 70 kg and average height of 178 cm) is assumed. This conservative assumption prevents any underestimating of the total needed food.

5) Considering the limitations with regard to food resupply frequency and food regeneration in space habitat (manpower, equipment, storage area, etc.), all our calculations are based on "10-days' consumption". However, food resupply and regeneration patterns could be adapted according to desirable programs (e.g. food resupply from Earth can be done 2-12 times per year). This is because the short 10-days' processing cycle needs smaller and lighter equipment, smaller storage areas, less manpower, etc. It is also consistent with our understanding of the plans of the "food production" planning groups.

6a) The minimum variety of plants which provide nutritional requirements will be grown in space habitat. This includes three items (except SCP) to be processed further in a processing plant (wheat, sugar beet, and soybean) and five items to be consumed fresh or after preparation in the kitchen (tomatoes, potatoes, lettuce, onions, and strawberries).

6b) Raw materials which are regenerated in space habitat (e.g. sugar beets, wheat, and soybeans) are delivered to storage areas for raw materials having capacity for storing materials needed for 10-days' operation.

6c) Raw materials are regenerated in space habitat "farm" and then delivered to the first storage room (grains, vegetables, fruits, etc.) are pre-cleaned as normally observed in wholesale trade. These operations are to be defined by the "Production" planning groups. However, all the raw materials which enter the plant are cleaned and wastes of the cleaning steps as well as non-usable by-products will be delivered to waste recycling (W.R.).

7) All products made from wheat will use "whole-wheat flour" prepared as in standard wheat milling technology. This decreases the solid waste and needed equipment. For sugar extraction and refining, conventional processing is assumed. For oil extraction from soybeans, however, an aqueous extraction (to minimize chemical use) with only about 65% recovery is assumed.

8) Processed foods leave the plant to the finished product storage areas. These storage areas have as stock, at all times, foods needed for 10-days' of consumption. We assume the need to package the stored foods. Packages for storage of these processed foods are supplied from Earth, and will be light, air-tight, and re-usable. Filling of processed foods in packages will be done with a minimum of automatic equipment.

9) For our assumed conditions, preservation of the locally harvested items for extended storage has not been considered. If population of the colony is over 100 people, then some degree

of mechanization will be required to decrease the labor involved in food preparation. Freezing or canning might be required to avoid shortages of some of the commodities produced on board.

10) Freeze-dried foods resupplied from Earth, except butter and miscellaneous items, contain 3% moisture (wet basis). These foods are in ready-to-use shape upon rehydration.

11) The original "thrifty diet" allows discard of 5% of the "edible" food as "spoilage and plate waste". We, however, assume "zero waste" for "spoilage and plate waste". This will increase the efficiency of food production and waste recycling in PCELSS. Our calculations for food waste during processing and preparation is based on data presented in Appendix I of this report.

Table 3. Food plan according to PCELSS Revised Scenario II. Products marked with an asterisk (*) are resupplied from Earth.

Food Products	Amount (person^{-1} · week^{-1})		Weight (g · person^{-1} · day^{-1})	Comment
*MILK PRODUCTS	1.3 qt	1230.5 g	175.8	For fluid milk, ref (1) item 1320
fluid milk			135.8	For conversion to cheddar cheese see footnote (1) of Thrifty Food Plan (Table 2). See also ref (1)(item 646e).
cheese			7.5	No ice cream
*MEAT PRODUCTS (boneless)	1.51 lb	685.0 g	97.9	For beef, ref (1) item 352b (round steak)
beef			50.0	For pork, ref (1) item 1715b (loin)
pork			10.4	For chicken, ref (1) item 685c (40% refuse for bone and skin)
poultry			50.0	
fish			7.5	For fish, ref (1) item 795b
*EGGS	2.0	114.0 g	16.3	Ref (1) item 968b (large egg = 57 g) (12% refuse for shell)
FLOUR (bread, cereal, bakery products, etc.)			300.0	Ref (1) item 2435. Whole wheat flour (100% extraction) is used for all purposes. Rice consumption is also considered as flour.
FATS & OILS	0.95 lb	431.0 g	61.6	Butter, ref (1) item 505
*butter			30.8	Soybean, ref (1) items 2139 & 1401 (Composition: fat 18%, protein 34%, water 10%). Assume 65% oil and 55% protein extraction by non-solvent aqueous method ref (2).
soy oil			30.8 (from 263 g soybean)	
SOY PROTEIN ISOLATE			49.2 (from 263 g soybean)	Ref (27)
SUGAR	1.72 lb	780 g	111.4 (from 891 g beets)	Ref (5) based on 12.5% sugar extraction from beets.
SCP (torula yeast)			20	Ref (1) item 2479
VEGETABLES & FRUITS:				
tomatoes	1.8 lb	816 g	116.6	Ref (1) item 2282, 3% refuse
potatoes	3.03 lb	1374 g	231.0	Ref (1) item 1785, 10% refuse
lettuce			50.0	Ref (1) item 1258a (iceberg), 10% refuse
onions			30.0	Ref (1) item 1412a, 5% refuse
strawberries			50.0	Ref (1) item 2217a, 6% refuse
*MISCELLANEOUS:			100.0	
a) food items (coffee, tea, spices, salt, soda powder, and vitamin and mineral pills)			50.0	
b) food-processing support items (dry yeast, baking powder, emulsifiers, antioxidants, cleaning agents, membranes, etc.)			50.0	

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Table 4. Calculation of the total daily energy and protein intake products marked with an asterisk (*) are resupplied from earth.

Food Item	Energy (Kcal)		Protein (g)		Comment
	per 100 g	amount	per 100 g	amount	
*MILK PRODUCTS					
fluid milk	65	88.3	3.5	4.8	
cheese	397	29.8	25.1	1.9	
*MEAT PRODUCTS					
beef	197	98.5	20.2	10.1	
pork	298	31.0	17.1	1.8	
poultry	136	68.0	23.8	11.9	
fish	170	12.8	28.5	2.1	
*EGGS	163	25.6	13.0	2.1	
				34.7	subtotal
FLOUR	333.3	1000.0	13.3	39.9	
FATS & OILS					
*butter	716	220.5	0.6	0.2	
soy oil	884	272.3	-	-	
SOY PROTEIN	412	238.5	85.0	41.8	contains 8% oil (Ref 27)
SUGAR	385	428.9	-	-	
SCP	282	56.4	39.0	7.8	
FRUITS & VEGETABLES					
tomatoes	20	22.6	1.0	1.1	
potatoes	57.2	118.9	1.6	3.3	
lettuce	12.3	5.5	0.8	0.4	
onion	38.2	10.9	1.5	0.4	
strawberries	35.6	16.7	0.7	0.3	
*MISCELLANEOUS	0.0	0.0	0.0	0.0	
Total		2745.2		129.9	

D. Calculation of Food Resupply and Regeneration in PCELSS

1) Calculation of "10-days'" food products to be "resupplied" from Earth (Table 5a).

2) Calculation of "10-days'" food products to be "regenerated" on board (Table 5b).

3) Schematic of overall food mass balance in space habitat (Figure 1).

Table 5B. "10-days " food production in PCELSS (20 inhabitants)

A	B	C (FOOD)		D (FOOD)		E	F
		water		solid		net amount consumed (kg) (B-waste*)	
		a	b	a	b		
Food Product	amount (kg)	%	amount (kg)	%	amount (kg)		Comment
WHEAT	60.0	12.0	7.2	88.0	52.8	-	
flour	-	12.0	7.2	88.0	52.8	60.0	
SOYBEAN	52.6	10.0	5.3	90.0	47.3	-	
soy oil	-	0.0	0.0	100.0	6.2	6.2	65% extraction of oil by aqueous method.
soy protein	-	5.0	0.5	95.0	9.3	9.8	55% extraction of protein by aqueous method.
SUGAR BEET	178.2	79.0	140.8	21.0	37.4	-	12.5% sugar extraction
sugar	-	0.5	0.1	99.5	22.2	22.3	
CELL CULTURE	150.0**	97.0	145.5	3.0	4.5	-	
s.c.p.	-	5.0	0.2	95.0	3.8	4.0	2.67% Efficiency of SCP from cell culture.
tomatoes	23.3	93.5	21.8	6.5	1.5	22.6	
potatoes	46.2	79.8	36.9	20.2	9.3	41.6	
lettuce	10.0	95.5	9.5	4.5	0.5	9.0	
onion	6.0	89.1	5.3	10.9	0.7	5.7	
straw-berries	10.0	89.9	9.0	10.1	1.0	9.4	
TOTAL	386.3					190.6	

*See Appendix I of this report.

**Used from food wastes, not included in total.

Table 5A. "10-days " food product deliveries to PCELSS from earth (20 inhabitants)

A	B	C		D		E	F	G	H
		Water		Solid					
		a	b	a	b				
Food Product	net amount consumed (kg)	%	amount (kg)	%	amount (kg)	freeze dried food supplied with 3% water (kg) (D_b ÷ 0.97)	Water remaining in supplied food (kg) ($E - D_b$)	Water to rehydrate foods in space ($C_b - F$)	Comment
MILK PRODUCTS									
fluid milk	27.2	87.4	23.8	12.6	3.4	3.5	0.1	23.7	We assumed an average moisture content of 3% for all freeze dried foods (except butter). which are supplied from earth For water and solids content see ref (1).
cheese	1.5	37.0	0.6	63.0	0.9	0.9	0.0	0.6	
butter	6.2	15.5	1.0	84.5	5.2	5.4	0.2	0.8	
MEAT PRODUCTS									
beef	10.0	66.6	6.7	33.4	3.3	3.4	0.1	6.6	
pork	2.1	57.2	1.2	42.8	0.9	0.9	0.0	1.2	
poultry	10.0	71.0	7.1	29.0	2.9	3.0	0.1	7.0	
fish	1.5	64.6	1.0	35.4	0.5	0.5	0.0	1.0	
EGGS	3.3	73.7	2.4	26.3	0.9	0.9	0.0	2.4	
MISCELLANEOUS	12.0	3.0	0.4	97.0	11.6	12.0	0.4	0.0	We assumed that butter and miscellaneous items do not need to be rehydrated in space.
Total	73.8					30.5		43.3	

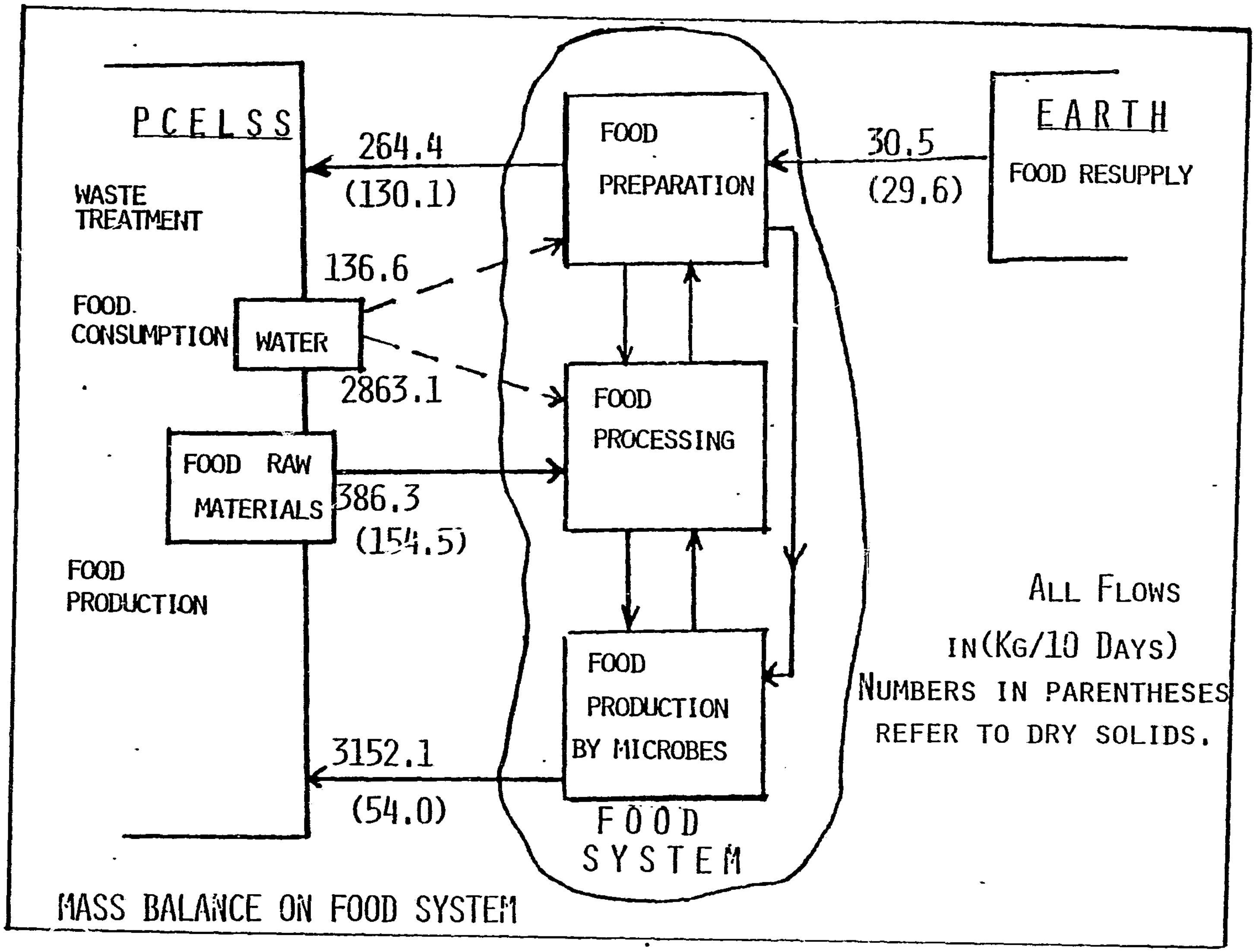


Fig. 1. Overall calculation of "10-day" food resupply and regeneration, in kg for 20 people in space habitat (PCELSS, revised Scenario II)

E. Flow Charts of Food Processes in Multipurpose Food Plant for Space Habitat (PCELSS, Scenario II)

All fruits and vegetables do not need any processing, but are prepared for consumption in the kitchen. There are three raw materials (wheat, sugarbeet, and soybean) to be processed in PCELSS pilot plant for production of foods such as flour, bread, cereal, sugar, oil, soy protein isolate, and fabricated foods. The waste material of these processes will be used to grow SCP which in turn can be used in fabricated foods or mixed with other food ingredients. The overall schematic of these processes is shown in Fig. 2.

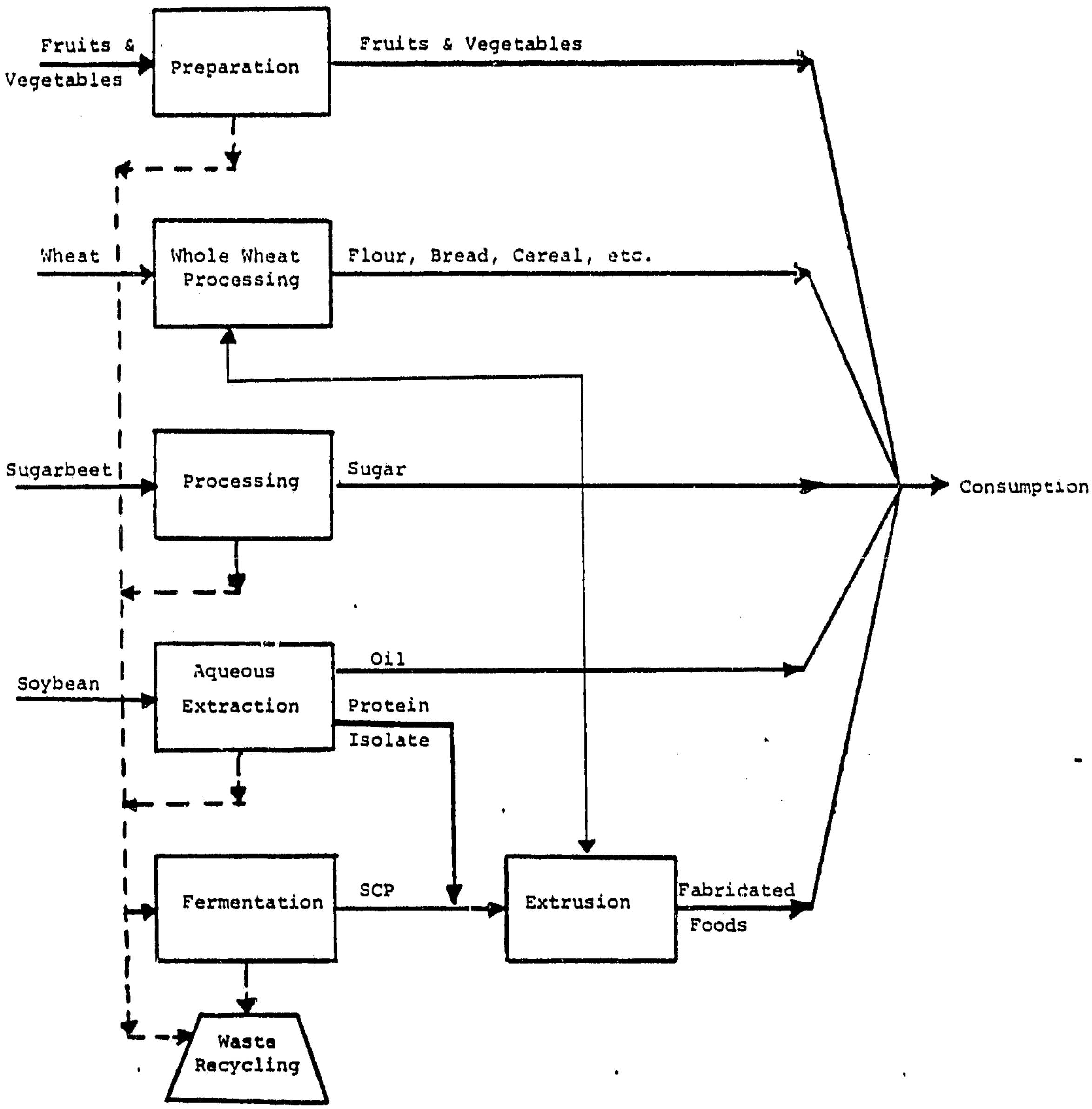


Fig. 2. Overall schematic of food processes to be operated in PCELSS (—— raw material or product; --- waste material).

Flow Chart for the Unit Operation of "Grain (Wheat) Milling" in Space Habitat (PCELSS, Revised Scenario II)
(Ref 3, 13, 19)

A. Assumptions

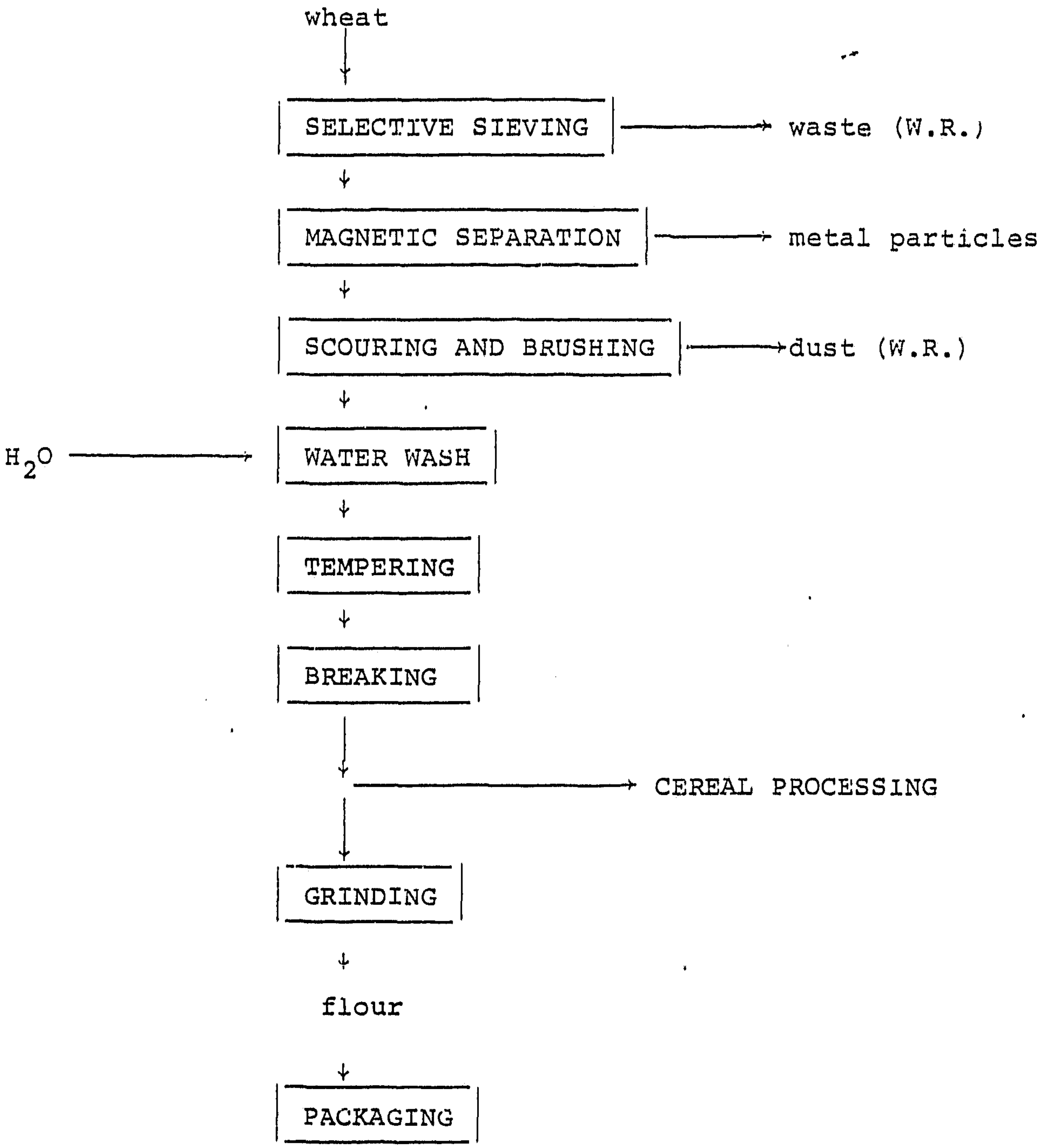
1) Grain (wheat) will be delivered from the "farm" harvested, threshed, pre-cleaned and dried (consideration should be given to direct solar drying of the grains).

2) All products made from wheat (bread, cereal, etc.) will use "whole-wheat flour" as in standard wheat milling technology. This decreases the solid waste and needed equipment.

3) The total wheat consumption (based on whole-wheat, 100% extraction) in the diet will be 300 (g/person · day) or 60 (kg/20 inhabitants · 10 days).

4) Wheat is harvested and processed once per "10 days" and consequently the milling equipment should have the capacity to process 60 kg wheat in one series of operation.

B. Material Flow Chart for Wheat Milling (W.R. = waste recycling)



Flow Chart for the Unit Operation of "Bread Baking" in Space Habitat (PCELSS, Scenario II)

(Ref 28, 29)

A. Assumptions

1) The bread is made by the "straight dough method". This procedure is simpler than the sponge dough method. All the ingredients are added at the start of the line.

2) The total bread consumption in the diet will be 150.0 (g/person · day) or 6.0 (kg/20 inhabitants · 2 days).

3) Bread is baked every other day (5 times per 10 days) and consequently the baking equipment should have the capacity to process 6 kg bread in one series of operations.

B. Material Flow Chart for Bread Baking (W.R. = waste recycling)

flour
yeast
yeast nutrient
malt
milk
salt
sugar
shortening
water

MIXING OF INGREDIENTS

↓

FERMENTATION AT 80°F AND 76% R.H. (3-4 hr)

↓

MIXING (DOUGH FORMATION)

↓

DOUGH DIVIDING

↓

ROUNDING

↓

INTERMEDIATE PROOF

↓

MOLDING

↓

PANNING

↓

PAN PROOF

↓

BAKING

↓ bread

COOLING

↓

PACKAGING

Flow Chart for the Unit Operation of "Breakfast Cereal Manufacturing" in Space Habitat (PCELSS, Scenario II)
(Ref. 13, 30)

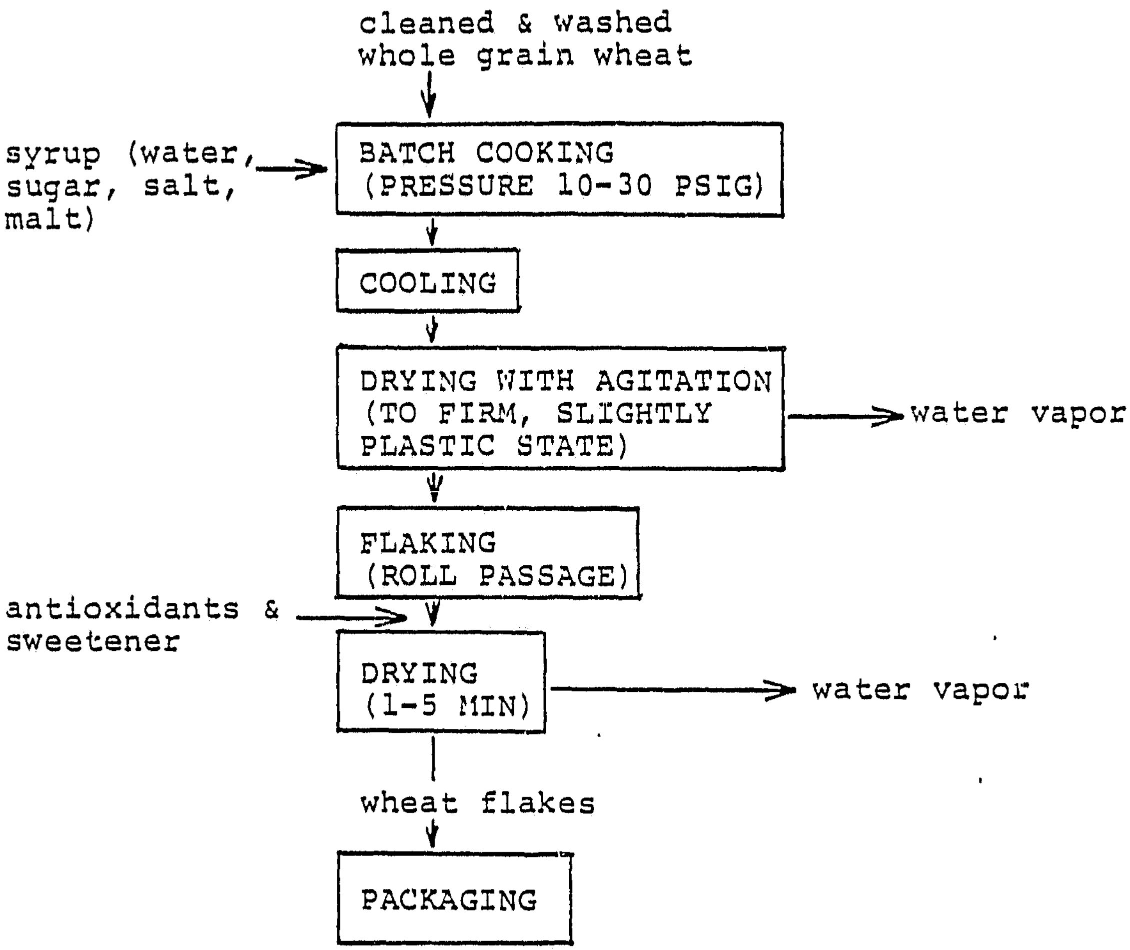
A. Assumptions

1) The total breakfast cereal consumption in the diet will be 50.0 (g/person · day) or 10.0 (kg/20 inhabitants · 10 days).

2) Breakfast cereal is prepared once per 10 days, and consequently the equipment should have the capacity to prepare 10.0 kg breakfast cereal in one series of operations.

3) The dry breakfast cereal will be lightly-presweetened flakes from whole wheat, a 100% wheat cereal. "Flakes" are preferred over other types of cereal such as "puffs", "shredded" and "granules" because the process is simpler and equipment from other processes can be used for "flake" preparation.

B. Material Flow in Manufacture of Wheat Flakes



Flow Chart for the Unit Operation of "Beet Sugar Manufacturing" in Space Habitat (PCELSS, Revised Scenario II)
(Ref. 4, 20, 41)

A. Assumptions

The entire process of preparation of sugar from beets can be done in a single, integrated operation, without intermediate production of raw sugar.

The following assumptions were used:

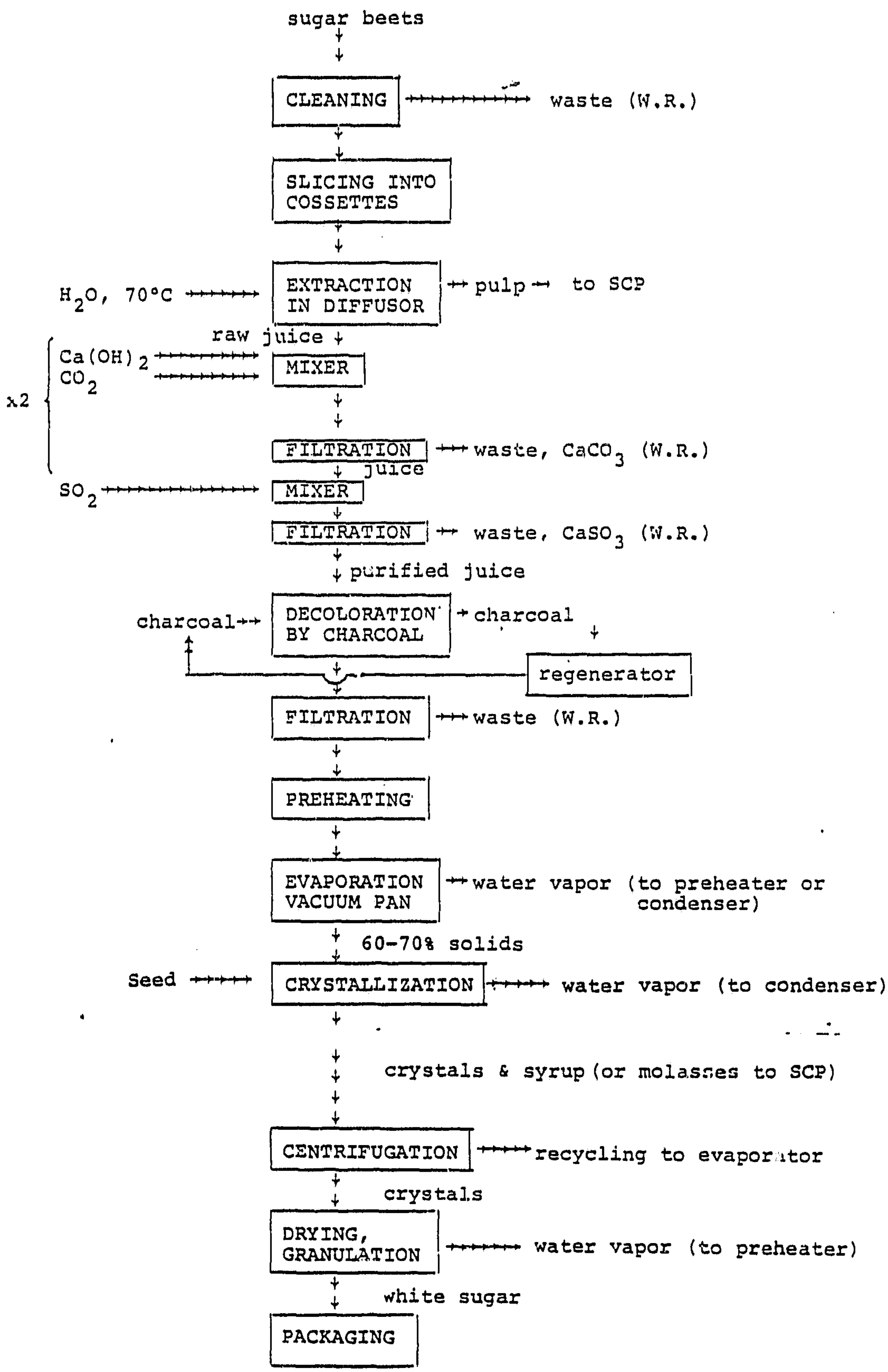
1) Sugar beets contain 16-20% of sugar as sucrose.

2) Sugar beets will be delivered from the "farm" harvested and pre-cleaned. All other plant parts (leaves, stems, etc.) are already removed.

3) The total pre-cleaned sugar beet requirement (12.5% sugar extraction is assumed) is 891 (g/person • day) or 178.2 (kg/20 inhabitants • 10 days).

4) Sugar beet is harvested once every 10 days and consequently the sugar manufacturing equipment should have the capacity to process 178.2 kg cleaned sugar beet in one series of operations.

B. Material Flow Chart for Beet Sugar (W.R. = waste recycling)



Flow Chart for the Unit Operation of "Aqueous Oil Extraction from Soybeans" in Space Habitat (PCELSS, Revised Scenario II)
(Ref. 5, 24, 25, 27)

A. Introduction

The overall advantages and disadvantages of aqueous oil extraction over conventional solvent extraction for use in space habitat may be summarized as follows:

Advantages:

1) Safety: Since a flammable solvent is not being used in the process, there is less fire hazard, less operational danger, and no air pollution from solvent losses.

2) Simplicity: Simultaneous separation of oil and protein in this process needs fewer processing steps than in conventional isolate production, i.e., solvent extraction and desolventization are eliminated and, also, the capability of discontinuous small-scale operation.

3) Adaptability: The required simple equipment for this process can be adapted for the other processes and vice versa.

4) Efficiency: The process is energy-efficient since there is neither solvent recovery nor meal desolventizing steps. The process also seems to require less initial capital investment.

Disadvantages:

1) Lower efficiency in oil and protein extraction, recovery, and purity (e.g. 65% extraction of initial soybean oil). The overall efficiency of the process is critically dependent upon several unit operations: grinding, solid-liquid separation, centrifugation, demulsification, and drying of products.

2) Higher oil content of protein products which can cause storage stability problems.

3) Necessity of demulsification to recover oil in case of emulsion formation.

4) Increased potential for microbial contamination because the materials undergo more processing steps while wet.

Considering the limitations of space habitat, it becomes clear that the said advantages overweight the disadvantages and consequently this process is recommended for oil and protein extraction.

B. Assumptions

1) Soybeans will be delivered from the "farm" harvested, and pre-cleaned. All other plant parts (leaves, stems, etc.) are already removed.

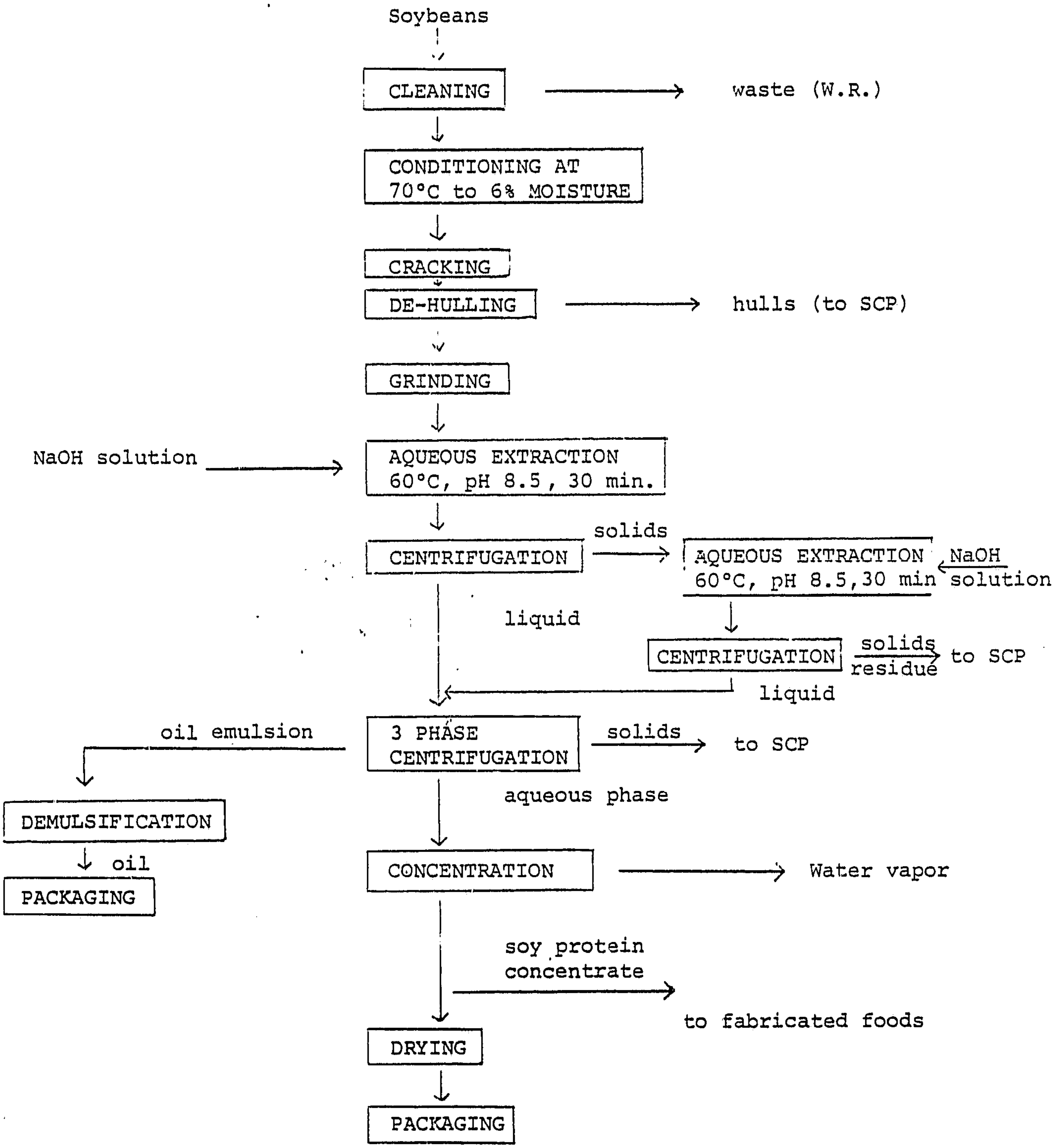
2) The soybean protein isolate contains at least 55% of the original soy protein, on a dry solid basis, and its protein content is at least 85%.

3) The total cleaned soybean consumption is 263 (g/person · day) or 52.6 (kg/20 inhabitants · 10 days).

4) The total amount of soy-derived products are 6.2 (kg oil/20 inhabitants · 10 days) and 9.8 (kg protein isolate/20 inhabitants · 10 days).

5) Soybeans are harvested once per 10 days and consequently the oil and protein manufacturing equipment should have the capacity to process 52.6 kg cleaned soybeans in one series of operations.

C. Material Flow for "Aqueous Oil Extraction" (W.R. = waste recycling,



Flow Chart for the Unit Operation of SCP (torula yeast) Production from Food Waste Material in Space Habitat (PCELSS, Scenario II)
(Ref. 11, 17, 31, 45, 47)

A. Assumptions

1) Waste materials from fruit and vegetable preparation as well as those from sugar beet and soybean processing will be converted to a suitable substrate for SCP production.

2) SCP is produced once every ten days and consequently the manufacturing equipment should have the capacity to process 4.0 kg dried SCP in one series of operations.

3) Total food waste material will be enough for production of 4 kg dried SCP/20 inhabitants • 10 days.

B. Flow Chart for SCP Processing

Food wastes as suitable substrate → FERMENTATION (30°C, 40 hr, pH 5) ← cell culture

↓

cells in spent growth medium

↓

HEAT SHOCKING (66-70°C, 3-5 sec)

↓

COOLING (to 53°C)

↓

INCUBATION (53°C, 2 hrs, pH 4.5-7)

↓

SEPARATION (e.g. centrifugation) → waste

↓

cells → WASHING ← water

WASHING → SEPARATION

cells

↓

DISINTEGRATION → to fabricated foods

↓ SCP

CONCENTRATION

↓

DRYING

PACKAGING

Flow Chart for Preparation of "Fabricated Foods (Based on Soy Isolate from Aqueous Oil Extraction and SCP)" in Space Habitat (PCELSS, Scenario II)
(Ref. 11, 12, 22, 23, 39, 43, 45)

A. Introduction

There are two approaches to prepare high-protein fabricated foods:

1) To prepare analogs such as those for meat, dry soups, flake breakfast cereal, pasta products, etc.

2) New products with no counterpart in nature. Since eating habits cannot be dramatically changed over a short period of time, it seems necessary to produce analogs.

Functional properties of soy isolate, prepared by aqueous oil extraction, such as solubility, water and fat binding viscosity, gelation, etc. (which can all be affected by the pH and temperature conditions during extraction) should be closely examined and modified, if possible, for different products.

B. Assumptions

1) Soy isolate from aqueous oil extraction process (9.8 kg/20 inhabitants · 10 days) and the yeast from SCP (4.0 kg/20 inhabitants · 10 days) will be used as base materials for production of fabricated foods.

2) Since soybean and SCP are produced only once every 10 days, the fabricated foods are also produced once every 10 days and the relevant equipment should have a capacity to process at least 13.8 kg fabricated food (based on dry weight).

3) Extrusion is selected as the method of production for engineered foods in PCELSS. For meat analogs the indirect (viscous-

drag) single-screw extruders are suitable (Rossen and Miller, 1973). The advantages of extrusion are as follows:

a. Large number of raw materials can be processed.

b. Process conditions (pH, temperature, etc.) can be modified to obtain a large variety of products with different forms, shapes, densities, and textures. However, for the sake of simplicity we can assume that only meat analogs are fabricated at this stage.

c. Equipment requirements are minimal and can be used for other purposes.

d. HTST extrusion cookers do not harm protein quality and minimize nutrient losses such as vitamins, particularly if they are encapsulated.

e. Simultaneous gelatinization, expansion, formation and texturization of cereals or starches in mixture with proteins or alone.

4) Soy proteins derived from aqueous oil extraction, have the same, if not better, functionality as those from solvent extracted materials. We know, however, that solvents do modify the properties of protein materials.

5) Yeast proteins have water and oil binding properties like soy protein and can be texturized by extrusion technique to produce varieties of products.

C. <u>Extrusion of Fabricated Foods</u>

soy isolate and SCP in
aqueous dispersion

↓

H_2O → MIXING ← other desirable ingredients

↓

additives
(binders, color, → EXTRUSION (T = 110-175°C P = 1000 psi) → volatile flavors and water vapor is flashed off
flavor, etc.)

↓

SIZE REDUCTION

↓

PACKAGING

F. Equipment for Multipurpose Food Plant

The general requirements for space habitat food processing are shown in Table 6. Using these criteria, we developed general specifications for equipment needed for each operational step of the previously discussed processes. Tables 7A through 7G present these specifications, including construction materials, maximum dimensions, maximum weight, and operational capacity. Specificatons of all equipment is summarized on page 48 . Common parts such as pipes, conveyors, pumps, containers, and other minor accessories are not presented in the above tables.

It is extremely important to note that, as the first step, selection of those equipment items has been based on commercially-available equipment currently used by the food industry. Some manufacturers of food processing machinery are listed as examples of potential sources of technical "know-how" in this field (Table 8). The number of equipment items was minimized by utilizing each one for various steps of all process operations.

Fig. 3 shows the combined food material flow charts for all steps of all processes.

Due to weight-transport limitations of the space habitat, research is needed to find a suitable light substitute at least for those metallic (usually stainless steel) parts of equipment which are not in contact with food. It is obvious that the optimization of equipment design, and especially unique multi-functionality needed under space conditions, and also application of maximum automation would be additional major tasks for future research.

Table 6. Requirements for food processes and equipment in space plant

A. Flexibility and versatility (multifunctionality)

B. Small scale of operations

C. Adaptation to habitat conditions

1. Lack of chemical and noise pollution
2. Reduced atmospheric pressure operation
3. Different "gravity" conditions
4. Utilization of solar energy (direct and indirect) and "hard vacuum"
5. Provision for "maximum possible recycling"
6. Area, volume and equipment configuration
7. Crew-size requirements (capacity)

D. Adaptation to "remoteness" from earth industries

1. Maintenance and replacement of parts
2. Fail-safe operations
3. Simplicity
4. Minimize the utilization of chemicals

E. Provide capability for modification: Provide for "the unexpected"

Table 7A. Equipment specifications for wheat milling process

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Selective sieving	Laboratory sifter	Koppers Engineering	Stainless steel	78x55x58 ($0.25m^3$)	136	25 kg/h	Can also be used for sieving of wheat flour
Magnetic separation	A long strong magnet						
Washing	Steam jacketed sanitary agitator kettle with controlled pressure	Groen Div., Dover Corp. Model RA	Stainless steel	127x127x216 ($3.5m^3$)	727	756 l	This item is also used for washing of beets, extraction, mixing, evaporation and crystallization in sugar process and, evaporation in soybean and SCP processes.
Dewatering	Centrifuge	Dorr-Oliver Mercone 250	Stainless steel	117x61x155 ($1.11m^3$)	453	4-100 lpm	This item can also be used to separate beet pulp from sugar juice, lime mud from sugar juice and sugar crystals from molasses in sugar process. Separation of solid from liquid phase in soybean process and yeast harvesting in SCP process.
Tempering	Constant temperature cabinet w/ humidity adjustments	Hot-pack Corp. Model 212041	Stainless steel	102x79x165 ($1.33m^3$)	280	270 l	This item can also be used for dough proofing and bread baking. Drying of wheat flakes cereal and sugar, conditioning of soybeans and drying of soy isolate and SCP.
Milling	Laboratory refiner attrition mill	Koppers Engineering	Stainless steel	105x45x75 ($0.35m^3$)	227	variable	This item can also be used for cracking and grinding of soybeans and also for grinding of waste material for SCP substrate.
Sieving	As in the selective sieving step						

Table 7B. Equipment specifications for bread baking process

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Mixing	Mixer, jacketed vacuumable	Stephan Machinery Corp. model UM40E	Stainless steel	100x135x154 ($2.08m^3$)	220	40 l	This item can also be used for dough fermentation, cooking, and drying w/ agitation in the wheat flakes cereal process and mixing in the fabricated food process.
Fermentation	As in above step						
Dough dividing	Manually						
Rounding	Manually						
Proofing	As in tempering step in wheat milling process						
Baking	As in tempering step in wheat milling process						

Table 7C. Equipment specifications for wheat flakes cereal process

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Cooking	As in mixing step in bread baking process						
Cooling	As in above step						
Drying w/ Agitation	As in above step						
Flaking	Laboratory pelletizer	C.W. Brabender Instrument, Model 1-16	Steel, Rubber	64x54x117 ($0.4 m^3$)	80 kg	Variable	
Drying	As in tempering step in wheat milling process						

Table 7D. Equipment specifications for sugar beet process

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Washing	As in washing step in wheat milling process						
Slicing	Cutter	Urschel Labs. GRL Cutter	Stainless steel	124x160x132 ($2.62m^3$)	372	Variable	This item can also be used for slicing french fried potatoes
Extraction 1	As in washing step in wheat milling process						This process due to capacity limitation is done in two steps
Extraction 2	As in above step						
Mixing	As in above step						
Filtration (pulp-juice, lime mud-juice)	As in dewatering step in wheat milling process						
Decoloration	Activated carbon cartridge	AMF-Cuno 46285-01 in 4DC1 filter	Activated carbon, plastic & stainless steel	27x27x49 ($0.04m^3$)	15	45 lpm liquid at 6 psi	
preheating	As in washing step in wheat milling process						

Table 7D. Equipment specifications for sugar beet process (cont.)

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Evaporation	As in above step						
Crystallization	As in above step						
Centrifugation	As in dewatering step in wheat milling process						
Drying	As in tempering step in wheat milling process						

Table 72. Equipment specifications for soybean process

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Conditioning	As in tempering step in wheat milling process						
Cracking	As in milling step in wheat milling process						
De-Hulling	Air or vacuum separator						
Grinding	As in milling step in wheat milling process						
Extraction 1	As in washing step in wheat milling process						
Extraction 2	As in above step						
Centrifugation 1	As in dewatering step in wheat milling process						
Centrifugation 2	As in above step						
Concentration	As in washing step in wheat milling process						
Drying	As in tempering step in wheat milling process						

Table 7F. Equipment specifications for single cell protein process

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Fermentation	250 l tank	Chempac, Inc.	Stainless steel			250 l	
Incubation	As in washing step in wheat milling process						
Separation	As in dewatering step in wheat milling process (w/ modification)						
Washing	As in washing step in wheat milling process						
Disintegration	Mill	Impandex, Inc. Dyno Mill Type KD5	Stainless steel	95x67x145 ($0.92 m^3$)	350	50 l/h	
Concentration	As in washing step in wheat milling process						
Drying	As in tempering step in wheat milling process						

Table 7G. Equipment specifications for fabricated food process

Operational Step	Required Equipment	Example of Equipment Currently Available	Construction Materials	Maximum Dimensions LxWxH (cm) (volume)	Maximum Weight (kg)	Operational Capacity (Raw Materials)	Comments
Mixing	As in mixing step in bread baking process						
Extrusion	Extruder	C.W. Brabender 1¼" extrucer	Stainless steel	91x100x125 ($1.14m^3$)	100	25 kg/h	
Sizing & Cutting	Attached to extruder						

Table 8. Names and addresses of some food equipment producing companies in U.S.

1. AMF Cuno Division
   400 Research Parkway
   Meriden, CT 06450
   (203) 237-5541

2. C.W. Brabender Instruments, Inc.
   50 E. Wesley St.
   P.O. Box 2127
   S. Hackensack, NJ 07606
   (201) 343-8425

3. Dorr-Oliver, Inc.
   77 Havemeyer Lane
   Stamford, CT 06904
   (203) 358-3876

4. Groen Division, Dover Corp.
   1900 Pratt Blvd.
   Elk Grove Village, IL 60007
   (312) 439-2400

5. Hotpack Corp.
   10940 Dutton Road
   Philadelphia, PA 19154
   (215) 824-1700

6. Koppers Company, Inc.
   Sprout-Waldron Division
   Muncy, PA 17754
   (717) 546-8211

7. Parr Instrument Company
   211 Fifty-Third St.
   Moline, IL 61265
   (309) 762-7716

8. Stephan Machinery Corp.
   30 Park Avenue
   Manhasset, NY 11030
   (516) 627-7422

Fig. 3. Combined food material flow chart for all steps of food process operations in PCELSS

Legend

- wheat milling
- bread baking
- wheat cereal
- sugar extraction
- soybean oil/protein
- single cell protein
- fabricated foods

1 sifter
2 kettle
3 centrifuge
4 oven
5 mill
6 mixer
7 flaker
8 slicer
9 activated carbon filter
10 fermentation tank
11 cell disintegration
12 extruder

A wheat
B liquid waste from wheat
C whole wheat flour
D bread ingredients
E bread
F wheat flakes cereal ingr.
G wheat flakes cereal
H sugar beets
I_1 beet pulp (concentrate)
I_2 beet pulp & lime to waste
r_j raw sugar juice
J water vapor
K molasses
L sugar
M soybeans
N soybean hulls
O_1 solid residue (concentrate)
O_2 solid residue to waste
P soy oil
spi soy protein isolate
Q dried soy protein isolate
R substrate for SCP
S scp cells
T effluent from SCP washing
U dried SCP
V fabricated food ingred.
W fabricated food

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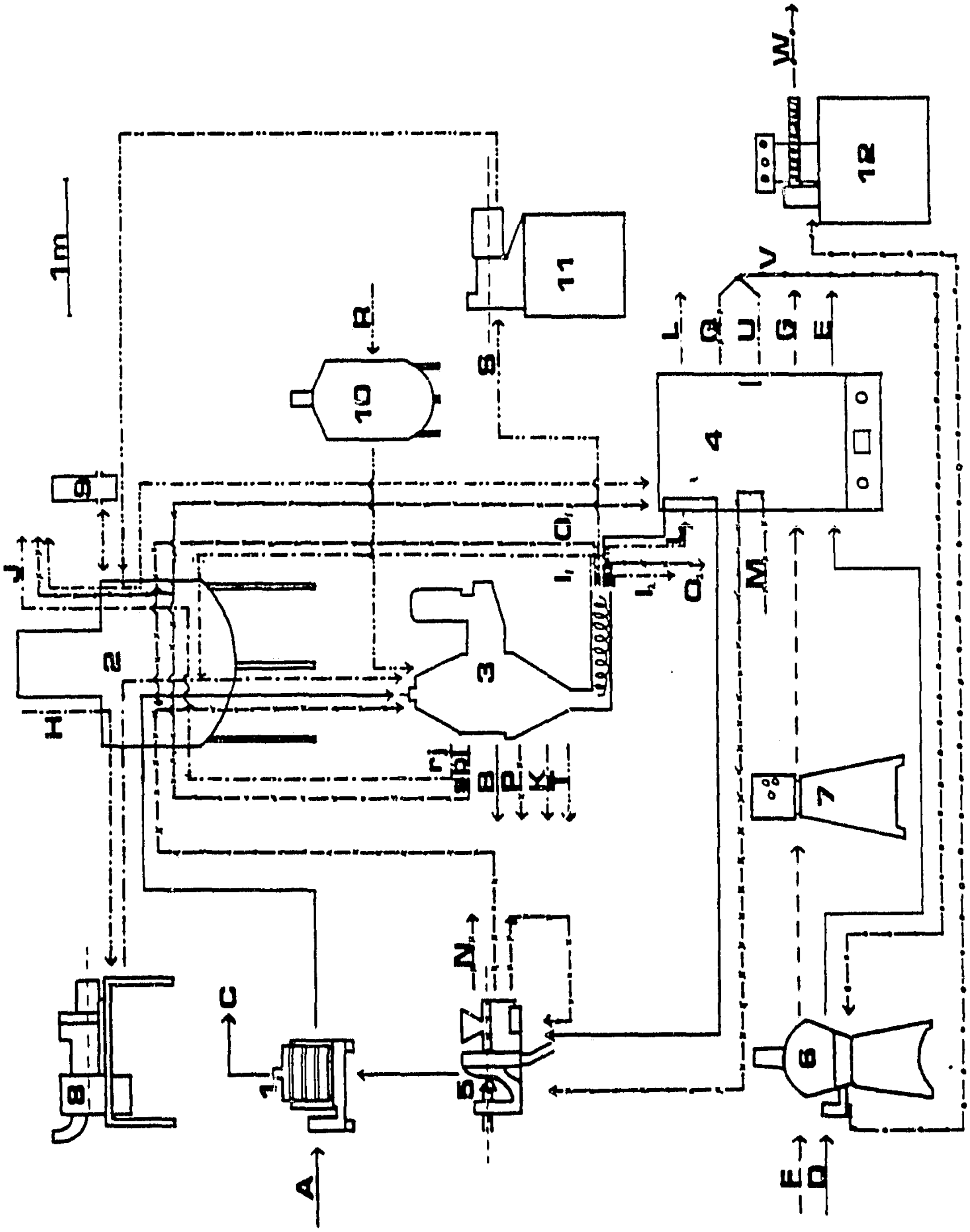


Table 9

Specifications of Available Equipment for All Operational Steps of Food Processes of PCELSS

1) Number of main items of equipment	12
2) Construction materials	mostly stainless steel
3) Actual volume of equipment	13.74 m^3
4) Total weight (appproximate)	2960 kg

G. Potential Simplifications of Processes to Further Reduce the Required Equipment and Load of Foods to be Processed

1) The possibility for removal of sifter, flaker, and slicer (equipment crossed out in Fig. 4), without compromising the quality of finished products, should be further considered.

Because the plants are hydroponically grown, we may assume that wheat is quite clean and does not need to be sieved before washing. Instead of flaking the breakfast cereal, we may extrude the wheat and manufacture puffed cereal. Instead of slicing the sugar beet to cossettes, we may use a rotary cutter on top of mixer. Effects of removal of these three pieces of equipment on the total weight and volume of food pilot-plant equipment is presented in Table 10.

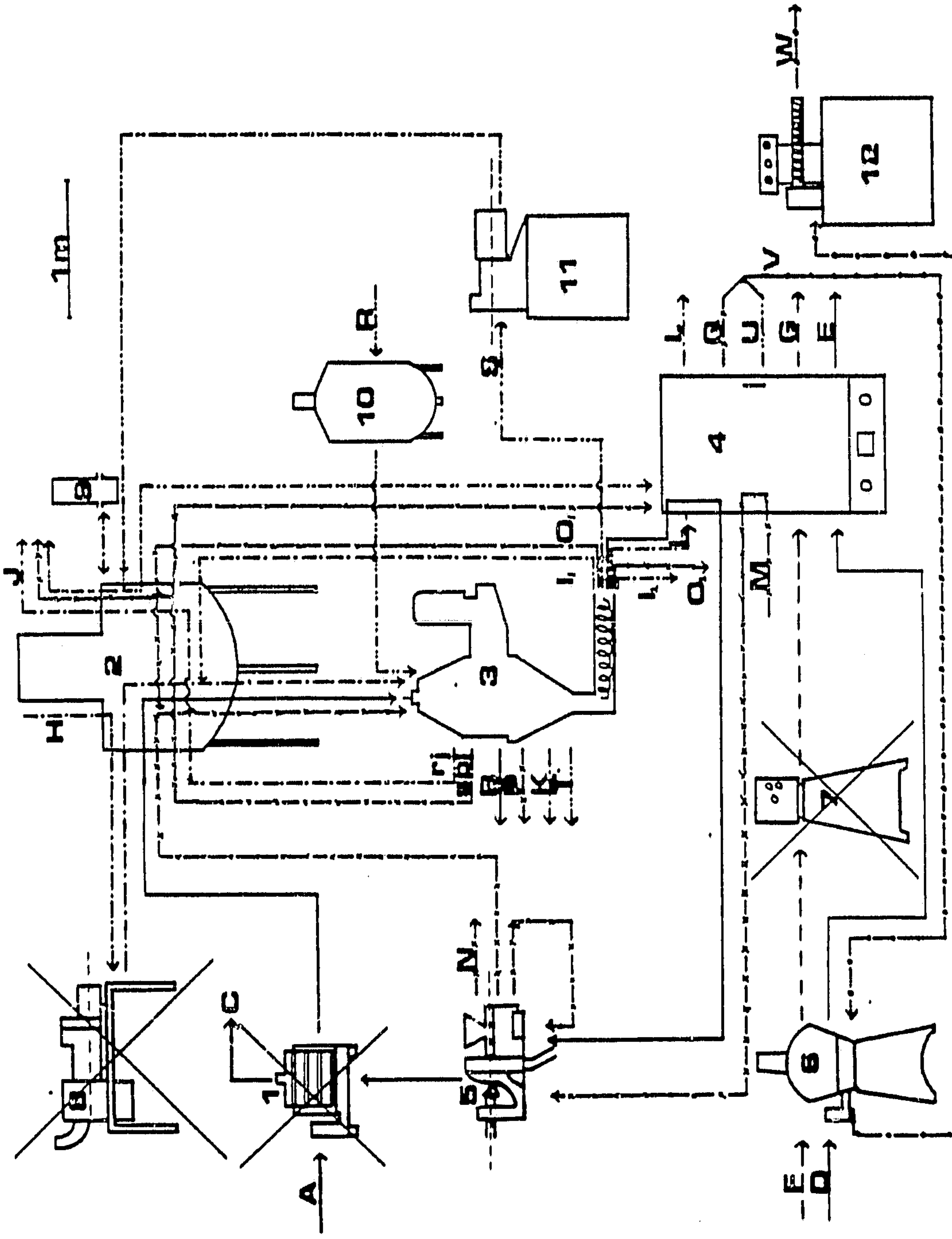


Fig. 4 Modified Fig. 3 with potential removal of sifter, flaker, and slicer.

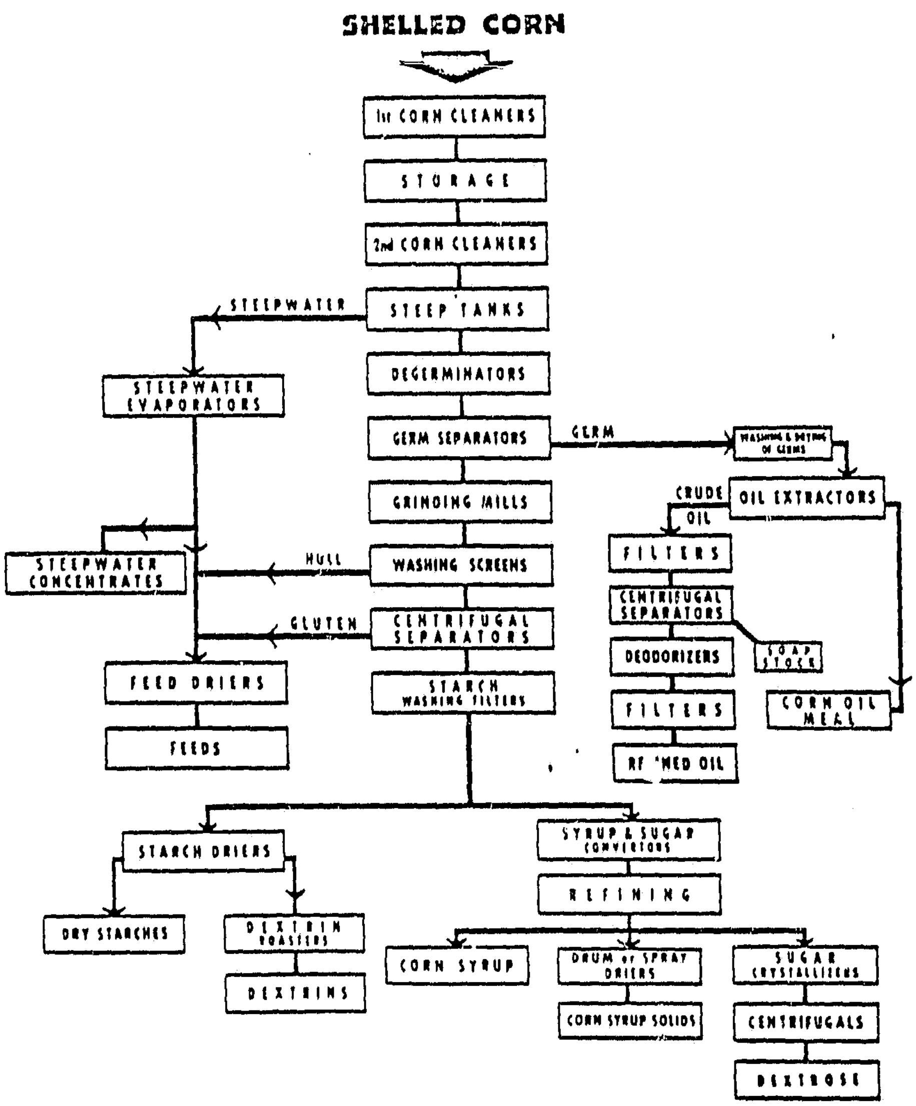
Table 10

Specifications of Available Equipment for All Operational Steps of Food Processes of PCELSS

	Original Plant	Simplified Plant
1) Number of main items of equipment	12	(9)
2) Construction materials	mostly stainless steel	(-)
3) Actual volume of equipment	$13.74m^3$	($10.47m^3$)
4) Total weight (approximate)	2960 kg	(2372 kg)

2) Since major processing loads arise from separation and purification of sugar from beet and of oil from soybean, modification and simplification of these two processes in very desirable.

2a) There is no simple substitute for sugar from beets. However, the potential use of corn syrup deserves more study and analysis (utilization of sugar cane, due to problems associated with production and generated waste seems improbable) Considering the overall process of corn syrup (Fig. 5) as an alternative sweetener for white sugar, we may find that this process is more complex than sugar beet extraction and hence needs more equipment. The steeping step for 40 hrs. means that more tanks



are needed in the pilot plant. One advantage of the corn process is that oil is a byproduct. This oil can partially substitute the soybean oil and therefore allow the production of full fat soy products.

2b) Waste load from aqueous extraction of soybean oil could possibly be decreased by using a substantial amount of tofu (Ref. 40) or other whole soy products. Tofu, a bean curd, is made by the process summarized in Fig. 6.

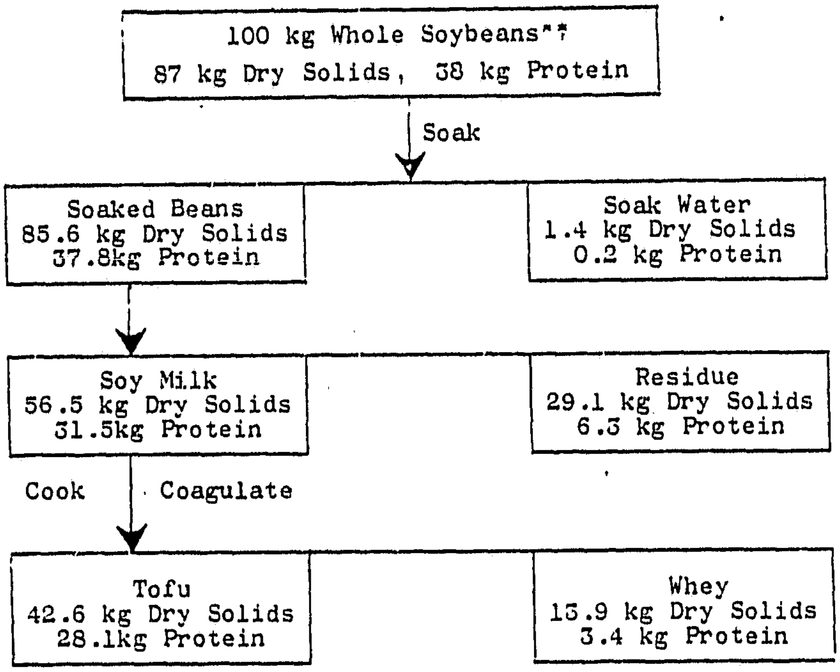


Fig. 6 Tofu process

Fig. 7 compares the composition of tofu with those of whole cow's milk and of cooked hamburger when adjusted to the same moisture level as that of the tofu.

	Tofu	Whole Cow's Milk	Cooked Hamburger Beef	
Calories	72.0	65.0	286.0	(87.0)**
Protein, %	7.8	3.5	24.2	(7.4)
Fat, %	4.2	3.5	20.3	(6.2)
Calcium, mg %	128.0	118.0	11.0	(3.3)
Phosphorus, mg %	126.0	93.0	194.0	(59.0)
Iron, mg %	1.9	Trace	3.2	(1.0)
Cholesterol, mg %	0.0	11.0	70.0	(21.0)
Typical Moisture, %	85.0	87.0	54.0	(86.0)

Fig. 7 Comparative composition of tofu, whole cow's milk, and cooked hamburger beef.

Tofu may be used, as an ingredient, in a variety of foods such as salads, desserts, entrees, sauces, heat and vegetable dishes, and soups.

It seems that tofu manufacturing, compared to aqueous extraction of soybean oil needs simpler equipment, and produce less waste. However, filtration is an unavoidable step in tofu processing, and should be considered in exchange for centrifugation (centrifuge weighed 453 kg and had the volume of 1.11 m^3). Conditioning and dehulling steps are also eliminated.

2c) Another potentially advantageous step is application of membrane ultrafiltration (UF). An inherent advantage of UF is its ability to recover all of the protein in the extract which is otherwise lost in the "whey" in conventional protein isolation techniques, and the potential to remove at the same time more than 90% of the oligosaccharides which are the causative agents in flatulence problems associated with ingestion of soybean products. It seems that UF can not replace centrifugation if oil is produced by aqueous extraction method. However, when full fat soy products are produced, UF improves the quality of the products. UF also could be used in the recovery of microorganisms from the fermentation broth and in the concentration of SCP.

2d) Another potential food ingredient for space habitat is utilization of lower organisms such as algae (e.g. chlorella and Spirulina). In practice, the nutrient content of algae reflects the composition of the media to a greater extent than does that of yeast. Protein content may range from 8 to 75%, lipid from <1 to 86%, carbohydrate from 4 to 40%, and ash from 4 to 45% (Ref. 48). Because of the tough cell wall of the algae, it is necessary to disintegrate the cells to increase the digestibility (Ref. 15, 16, and 37). One way to reduce the nucleic acid content in algae is to precipitate the proteins after disintegration. However, even without any RNA reduction, consumption of 50-60 g algae per day seems to be safe (Ref. 14). Among food formulations, best results have been obtained with cereals supplemented with Spirulina. Numerous nutritional tests on animals have demonstrated the nontoxicity of Spirulina and have provided a good idea of their nutritive qualities. Clinical tests on humans, both adults and babies, have been performed in Mexico and France have given satisfactory results (Ref. 7).

At this stage, it is difficult to state that if the algae is a better candidate protein source than yeast (SCP) for PCELSS. However, we are currently analyzing both of them as possible candidates with respect to PCELSS conditions.

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A P P E N D I X I

FOOD-WASTE TREATMENT AND WATER USAGE IN FOOD PROCESSING AND PREPARATION

PCELSS Revised Scenario II

A. INTRODUCTION

This report considers the fate of waste streams upon leaving the food processing and preparation area of PCELSS. A major waste product in food plants is water, used for washing, extraction (e.g. sugar and oil), cooking, cleaning, etc. This waste water is called "liquid waste" and contains residual solids. Based on literature surveys and some experiments, we established the amounts and composition of solid and liquid wastes originated in food processing and preparation in the revised scenario of PCELSS.

Unfortunately, a complete and accurate specification of composition of all waste streams is not feasible on this basis. In the case of vegetables, for instance, information is critical and extrapolation of overall process information as practiced on earth to PCELSS could be misleading. Differences in the state of the raw material would give origin to great discrepancies. As much as 5% of the raw material might be soil in root vegetables commonly processed by industry as opposed to the same type of vegetables if grown in hydroponic solutions. The information must therefore be considered as a preliminary and tentative basis for design.

An overall scheme of PCELSS food resupply and regeneration in the revised scenario is presented in Fig. 1. Fig. 2 shows the overall scheme of food processes to be operated.

B. ASSUMPTIONS

1) All assumptions and calculations made in the attached report on food supply, generation, processing, preparation, storage, and consumption in PCELSS (revised scenario II) have been taken into consideration.

2) It is important to determine the possibility of joint treatment of "food-production" wastes (e.g. roots, leaves, etc.) together with "food-processing and preparation" wastes. However, since the "food production" waste analysis is not yet available to us, we are presenting the analysis only for "food processing and preparation" wastes.

3) For hydroponically grown vegetables and fruits, we assume that the solid waste originates in food preparation and processing, and that solid waste due to damaged or spoiled raw material is minimal.

4) The solids content in the liquid is approximately 0.2-2% for most processes in the food industry; exact values will depend on the specific commodity.

5) "Non-food" wastes from various steps of food processing such as metal particles, dust and dirt, calcium carbonate and sulphite, charcoal, acid and alkaline solutions, gas phase wastes (e.g. CO_2 and minor water vapors), etc. are not suitable as substrate for single cell protein (SCP) production, or mixing and treatment with other food wastes. These wastes should be considered and treated separately in collaboration with the environmental safety group.

6) In order to conserve water usage and reduce pollutant levels, a series of factors must be carefully considered when determining levels and composition of food-waste materials. The following factors are among those which should be studied jointly with the "food-production" planning group.

6a) Plant size and percentage of plant capacity utilized: In general, larger plants present a more efficient use of water.

A similar trend has been observed in regard to percent of used plant capacity.

6b) Type of commodity and quality of the raw material: It is commonly accepted that information available for one product cannot be extrapolated to another. Each product is different. Consequently, selection of different food plants to be grown on board has a definite influence on the size and composition of the waste streams. As an example, the major steps for water use as well as generation of solids and dissolved residual for vegetable processing are as follows:

-Washing and Rinsing

A large quantity of the total liquid stream comes from these operations. These particular sources of waste material require special considerations. However, since plants will be grown in nutrient solution, less water will be required for washing. The proximate analysis of these streams will be very different, particularly in the case of root vegetables. Most metals found in vegetables originate from the soil in which they are grown. Plants absorb metal traces with higher concentrations usually observed in the peel. Fluctuations in the composition of the solid and liquid waste are due in part to the origin of the raw material.

-Peeling

High concentration of suspended solids originate in this operation. It varies with the type of peeling and whether or not the vegetables have been blanched or lye-treated prior to peeling.

-Blanching

Although small in volume, the blanch water contains the largest portion of the soluble components in the liquid waste of an entire food processing operation. This operation is optional, depending on whether enzyme action prior to consumption must be inhibited.

-Processing

Cooling waters are, among others, the most important sources of liquid waste in vegetable processing operations (optional).

-Cleanup Water

Washing of equipment, utensils, cookers, floors and general food preparation areas are major contributors of waste materials in food processing operations.

6c) Technology available and water use: The particular type of technology available at a plant influences the generation of waste. Modern technology has been geared towards the minimization of pollution. Operations such as peeling, blanching, transport of solids, etc., can be carried out using different methods, which will result in marked differences in size, as well as composition of waste materials. Water reuse is another factor that needs to be carefully considered.

7) For our assumed conditions, preservation of the locally harvested items for extended storage is not needed. If food operations such as freezing or canning are needed, this will affect the type and size of the liquid and solid waste streams.

8) To reduce amounts as well as loads of wastes in processing and preparation, we assume (in case needed):

-Use of microwave cooking and steam blanching, rather than hot water blanching and cooking.

-Dry size graders rather than hydrograders.

-Use of dry belt conveyors and/or negative air for transport rather than fluming.

-Utilization of air transport methods for dry-cleaning.

-In the cases in which peeling is required, such as in the case of potatoes, etc., steam-peeling has been considered the most suitable way to accomplish this stage.

9) Cleanup water for washing equipment, utensils, cookers, floors, and also water needed for heating and cooling of processing equipment are not considered in this report.

C. CALCULATIONS

The overall calculations for waste streams (solid and liquid) are presented in the following section.

Where feasible, waste streams have been broken down into individual streams coming from each one of the food processing operations and overall results estimated. Estimation of solid and liquid wastes will be improved by further measurement of waste materials of plant foods resembling those grown hydroponically in space as well as clarifications of details of food processes and equipment which will be used in space.

Calculations are divided into two sections:

1) Liquid waste which is mainly derived from the water used during processing and preparaton.

2) Solid waste material from food processing and preparation.

Liquid Waste

Water usage in the food processing and preparation area can be divided into three categories:

1) Water for washing of raw material.

2) Water for food processes such as extraction and purification, etc.

3) Water used for food preparations such as making of bread or food fabrication.

For calculation of liquid waste, the following points were assumed:

Washing

a) Values for washing of fruits and vegetables are assumed from our preliminary experimental data.

b) Wheat washing needs 200% water (Ref. 3).

c) Sugar beets require washing similar to potatoes.

d) Soybeans, because of dehulling, do not need washing.

Preparation

Preparation of washed fruits and vegetables does not require additional water.

Processing

a) Water use in bread baking is 35% of the total wheat (or whole wheat flour).

b) The ratio of water to sugar beet, for sugar extraction, is assumed at 8:1 (Ref. 2).

c) Aqueous oil extraction and protein isolation from soybean needs 2158% water (Ref. 4).

d) Water needs for addition to the dry fabricated food from soybean isolate is assumed to be 20%.

e) Water needed for washing and dilution of cells (before disintegration) is 48%. Water needed for addition to the dry fabricated food from SCP is 100% (Ref. 1, 6).

Table 1 shows the calculations for water usage in PCELSS food processing and preparation (revised scenario II).

Solid Waste

For calculation of solid waste, the following points were assumed:

1) The quantity of solid content in wash water, compared to waste from processes and preparation is negligible. It is not suitable as substrate for single cell protein production.

2) Values for fruit and vegetable wastes are assumed from our preliminary experimental data.

3) Water content in waste material of fruits and vegetables is the same as in the edible parts.

4a) Trimming loss of sugar beets before cossetting is 10%

4b) Lime waste (50% water) is 10% of the sugar beet (Ref. 2).

4c) Pulp waste (95% water) is 100% of the sugar beet (Ref. 2).

4d) Molasses waste (16% water) is 5% of the sugar beets (Ref. 2, 5).

5a) Soybean hulls (6% water) are 8% of the soybean (Ref. 7).

5b) The solid residue (75% water), from centrifugation during aqueous extraction, is 206% of the soybeans (Ref. 4).

6) All or part of the waste material (e.g. sugarbeet pulp, molasses, soybean extraction residue, etc.) which seems to be suitable as substrate for SCP production, will be converted to such substrates. It is extremely important to explore and determine the suitability, amount, and composition of waste material to be used as substrate for SCP.

7) Waste from cell culture (99.7% water) is 121% of the culture (including washing steps in purification).

8) Those portions of food wastes that are not used for SCP production, together with wastes from SCP, are further processed. All solids (including fine and very fine particles) of these food wastes could be screened and separated. The resultant water could be cleared and sanitized and re-entered into the water cycle. The resultant solids could be blended to a slurry, sanitized (if necessary), freeze dried, reduced in size, and be used, e.g., as agricultural fertilizer in PCELSS or returned to earth. Table 2 shows calculations for solid waste in PCELSS food processing and preparation area. Fig. 1 shows overall scheme of mass balance for food waste treatment in PCELSS.

TABLE 1. Water Usage in Food Preparation and Processing in PCELSS (20 inhabitants, 10 days)

Raw Material		Washing of Raw Material		Processing		Preparation	
Type	amount (kg)	% of raw material	amount (kg)	% of raw material	amount (kg)	% of raw material	amount (kg)
Tomatoes	23.3	80	18.6	-	-	-	-
Potatoes	46.2	50	23.1	-	-	-	-
Lettuce	10.0	300	30.0	-	-	-	-
Onion	6.0	40	2.4	-	-	-	-
Strawberries	10.0	150	15.0	-	-	-	-
Wheat	60.0	200	120.0	-	-	-	-
flour	60.0	-	-	35	21	-	-
Sugar Beets	178.2	50	89.1	800	1426	-	-
sugar	22.0	-	-	-	-	-	-
Soy Beans	52.6	-	-	2158	1135	-	-
soy oil	6.2	-	-	-	-	-	-
soy isolate	9.8	-	-	-	-	20	0.2
Cell & Culture	150.0	-	-	48	72	-	-
SCP	4.0	-	-	-	-	100	4.0
Total			298.2		2654		4.2

TABLE 2. Solid Food-Waste from Food Preparation and Processing Area in PCELSS (2C inhabitants, 10 days)

Raw Material			Total		Dry Weight		Water	
Type	Amount (kg)	Type of Waste	% of raw Material	Amount (kg)	% dry Weight	Amount (kg)	% of Water	Amount (kg)
Tomatoes	23.3	cores	3	0.7	6.5	0.05	93.5	0.65
Potatoes	46.2	peel	10	4.6	20.2	0.93	79.8	3.67
Lettuce	10.2	outer leaves & butt	10	1.0	4.5	0.05	95.5	0.95
Onion	6.0	peel	5	0.3	10.9	0.03	89.1	0.27
Strawberries	10.0	cores & stems	6	0.6	10.1	0.06	89.9	0.54
Wheat	60.0	-	0	0	0	0	0	0
Sugar Beets	178.2	trimming	10	17.8	21	3.7	79	14.1
		lime*	(10)	(17.8)	(50)	(8.9)	(50)	(8.9)
		pulp	100	178.2	5	8.9	95	169.3
		molasses	5	8.9	84	7.5	16	1.4
Soy Beans	52.6	hulls	8	4.2	94	3.9	6	0.3
		residue	247	129.6	25	32.4	75	97.2
Cell & Culture	150.0	effluent*	121	182	0.3	0.5	99.7	181.5
Total				527.9		58		469.9

*Not suitable as substrate for SCP

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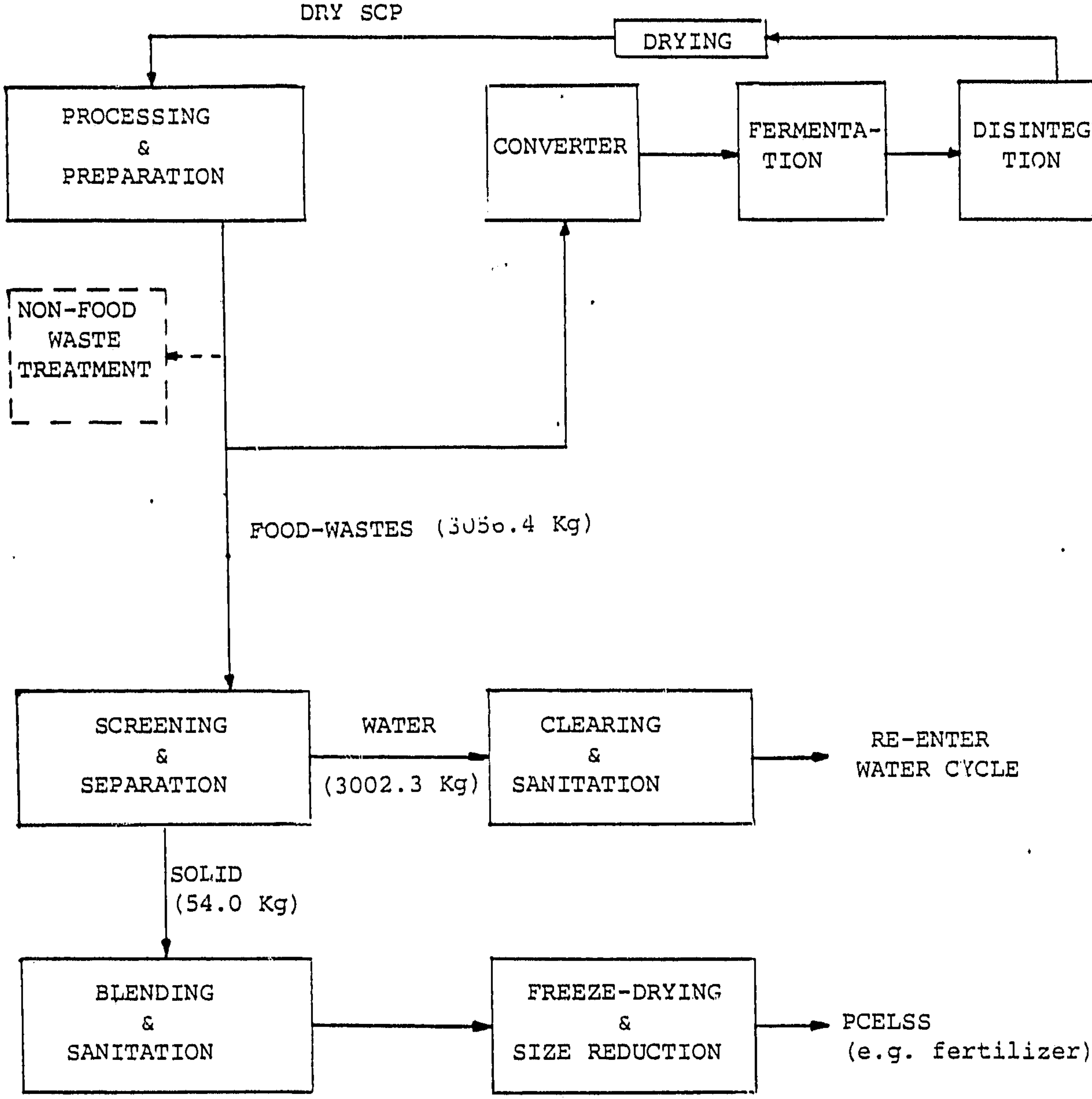

Fig. 1 Overall scheme for waste treatment in PCELSS

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FINAL REPORT ON CONTRACT NAS 9-16008
Principal Investigator :Dr.Marcus Karel
M.I.T.
A P P E N D I X II

Engineered Foods in PCELSS

An Analysis

Report to Johnson Space Center

NASA

Attention: Mr. Richard Sauer

Prepared under Contract #NAS-9-16008

Principal Investigator: Prof. Marcus Karel

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I. Introduction: The Need for Fabricated Foods

The ultimate goal in the designing of space colonies is to be able to have a space habitat as independent or self-sufficient as possible. Maximum efficiency in the use of resources produced on board, therefore, is highly desirable. This approach will also minimize the production of waste materials.

We consider that, of the four food supply scenarios proposed, the second food supply scenario, when hydroponic plants are produced on board will be the most important (Table 1). Transition from this stage to stages in which animals are produced on board is expected to require a long time due to complications arising from having more complex systems on board, lower productivity, and certainly larger amounts of waste materials.

Fabricated foods appear to be the obvious solution to a number of problems associated with providing adequate nutrition to a space colony. In Table 2, some of the potential benefits of engineered foods in their application to the space program are presented. Nutritionally, toxicologically and organoleptically, fabricated foods have to be of the highest quality. It is impossible to base the acceptability of engineered foods only on nutrition.

Perhaps the principal drawback of engineered foods is lack of acceptability from an organoleptic point of view. Two approaches can be taken to prepare high-protein foods. The first approach would be to prepare analogs. Analogs for chicken, beef ham sausages, cheese etc. are today a reality. The second alternative is to produce entirely new products or products that have no counterpart in nature. Production of analogs presents the disadvantage that the organoleptic characteristics of the analog have to resemble closely characteristics of the product they replace. On the other hand, substitutes are less demanding. However, eating habits cannot be dramatically changed over a short period of time, and it may be necessary to produce analogs.

Fabricated foods, would contribute to solving a large number of problems if they are prepared using raw materials produced in the colony. A transition from a predominantly animal protein diet to a plant protein one is almost necessary. From a nutritional point of view, proteins from strictly plant origin can provide humans with an adequate amino acid pattern as well as other nutrients to satisfy their metabolism. A diet can be tailored to correct imbalances associated with amino acid deficiencies. Fortification with amino acids, vitamins and trace elements may be required depending on the particular diet selected.

If we consider food supply scenarios II and III, the products that need to be substituted are meat and meat products, fish, milk and milk products, eggs, and tree-fruits.

One of the most important aspects of fabricated foods is texture. Texture is perhaps the most controversial quality in food analogs. Flavor, however, may be a barrier to extensive use of vegetable proteins at levels high enough to be a significant source of protein in the diet.

The protein content as well as the quality of the protein to be used in engineered foods are important factors to be considered when preparing analogs or substitutes. Carbohydrates are used primarily to impart texture, mouthfeel, viscosity, sweetness, etc. and thus, they also require special attention. Other ingredients, such as fats, colors, flavors, antioxidants, emulsifiers, preservatives, vitamins and minerals among others contribute to the overall success of a product.

At present, little is known about the interactions between basic components which give a food product certain desired characteristics. Therefore, it is difficult to predict texture, flavor or other organoleptic characteristics based on the basic raw materials.

II. Nutritional Considerations

Considering the different diet scenarios planned for the space colony, we believe that vegetable, cereal and single cell proteins should be the most important sources of dietary protein, particularly in the preliminary stages. Animal protein consumption should be kept at a minimum due to transport limitations of meat products which have to be resupplied from earth and the low productivity of animals if raised in the colony. A series of factors, however need to be carefully considered. The nutritional value of most proteins is not the ideal. Deficiency in some essential amino acids, metal traces and vitamins would require a closer look at these protein sources. The presence of toxic compounds and/or antigrowth agents will certainly make imperative a close study of the processes for the conversion of the raw materials into ingredients for food fabrication. Guidelines for the utilization of proteins, nutritional value and safety in their use need to be clearly established. The protein content and amino acid composition of selected legumes and cereals is presented in Table 3.

Fortification of engineered foods is of critical importance. In Table 4, the tentative nutrient profiles stipulated by the FDA for vegetable protein substitutes is presented. It should be realized however, that nutritional requirements in space might be different according to the patterns of food consumption. Nutritional equivalency does not necessarily imply suitability or wholesomeness. Adequate tests to determine the nutritional quality of new products are needed.

The case of methionine supplementation presents a number of problems and difficulties. Development of unacceptable flavors due to methionine degradation is one of the problems incurred when foods are supplemented with crystalline methionine. N-acetyl-L-methionine which is not degraded during processing, to fortify soy products, for instance, might be a better choice (1). However, one of the goals of this project is to be able to combine appropriate ingredients to prepare well balanced foods without having to rely on fortification only. Table 5 shows the feasibility of fortifying cereal grain-based products.

Film coating and encapsulation will be taken into consideration for the fortification of foods with highly sensitive nutrients.

III. Raw Materials

A. Requirements for Raw Materials

1. Raw materials should be easily attainable.
2. Materials should be free of toxic compounds.
3. Raw materials should have good functional properties.
4. Good organoleptic properties are highly desirable.
5. Good nutritional quality is of primary importance.

B. Possible Protein Sources

Oilseeds

- soybeans
- rapeseed
- sunflower
- peanuts
- cottonseed

Cereals

- wheat
- oats
- barley

Leaf protein

- alfalfa

Single-cell protein

- bacteria
- yeast
- algae

microfungi

Dehydrated products resupplied from earth

milk

eggs

meats

Caloric and protein contents of selected cereals and legumes are given in Tables 6 and 7.

C. Soy Protein

One of the main limitations in dealing with soy proteins is flavor. The amount of soy that can be incorporated in a particular food is limited by the natural beany or bitter flavor of soybeans. However, the presence of other ingredients as well as treatments such as baking, roasting, cooking, and extruding may help to alleviate the problem of unpleasant flavors (2). Although concentrates and isolates present blander and cleaner flavors, their protein nutritive value is also decreased. In general, solubility is affected by extraction. Highly purified proteins, such as isolates present lower solubilities. pH and temperature conditions during extraction may result in protein denaturation or aggregation with associated lower solubility. Water and fat binding, high viscosity and gelation are quite desirable properties for some products but not for others. Heat in particular has marked influence on the viscosity and gelation characteristics. Another factor that deserves some attention when dealing with soy products, especially soymeals, is the presence of two low molecular weight oligosaccharides. Raffinose and stachyose are not broken down by man's digestive system, therefore giving origin to flatulence (3).

When soy protein is compared to animal protein, some definite advantages are observed. Factors such as lack of cholesterol, low saturated fat and the presence of plant fiber are desirable characteristics of plant proteins. However, the low levels of iron and other trace elements, the low levels of sulphur amino acids and some of the B vitamins would make soy less suitable for human nutrition than animal proteins. However, overall supplementation and modification of soy proteins can make this protein source more suitable for human consumption.

In the following paragraphs, we will present some of the major findings reported on soybean proteins in human nutrition.

1. As in the case of other protein sources, the nutritional quality of soy protein will vary depending upon the age of the individual consuming it (1).

2. S-amino acids are the most limiting essential amino acid in soy and soy protein isolates (1). Variability in sulphur amino acid content needs to be considered in soybean products (4).

3. Methionine supplementation improves dietary N in adults when soy is consumed as the sole source of protein at a deficient level of total N intake. Adverse response may occur with levels of methionine supplementation which do not greatly exceed that estimated to meet the S-amino acid need per unit of total N intake. No measurable effect of methionine supplementation is

observed when the level of soy intake was sufficient to meet the dietary allowance for total protein in young adults (2.8 g protein/kg/day)(1).

4. As the sole source of dietary protein, soy protein isolates increase requirements for certain vitamins, decrease phosphorus utilization, and decrease bioavailability of essential trace minerals (4).

5. Formation of phytate complexes affect bioavailability of essential minerals, particularly zinc (4).

6. Soy protein isolates prepared from hexane:ethanol azeotrope extracted flakes contain much lower amounts of choline derivatives. Choline deficiency is associated with soy protein isolates (4).

7. When soy is incorporated with cereal grains, the overall protein quality of the diet is high, and it is similar to that for good quality animal protein sources (1).

8. Soy can be a primary cause of allergy (1).

9. Processing of protein foods is known to be capable of producing allergenic substances not detectable in the original product (1).

10. Well processed soy products consumed over long periods of time are well tolerated and accepted by human subjects (1)

It should be kept in mind, however, that soy protein products may differ in enzyme activity, protein dispersibility, flavor, nutritive value and functional properties, therefore being difficult to generalize on the overall properties of soybean proteins.

Functional properties of soy proteins in relation to other components in a food system vary widely. Prediction of the behavior of a protein cannot be done on the basis of the protein alone. Other components such as water, proteins, carbohydrates, fats and a number of unknown constituents present in oilseed meals will determine as a whole the overall behavior of a system.

Flavor, color, solubility, rheological behavior, water uptake, emulsification and foaming ability are the most important functional properties. Desirable functional properties, however, vary from product to product. For instance, in the case of beverages, solubility and suitable viscosity are two critical functional properties. When dealing with meat systems, water-holding capacity, emulsification properties and spinability are the most desirable characteristics. For other systems, required functional properties may be completely different. For the case of bread, requirements call for a protein compatible with gluten and in pasta, a protein should not give excessive water absorption and should permit uniform and rapid drying of the product without causing case hardening.

Table 8 shows the most important functional properties of soybean proteins in different food systems.

D. Possible Applications of Soy Proteins

The characteristic bitter, beany flavor of soy flours has greatly limited the applicability of this protein source to food beverages.

Flavor can be improved by heat, but heat denaturation lowers solubility of the protein (5). The presence of lecithin in full-fat soy flours, without solvent extraction, contributes to improvement of the dispersibility, making it feasible to prepare high protein beverages (Mustakas, et al. 1971). A large number of attempts have been made to prepare high protein beverages using soybean proteins. Overall, difficulties in the masking of the soy flavor and the presence of flatulence factors have limited their use. The use of concentrates and isolates, free of flavor and flatulence problems seems to be an alternative. Low solubilities at low pH, as well as increased cost, are disadvantages of this approach. In the colony, limited waste makes the full-fat soy flours the ideal vehicle, and it is necessary, therefore to overcome the flavor problem.

The use of soy in meat extenders and analogs will be covered in the section on protein texturization.

Fortification of bread with soy flour at the 6 and 12% levels has been successfully achieved by adding calcium and sodium stearoyl 2-lactylate and some other additives to minimize changes and to provide adequate loaf volume and crumb structure (6).

E. Rapeseed Protein

1. Advantages (7)

- Rapeseed protein has substantially higher contents of sulphur-containing amino acids than soy protein.
- Rapeseed protein contains adequate amounts of other

essential amino acids and in practice there is no limiting amino acid in RPC.

-RPC is equal to or better than a good animal protein.

-Very bland rapeseed protein products can be produced.

-Although oil emulsification and whippability characteristics depend upon processing, rapeseed protein concentrates and isolates show in general excellent water and fat-binding capacity.

2. Disadvantages (7)

-Rapeseed proteins have a negative effect on zinc balance, therefore requiring a suffuciently high zinc level in the diet to obtain a normal PER.

-From the point of view of toxicology, glucosinolate levels need to be kept low to avoid growth-depressing effects (8). 99% glucosinolates can be removed by water leaching.

-Oxazolidinethiones and isothiocyanates from the glucosinolates cause goitrogenic effects. However, at normal RPC glucosinolate levels (0.2 mg/g), no effect is expected.

-Nitriles, which can be products of glucosinolates, have a higher toxicity than oxazolidinethiones. No problems are expected, however, at the normal level in RPC (1 mg/kg).

-In rats, phytic acid content and its effects on zinc absorption have been associated with anorexia, weight loss during the last days of pregnancy and in more severe cases, high fetal mortality. Removal of glucosinolates is not adequate to make a rapeseed diet safe. Further processing would be required to lower the phytic acid content.

-RPCC, although light colored, has a tendency to turn darker during heat treatments, especially during extrusion cooking. Color problems are usually due to chlorogenic acid. Rapeseed protein isolates are usually greyish. The field of texturization of RPCC although studied to some extent, still presents a series of unknowns, and the technology for this novel protein source is certainly not as developed as is the case of soy proteins. Rapeseed proteins can be used as extenders or binders in meat patties and sausages, or used in bread, although incorporation at the 5-15% level results in poor volume due to poor gas retention. Rapeseed proteins have not gone beyond the stage of ingredients.

F. Sunflower Protein

1. Advantages (9)

-Sunflower seed protein does not contain any toxic substances.

-Essential amino acid ratios are higher than those of cereal proteins.

-No flatulence has been reported to occur in sunflower-based diets as associated to sugars present in the defatted flour (10).

-Sunflower oil cake can be extruded and protein isolates can be spun.

2. Disadvantages

-There is little known about the proteins.

-The presence of chlorogenic acid results upon processing of the proteins, in color problems. Under neutral and alkaline conditions, sunflower proteins develop dark green and brown colors because of bonding with oxidation products of polyphenolic compounds, especially chlorogenic acid.

-Procedures have been developed for chlorogenic acid removal and low chlorogenic acid cultivars are underway in plant breeding programs (9, 10, 11).

-Lysinoalanine may form under drastic conditions of pH and temperature.

-Complete dehulling is difficult to achieve (10).

-Sunflower meals and flours contain high proportions of sugars, di- and oligosaccharides which may cause darkening of sunflower-supplemented food products. Protein concentrates prepared by aqueous extraction contain only low concentration of these sugars (10).

-Sunflower products are low in lysine. However, being rich in other essential amino acids, especially the sulphur-containing amino acids, they provide excellent supplementation for legume and animal protein sources (10).

3. Functional properties of sunflower proteins- flours, concentrates and isolates (12)

-Fair water absorption. Limited applications in beverage products (poor water solubility). High emulsification characteristics. Excellent whippability, although aqueous extraction to remove chlorogenic acid has adverse effects on this property (10).

-Excellent foam stability.

-Lack ability to form a firm gel.

-Texturization by extrusion of sunflower flour gives fibrous chunks, greyish in appearance, with chewy texture and meat-like flavor.

-Spun sunflower protein/casein (1:1) blends are superior to other vegetable proteins in shear strength, swellability and firmness.

-Sunflower flours are particularly deleterious to breadloaf characteristics. Sunflower proteins are highly soluble in low or high concentrations of sodium and calcium chloride, a property which is lacking in soybean and groundnut proteins.

-Food applications of sunflower are restricted to neutral and acidic products. Protein concentrates from which phenolic compounds have been removed can be used successfully under alkaline pH conditions.

G. Cottonseed Protein

-Flavor may be a problem depending on the type and the degree of processing. The cereal and green flavor notes of the flour are accentuated in the protein isolates (13).

-A large amount of hull particles is usually found in this type of protein.

-Desirable functionality is lost during processing and drying.

-The removal of gossypol with the liquid cyclone process has been impressive, solving the toxicological aspect of this protein.

H. Peanut Protein

1. Advantages

-Peanut products are pleasantly flavored, and do not require severe refining. Concentrates and isolates are very bland and close to colorless.

-Some interesting viscosity and solubility properties are observed in some fractions.

-Peanut protein isolates would probably perform well in beverage products where bland flavor, high solubility and low viscosity are desired.

2. Disadvantages

-Appearance of aflatoxins in peanuts is more common than in any other oilseed crop.

- As in many oilseeds, antinutritional factors including trypsin inhibitors, goitrogenic factors, phytohemagglutinins, phytic acid, and oxalic acid, are found in peanuts.
- Hexoses such as stachyose and raffinose, which cause a flatus problem, are found in peanuts, although at lower levels than in soybeans.
- Methionine, lysine and threonine are the limiting amino acids in peanut products at low protein dietary level.
- A great deal of research is still needed in the area of applications of peanut protein (14).

I. Leaf Protein

The area of leaf protein has not been extensively explored (15, 16, 17). In Table 9, the protein yields of various crops are compared. It is clearly advantageous from a productivity point of view to be able to use leaf protein. However, the high processing required to prepare leaf protein suitable for human consumption is a very convincing argument against the application of this protein source to the space program.

Research is needed to develop improved methods for protein extraction and to establish adequate procedures for the removal of undesirable colors and flavors while still retaining good functional properties. Solvent extraction will most likely be required for the obtaining of good quality protein for human consumption. However, it is a main concern of this project to be able to obtain ingredients that do not require extensive processing or use of chemicals.

Finally, little has been done on the possible applications of leaf protein and in its raw state, this protein would have very limited use.

J. Cereal Proteins

Cereal proteins are known to be deficient in lysine. Fortification at the 0.2% level with L-lysine has been found to increase protein availability without causing any adverse effect on the organoleptic properties. However, the added lysine may be destroyed upon processing. The incorporation of other proteins rich in lysine, presents an alternative to upgrade cereal proteins. Since 10-20% levels of the other proteins may be required to achieve this upgrading of cereal proteins, functional and organoleptic properties are expected to be altered.

Genetic improvement in protein quality and quantity is possible in food crops. In the case of soybeans, however, low priority has been given to breeding for change in amino acids. In the case of safflower, the high fiber content is still a problem, and varieties with lower fiber content as would be the case of the thin hull types, have low yields. Sunflower production has been limited by the high susceptibility of these plants to pests. New varieties of sesame seeds are sought, to reduce the oxalic acid content, although this problem is not critical considering that 2/3 of the oxalic acid is located in the seed coat which is removed upon decortication (18). Progress has been achieved in increasing the protein content in rice.

quality of cereals and legumes has been improved. Overall, however, cereals as a group are highly deficient in lysine and legumes are most likely to be deficient in methionine (19).

K. Protein Modification

As an alternative to the use of proteins and in order to enhance certain functional characteristics, modification of proteins has been suggested. Proteins can be modified either enzymatically or chemically to obtain variations in aroma, color, flavor, solubility, etc. Modification of side chains of amino acids as well as enzymatic and chemical hydrolysis have been tried. However, hydrolysis of proteins may also result in the formation of undesirable components such as bitter tasting peptides, whose characteristics will depend largely upon the amino acid sequence and composition (20).

Protein modification presents, however, a lot of potential. For instance, soy happens to be one of the more difficult proteins to flavor because of its native lack of blandness and the astringent character which develops in the higher range purities.

L. Single-cell Protein

Single cell protein has been suggested as one of the most suitable approaches of providing adequate nutrition to space missions. In particular, algae such as Chlorella and bacteria such as Hydrogenomonas have been proposed as possible microorganisms from which protein and other nutrients can be obtained (4, 8, 21).

Protein productivity for algae as compared to other protein sources is presented in Table 10, clearly showing the advantages of SCP from the point of view of protein productivity. In the following sections, we will be discussing the advantages and disadvantages of using this approach from a nutritional as well as from a technical point of view. Consideration will be given to bacteria, yeast, fungi, and algae.

In the past few years, it has become more clear that physiologically and psychologically the raw biomass of any biosystem cannot be used as acceptable food for humans. Extensive processing and supplementation as well as adequate formulation with other ingredients are required to produce acceptable foods.

A series of factors need to be taken into consideration for the selection of a particular microorganism for the production of SCP. For instance, yeast can be grown at a relatively low pH and thus sterile conditions are more easily attainable. Yeast cells are considerably larger than bacteria, resulting in less cumbersome harvesting operations. Yeast cells, however, present high levels of nucleic acids that need to be removed and protein functionality needs to be increased through protein solubilization, resulting in an overall low protein yield (22). Table 11 shows a summary of desirable characteristics for microorganisms used for SCP.

Raw materials for the production of SCP not only can have a major effect on the organoleptic properties of the material, but what is more important, on the toxic properties.

From the point of view of protein recovery some microorganisms are more suitable than others. Although protein recovery levels would be usually in the 50-60% range for most SCP sources, microorganisms such as Chlorella are more troublesome than yeast and protein recoveries are lower than average (23).

Major findings regarding microorganisms for SCP production can be summarized as follows:

Bacteria (24, 25)

1. Very fast growth rates.
2. High protein content (as high as 80%).
3. Amino acid content can be partially controlled by process conditions.
4. Nucleic acid content approximately 13-14%.
5. Difficult to harvest, particularly under weightless conditions.
6. Bacterial cultures are susceptible to viral attack.
7. No textural properties.
8. Cells are subject to spoilage thus requiring continuous processing or good preservation techniques.
9. Difficult to incorporate in foods at levels above 25%.

Yeast (24)

1. Higher amounts of protein than in fungi (50-55%).
2. Good quality protein.
3. Larger in size than bacteria.
4. Nucleic acid content approximately 8-10%.
5. More vitamins than most fungae or bacteria.

6. Higher in lysine than most fungae or bacteria.
7. No textural properties.
8. Cells are subject to spoilage thus requiring continuous processing or good preservation techniques.

Microfungi (24, 26, 27)

1. Capable of growing on a number of crude substrates.
2. Easy to harvest.
3. Lower nitrogen content. Protein content ~40%.
4. Nucleic acid content approximately 3-5% in most cases.
5. Slow rate of multiplication as compared to yeast or bacteria.
6. Because its filamentous stucture can be baked, fried, or puffed into a rice-like product. It does have texture on its own.
7. High sulphur amino acid content. Higher than it is normally found in SCP.

Algae

1. Algae cultures are susceptible to contamination. Serious limitations of algae for human consumption may result due to contamination by pathogenic microorganisms or by formation of toxins (28).
2. Harvesting of algae involves cumbersome operations intensified under weightless conditions (25).
3. Harvested algal cells are subject to spoilage, thus requiring continuous processing or good preservation techniques (25).

4. Algae as other SCP requires considerable processing and supplementation for its adequacy as human food (25).
5. The protein content of algal cells is extremely high in comparison to human requirements. The carbohydrate content is low.
6. Algae have a deficiency in sulphur-containing amino acids such as methionine. The protein contains 1.15% methionine and only traces of cysteine and cystine. The lysine and threonine contents are large.
7. Algae are susceptible to ionizing radiation (25). Mutation may become a serious problem.
8. No textural properties.
9. Fat removal and decoloration are necessary for human use. Cell wall disintegration is required to render proteins available for human metabolism (29).

Overall Advantages of SCP (29, 30, 31)

1. Microorganisms have a very short generation time.
2. Genetic modifications can be easily achieved.
3. The quality and amount of protein in microorganisms is high.
4. Microorganisms can be grown on a large variety of substrates.
5. One of the main advantages of microorganisms is that they can be obtained in continuous cultures with a minimum of space and water requirements.
6. SCP can be used to enrich the vitamin and mineral contents of foods. Due to its high lysine content, SCP can be used to

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improve the nutritional value of cereal proteins.

7. As an ingredient, SCP may improve the physical properties of foods.

Limitations in the Use of SCP (27, 30, 31, 32)

1. Need for removal of nucleic acid: Considering that a diet of 50-60 g of microalgae or 20-30 g of yeast will be above the nucleic acid limit of acceptability for humans, removal of nucleic acid is imperative. However, removal of nucleic acid in a safe and economic way has been difficult to achieve. The use of endogenous enzymes presents the most promising way due to the low cost and safety. The use of exogenous enzymes may result in the formation of toxic compounds. The process of using endogenous enzymes is time consuming since this process involves enzymatic hydrolysis initiated by a short heat shock, followed by hydrolysis by incubation during which accumulated products of hydrolysis leak out of the cell (33, 34).
2. Significance of the cell wall from a nutritional point of view and necessary treatments to eliminate any negative effect.
3. Significance of long term ingestion of other cell components such as pigments, steroids, unusual carbohydrates and lipids. High levels of consumption may cause allergic reactions.
4. Presence of toxic compounds.
5. Extra processing is required in most cases not only to guarantee safety for human consumption but to improve organoleptic

and functional properties.

M. Nucleic Acid Removal

A series of methods have been proposed for the removal of nucleic acids. The selection of a particular method, however, has to be based on the type of microorganism involved, the allowed levels of nucleic acid and the organoleptic properties of the resulting product. Sinskey and Tannenbaum (1975) compiled the methods to modify the nucleic acid content of SCP. The most important methods are the following (35):

1. Control of growth rate and/or cell physiology. This method provides a limited nucleic acid reduction.
2. Base-catalyzed hydrolysis. This method results in high weight losses due to partial cell hydrolysis.
3. Chemical extraction such as 10% hot NaCl and 85% phenol. Loss of amino acids and vitamins is one of the major drawbacks of this approach.
4. Mechanical and chemical cell disruption accompanied by chemical or enzyme hydrolysis of RNA. Removal of cell components can be achieved by using much milder methods after cell disruption as compared to methods required for intact cells. However, a strong decrease in the RNA content through alkaline extraction is followed by a decrease in the yield of protein concentrate (36).
5. Exogenous enzymes. High weight losses and high cost of enzymes are limitations of this method.
6. Endogenous RNase. Since no chemicals are used, this method is

the one that has received more attention and the only one used commercially at this point. The use of enzymes results in high protein yields. Ideal processes for RNA reduction should not involve concomitant loss of protein.

N. Functionality of SCP

1. General

SCP from algae, yeast or bacteria lacks texture and as such the number of applications is very limited. Many workers have found it difficult to incorporate SCP into acceptable foods. With the exception of yeast as an enrichment ingredient in breads, pastas, macaroni and similar foods, and as a flavor carrier in chips, crackers, bits, etc. (37), and bacteria as agents in foods, SCP has not been accepted as foodstuffs in their own right. Table 12 shows levels of incorporation of yeast in a variety of products.

Disruption of cells for the obtaining of protein concentrates and isolates is a required step to increase protein functionality. Disruption of cells is difficult on a large scale. A series of problems is associated with obtaining SCP isolates. Formation of lysinoalanine and lysine losses occur upon alkaline extraction. Furthermore, losses of protein, vitamins and other desirable cell components are also problems related to cell disruption and protein extraction (23, 38).

Impact-cell-mill (ICM) has been found to be superior to alkaline extraction, both in separation and yield. However, SCP protein prepared by this method has a strong off-flavor. Hot ethanol treatment reduces the off-flavor and also modifies the rheological properteis and spinnability of the material. Lipids, carbohydrates and nucleic acids (below 2%) are greatly reduced by this treatment (39). Need for solvent recovery is one of the drawbacks of this approach. Mechanical disintegration has been reported as presenting advantages such as improvement in the nutritional value of yeast, as well as high protein and nucleic acid extractability (40).

Although drum-drying has been used for fodder yeast to burst the cell wall, the protein obtained by this process is not only nutritionally impaired but cannot be fractioned or modified (23).

Alkaline extraction presents technical difficulties when applied to large scale production of microbial isolates. Strong foaminess of the solution, alkalinity of the extract and bulky residues are problems that require careful considerations (41). In general, the best method for the obtaining of isolates varies with the microorganism selected.

Although alkali and heat treatments may have a deleterious effect on the protein, chemical methods are more generally applicable and reliable than RNase activity. Moreover, organic solvent extraction may be necessary to improve appearance or palability of RNA-reduced preparations (42).

Although no toxic or nonphysiological substances have been reported in yeast cell walls, cell wall removal may be necessary to improve functionality of the protein.

Growth conditions can be manipulated to obtain microbial cells with more desirable properties. Chlorella, for instance, can be grown in a high carbon-to-nitrogen ratio and high temperatures to obtain colorless cells which will result in superior isolates. Combination of precipitation methods, dialysis and ion exchange etc. may be required to prepare protein isolates with desirable nutritional and organoleptic qualities (43).

With adequate technology, functionality can be built into SCP as has been the case of soy protein. Study of functional properties of isolates of SCP has been rarely done. Protein modification such as succynilation has been suggested (44).

2. Fungi

As previously mentioned, one of the advantages of fungal mycelium is the presence of texture. Fungal mycelium from Fusarium graminearum, for instance, has very good water binding capacity, and may be useful as a thickening and gelling agent. Not being an isolate it also contains other important cell components such as vitamins, lipids, and carbohydrates. The mycelium has good baking characteristics, thus being suitable as an enrichment ingredient in breads, cereals and snacks. It can also be purified, baked, or fried (45). Microfungal protein can be texturized into straws, chunks, or any form for food use (46).

Further texturization of mycelial fibers can be accomplished by gas entrapment followed by a drying process (47). Most fibers treated for RNA removal followed by drying become tough, and therefore methods for RNA removal as well as further fiber treatments should be aimed at a preservation of the quality of the fibers.

An appreciable decrease in RNA content in Fusarium graminearum has been achieved by suspending the cake at a pH between 4.7 and 7.6, and at a temperature between 55 and 72 C for a time of at least 60 seconds. This approach results in a minimum of protein loss and in a substantial decrease in RNA from 7-12% in the untreated microorganism to 1-4% (37).

3. Algae

The use of algae for human consumption has been very limited. Although for a long time, Spirulina has been used as part of the diet in areas of Chad and Mexico, a safe and efficient use of this protein source has not been achieved. It has been suggested however, that algal protein should be incorporated into already developed products rather than constituting the basis for newly texturized protein products (42).

4. Texturization

Texturization of SCP has not been attempted by many authors. Safety and economic factors have limited research for technological advancement in this field. Food applications of SCP have been limited almost completely to yeast and yeast products.

A large selection of bacteria and yeast has been found suitable to be texturized into chewy, crunchy or crispy material by extrusion. Reversion back into single cells is avoided through this process (48). The advantages that extrusion of whole cells presents include a minimum of complex and extensive equipment, no necessity of close pH control and specific additives. Moreover, other components of the cell can be preserved by this approach.

The presence of nucleic acids and other cell components interferes with fiber formation of SCP. However, unless the SCP concentrate is obtained under mild conditions, it is doubtful that fibers with adequate tensile strength can be made. Huang and Rha (1972) were able to prepare filaments of alkali-extracted single cell protein exhibiting considerable tensile strength, although lacking elasticity and resistance to shear (49). In 1971, Heden et al. had shown already the feasibility of preparing SCP fibers through wet spinning experiments (50). The addition of hydrocolloids such as CMC has been found to improve the tensile strength of the fibers (51).

On the other hand, Mitsuda (1973), working with a protein isolate from hydrocarbon yeast, found it difficult to texturize the protein into fibers under the same conditions required for fiber formation for protein materials such as casein, soybean protein isolate, and egg. The state of the protein made entwinement difficult and it is still unclear whether or not the amino acid composition had any effect on the spinnability of the protein. The author also reported that the addition of sodium alginate or other proteins made fibril formation possible (41).

Research in the area of fiber formation is very limited and a great deal of information is still required. A large number of variables in a spinning process need to be investigated separately to optimize the quality of the filaments obtained for their further use in fabricated foods.

5. Nutritional Considerations

From a theoretical and technical point of view, SCP seems to be a feasible approach to provide adequate nutrition to space bases. One of the major drawbacks is certainly safety. SCP feeding at high levels has not guaranteed freedom from gastrointestinal disorders in human subjects. Long term studies have not been carried out on the clinical evaluation of SCP for the cases in which SCP would represent a major dietary source of protein.

Testing of SCP on human subjects, however, is not only time consuming but it also involves risk. Clinical evaluation still remains as the most important issue regarding the applicability of this protein source. Studies on humans have been limited to yeast preferentially, and to algae. Contradictory results have been reported regarding the maximum levels of yeast protein that humans can tolerate. The use of yeast protein as a primary source of protein has been limited by flavor, acceptability and safety considerations. According to Edozien et al. (1970), gastrointestinal disturbances were not observed even at levels of 135 g yeast/day; however, only a dietary level of 2 g of SCP nucleic acid would be recommended as involving little risk of stone formation in the urinary tract, therefore limiting the daily consumption of yeast to much lower levels depending on its nucleic acid content (52). Mitsuda et al. (1969) showed in vitro that yeast isolates had a better digestibility than whole cells (53). Digestibilities by pepsin and trypsin were fairly comparable to casein. These results clearly show that cell wall removal is a desirable step in preparing SCP. The authors also believe that Chlorella cannot be used as whole-cell protein in human food due to inability of humans to break down the cell wall. Dam et al. (1965) had also obtained results showing the effect of algal cell wall on the poor digestibility of the material (54). Powell et al. (1961) showed in humans that ingestion of algae in amounts over 100 g/day would result in severe gastrointestinal upsets involving nausea, vomiting, abdominal distortion, flatulence and lower abdominal cramping pains (55). Allergic reactions have also been reported for algae intakes over 100 g/day (29). With algae, however, other adverse gastrointestinal responses to large doses must also be considered. According to Waslien et al. (1970), calcium and magnesium assfmilation was impaired when algae were fed at levels of 64 g/day (56). Similar results had previously been reported by Prokovskaia et al. (1968) (57).

In general, adverse gastrointestinal reactions, allergic reactions, potential danger of kidney stone formation or development of gout, and presence of carcinogenic residues in hydrocarbon, or even carbohydrate grown SCP, are the main concerns and limitations of this protein source (58).

The limiting amino acid in most microbial protein isolates tested is the sulfur-containing amino acids (43). Fortification however, is not a simple task. Methionine not only may affect the organoleptic properties of the product, but losses may occur during processing and cooking of the product. Deficiency in essential nutrients in SCP has resulted in poor protein utilization, slow growth and diseases as well, in experimental animals. A torula yeast diet as the sole source of nitrogen resulted in liver necrosis in rats due to selenium deficiency (31). The deficit in sulfur amino acids is generally less pronounced in bacterial protein than in yeast protein, thus giving bacteria a larger biological value (30). Chlorella and Spirullina, the most common algae considered for SCP also have shortages in sulfur containing amino acids (41, 59). Amino acid composition of most important protein sources as compared to SCP sources is given in Table 13.

6. Waste Materials

In general, a problem that needs to be carefully considered is the treatment of waste products originated in fermentations. Spent media, cell washings and cell walls, and chemicals from protein recovery are the main sources of waste in SCP production.

In the case of yeast, residues of hydrocarbon-assimilating yeast after alkali extraction are believed to be composed mainly of the cell wall materials: 70% polysaccharides, 19% crude protein, 1% ash and 10% moisture. Solidification, resinification and carboxymethylation have been used as possible methods of residue disposition (41).

7. Research Needed

- Effects of culture conditions and species on protein digestibility.
- Determination on the availability of vitamin and caloric content of SCP.
- Standardization of SCP production after adequate screening for strains, culture conditions, and biomass processing.
- Determination of functional properties of isolates, which is almost non-existant.
- Determination of compositions and process conditions leading to the production of SCP-based engineered foods with good organoleptic properties and nutritional value.
- Testing for safety and nutritional adequacy of products obtained from texturized SCP in long term feeding studies.

Further processing is highly necessary when one considers that in its unprocessed state, vegetable and legume flours and meals have limited appeal and hence limited applications. Texturization then becomes the key issue. New products, however, and in particular analogs, have to fulfill a number of requirements not only for their acceptability but for their suitability as food for space colonies. Some of these requirements include (60):

- Desirable size and shape.
- Suitable color, flavor and texture. They should closely

resemble the product they are substituting.

- Their shelf life should be adequate.
- The product should be able to withstand harsh processing conditions such as boiling, retorting or in general, conditions used during food preparation.

O. Protein Texturization as a Method for Production of Engineered Food

Table 14 shows the most common methods for protein texturization. In the following paragraphs, some of these methods will be discussed and emphasis will be given to those methods which present a greater potential for their application to the case of space colonies.

1. Fiber Spinning

This process is based on the unfolding of the protein chains to form filaments. These filaments are then assembled together to form a tow, cut into suitable length for handling, and by the use of binders and flavorings can be made to resemble cooked meats in appearance and texture. Properties of the fibers can be modified by the incorporation of additives such as gums and starches. Although products prepared in this manner have the advantage that they closely resemble meat products, they not only require much more sophisticated technology, but are more demanding as far as raw materials are concerned. Presence of other compounds in the raw material will interfere with the spinnability and quality of the fibers.

2. Characteristics of Fibers

-Good technological flexibility.

-Continuous filament character.

-Expensive.

-Required highly processed (purified) raw material.

-High waste production.

-High use of chemicals.

-Highly sophisticated technology and equipment.

-Alkali treatment may have an undesirable effect on the nutritional quality of the protein.

Textural quality, however, still leaves something to be desired. Shelf life is another critical issue. For instance, freshly manufactured soy filaments are cream-white in color, tender and elastic. Upon prolonged storage, before formulation, unfrozen fibers turn gray and become tough, inextensible and lose water-holding capacity (61).

3. Extrusion

Texturization by extrusion can result in a large variety of products with textures being dense, fibrous, or puffed depending on the composition of the dough and the process conditions. Oriented, expanded meat-like products have been of particular interest. Understanding of the rheological changes in food materials, particularly those associated with physical and chemical changes as a function of time has been considered as the most important requirement for the development of a better technology for extrusion processes (62).

a. Advantages

-Great production capacities in a single processing step.

-Less labor/ton of product is required as compared to any cooking system.

-It requires limited amounts of floor space per ton of production capacity.

-Extruders require very little energy and steam consumption.

-A large variety of raw ingredients can be processed: extrusion is less demanding as far as the purity and quality of raw materials is concerned.

-Versatility is a very important characteristic of extruders: interchangeable extruder components can be utilized to obtain new variety of products: the extruder assembly can be shortened or lengthened according to requirements. A variety of process conditions can also be controlled to obtain final products.

-A wide range of product forms, shapes, densities, and can be obtained. Textures ranging from crunchy to fiber-like can be developed.

-Growth inhibitors such as the ones found in soy and pulse protein can be destroyed. Undesirable enzymes also inactivated.

-HTST extrusion cookers practically do not harm protein quality and minimize nutrient losses such as vitamins, particularly if they are encapsulated.

-An excellent bacteriological status is obtained.

-Protein materials can be modified and restructured to produce texturized products.

-Extrusion can simultaneously gelatinize, expand, form and texture cereals or starches in mixture with proteins or alone.

-It permits tailoring of end products.

-Products with good shelf life are obtained.

-No effluent or other ecological hazards are originated during extrusion. Waste production is minimum.

-Extruders, dryers, and coolers are designed to be quickly and easily disassembled for clean-out.

b. Disadvantages

-A continuous structure necessary to facilitate the obtaining of fully formed items cannot be achieved.

c. Traditional Products Prepared by Extrusion (65)

Beverage powders

-soy milks

-infant foods

-hot or cold beverages for school lunch programs

-instantized hot breakfast gruels

Dry soups

-extrusion of dry flours from beans, lentils, peas and other legumes

Flake breakfast cereals

-corn flakes

-wheat flakes

-oat flakes

-enriched breakfast flakes

Meat extenders

Pasta products

-macaroni and similar products (PE)

-quick cooking noodles

d. Meat Analogs by Extrusion

Meat analogs with excellent characteristics have been processed by using a double extrusion process. A wide variety of raw materials have been used to manufacture these products. Defatted soy flour, soybean meal, wheat gluten, corn gluten, defatted cottonseed flour, vegetable concentrates, vegetable isolates, peanut flour, rapeseed flour, sesame flour, sunflower flour, mungbean flour and mixtures of these materials have been tested and found to be adequate materials to obtain dense, uniformly layered vegetable protein meat analogs. In this process a protein-water admixture is passed through a first extruding cooker where it is heated, denatured and thoroughly mixed without occuring into substantial texturization or orientation. The hot and flowable product is then allowed to pass through the atmosphere to let undesirable volatile flavor precursors such as phenolic compounds to leave the mixture. A second extruding cooker will receive the material coming from the first extruder and form it into a dense, layered, untwisted meatlike product. This second extruder is provided with an elongated processing area to allow buildup of the meat-like structure with conditions in this extruder being such as to allow the formation of layers and keeping a dense and relatively unexpanded product. Some of the characteristics of the product are the following (67):

- -Bland in flavor
- -Mouthfeel, appearance and texture of meat
- -Made to resemble ham, beef, chicken, turkey, and shrimp.
- -The product is relatively dense (25-35 lbs/cu. ft)
- -Product does not require refrigeration.
- -Can be packaged inexpensively.
- -Low moisture content (6-8% moisture content).
- -Can be readily retorted.
- -Hydrates in boiling water to about the same moisture content as meat (65%).
- -Uniform layering of protein fibers.
- -Texture can be modified and final product can have the chewiness of a tender steak or can be made as tender as mushrooms.
- -Exceptional shelf-life.
- -A large variety of materials are suitable.

It should be mentioned, however, that extrusion of meat analogs, using a single extruder, is also feasible.

e. Seafood Substitutes by Extrusion

Although not as extensively studied as the area of meat analogs, some work has been done leading to the preparation of seafood substitutes. Products with characteristics resembling shrimp, scallops, crabmeat, etc. have been obtained by a variety of processes.

Products such as shrimp, scallop, lobster, etc. substitutes have been prepared by first precipitating a curd from a protein solution such as soybean or peanut protein, followed by dispersing the curd in a microcut colloid mill. After pH adjustment, the material is finally texturized by extrusion. Modifications in process conditions such as Temperature, screw speed as well as ingredient characteristics will determine the properties of the resulting product (68).

Seafood substitutes prepared in this manner may be further processed including breading, baking, deep frying, sauteing, etc. This type of product presents the advantage over natural products that antioxidants or preservatives can be blended for uniform dispersion throughout the product. The product can be refrigerated, frozen or dried, resulting in good storage shelf life.

f. Research Required in the Area of Extrusion

- Determination of oil levels in the raw materials for the obtaining of good texture, particularly in the case of meat analogs. Use of mechanically extracted oilseeds with oil levels well above 1%.
- Use of blends to upgrade proteins and still obtain products with good quality. Determination

of what kinds of textures can be obtained by modifying not only composition but also process conditions.

-Removal of flatus problem in the case when soy-flours are used. Enzymic or chemical pretreatments of the raw material may be required.

-Control of flavor problems particularly in the case when heavy density extruded products are prepared. Genetic modification may help to ease some of the flavor problems.

-Process conditions required to optimize organoleptic and nutritional properties of end products. Although extruded materials have been used mainly at an ingredient level when a product needs to be nutritionally upgraded or modified, recent technological advances in this field clearly indicate that with further research it is possible to prepare extruded products suitable not only as ingredients or extenders but as products of their own and analogs.

5. Other Ways of Texturizing Proteins

a. Chewy Gel Formation

Chewy gels from protein materials can be obtained by using special conditions of pH, temperature, protein concentration, and with or without the aid of additives. Products obtained in this fashion can be used as meat, fish and cheese flavored substitutes. Under this category we find products such as tofu and its derivatives. These types of products present some advantages (69, 70, 71):

- -Materials are readily available and whole seeds can be used as raw material.
- -Production does not require any sophisticated equipment.
- -The process for their manufacture is simple.
- -Products prepared in this manner show higher nutritional value due to less damage to the protein which may occur during normal oil extraction processes.
- -Process can be modified to obtain different textural characteristics.
- -The product is bland in flavor and it readily accepts flavorings such as meat, cheese, etc.

However, there are also disadvantages associated with this approach:

- -The product is a substitute rather than an analog. The texture differs from the products they replace.
- -The product is highly perishable.
- -Flatulence problems still remain.
- -Labor demands are high, although mechanization of the process is feasible.
- -Process time is usually long.

Table 15 presents a summary of tofu and its derivatives, including process conditions, composition and textural properties (71). In the particular case of kori-tofu, process conditions are much more less severe than spinning and extrusion, therefore resulting into a better nutritional product. Freezing and drying conditions can be modified to obtain a wide range of textural properties. Applications of these products can be very diverse. One of the disadvantages of tofu-like material for western cultures has been the bland flavor. However, in the long run this may become a quality since the material readily accepts flavorings. Tofu-like products can be modified during the process to obtain a final product that can withstand further processing. In general this chewy gel formation can be fried, braised, broiled, barbecued, deep-fried or baked. Boiling losses seem to be greatly influenced by freezing conditions in the case of kori-tofu. In general, processing conditions will determine the performance of the material under harsh conditions such as retorting, boiling, etc.

Applications of chewy gel formations include meat and vegetable dishes, soups, salads, casseroles, dips, sauces, salad dressings and even desserts.

Modifications to the manufacture of this type of product have been introduced in order to improve flavor, body, shelf life and to adapt the process to a continuous one (72). Modifications have also been made to avoid the use of coagulants, to improve yields, to minimize waste production and to avoid the use of chemicals to modify texture (73).

b. Sausage Analogs

Sausage-like products have been formulated and processed to resemble sausage meat products, such as bologna, olive loaf, hot dogs and other sausage meats. In this process, a vegetable protein dispersion is formed into a gel system by application of heat. By using a desirable pH and with a heat setting condition a permanent gel is obtained.

Fibrous materials can be added in small amounts to the formulation to improve flavor and textural qualities; however, these materials are considered additives rather than an integral system. Mixtures of wheat gluten, soya grits and flour (24, 75) have been used as fillers.

Although a source of vegetable protein only has been found to yield meat analogs with satisfactory quality, it is recommended that at least a non-vegetable protein source be used for superior results. Albumin, casein, whey or combinations have been found to be suitable choices (74).

While fat or oil from any conventional source can be added at levels below 35% based on the total weight of the product, superior results have been observed when nonrendered fatty animal tissue is used. Juiciness of the product is highly improved due to the cellular structure of non-rendered animal fat as opposed to oil and similar sources which due to the emulsification properties of the vegetable protein, result in a degree of dryness (75).

Flavorings, spices and colorings are the remaining ingredients to obtain this type of analog.

c. Protein-lipid Films

The formation of protein-lipid films presents another alternative for texturizing proteins. The product obtained, however, has limited applications. The film can be consumed directly as an ingredient of soups or used as a sheet for wrapping and shaping ground meats or vegetables into various forms (76). The process of film formation is considered as being an endothermic polymerization of heat denatured protein simultaneous with dehydration (77). Although a variety of raw materials (i.e. peanuts, cottonseed, soybeans, etc.) are suitable for film formation, a better quality product is obtained when the high lipid content has been reduced by oil recovery. Yield and quality are quite variable. The product has great potential due to its nature, pleasing texture, and flavor characteristics. Flavor can be easily corrected. However, there are some disadvantages associated with the product or its process of manufacture. Some of those disadvantages include:

1. Extensive labor.
2. A great deal of basic and applied research is still required.
3. The process is a severe process and the protein quality is lower than the level of most derived textured vegetable protein. The product requires methionine supplementation (78,

78, 79).

Typical dried films contain approximately 55% protein, 26% neutral lipids, 2% phospholipids, 12% CHO, 2% ash and 9% moisture (76).

6. Restructured Meats

The area of restructured meats deserves some consideration. Restructured meats present the advantage that animal protein supplies can be stretched. Also, not very appealing parts of poultry and beef can be used to formulate good quality products.

Restructuring of meats offers several possibilities in the space era. Weight and shape control, as well as formulation can be easily attained. Control of fat, protein, vitamins and mineral content is possible. Organoleptic properties such as mouthfeel, juiciness and bind of the product can be controlled. Formulation as well as processing conditions can determine the properties of the final product. Minimization of waste production as well as good nutrition can be achieved this way. "Coextrusion" processes can be designed as to obtain more complicated systems such as bacon-like products, in which the product is laminated to reproduce fat and lean portions (80).

P. Process and Equipment

In Table 16 we are presenting some of the most important requirements for food technology for its application to the space program.

We consider that in a system where hydroponic plants are available, consumption of animal protein should be minimized in order to have a system geared towards self-sufficiency. Extrusion presents one of the better alternatives for the production of engineered foods for partially closed life support systems.

Extrusion presents the advantages that a large number of raw materials can be processed and that process conditions can be modified to obtain a large number of products. From the point of view of equipment requirements, they are minimum. For the production of meat analogs, for instance, a mixer, two (1) extruders, a steam dryer and an electrode boiler are all the necessary pieces of equipment required, with the additional advantage that they can be used for other processes.

Equipment (extruders) can most likely be modified to take advantage of the hard vacuum present in space. Hard vacuum can possibly help in the removal of volatile flavor components present in oil seeds concurrent with controlled unidimensional expansion.

Considerations regarding the nutritional quality of suggested engineered foods have been based on the diet scenario proposed by the 1977 Ames Summer study on space settlements. According to this diet, it has been observed that in order to provide the amount of oil required, a large amount of soybeans needs to be processed. It has been determined that the most suitable approach for the obtaining of this oil would be a mechanical oil-water extraction of the soybeans. Although, from the point of efficiency we are dealing with oil recoveries in the range of 65%, implying a higher level of waste materials, we would have the clear advantage of dealing with a process that will not require the use of solvents. Solvent extraction gives a 95% yield. Most of the waste material originated in this process, however, can be used to obtain engineered foods. The partially defatted soymeal (waste) contains a large amount of good quality protein. In a previous section, we have presented some relevant information on the most common ways of protein texturization. It should be added at this point that most information available in the literature is for soy proteins. Other vegetable protein sources have not been as extensively studied.

In regard to the utilization of soymeal and other vegetable meals, we consider that due to the problems encountered, such as high phytate levels and an appreciable level of undesirable oligosaccharides, and our objective in trying to minimize the use of chemicals, some consideration should be given to the area of membrane processing. Ultrafiltration (UF) for instance, not only can remove efficiently, components, but it is a very mild process. The functional properties of the native proteins are retained almost intact. Other protein sources such as SCP, can possibly be processed in the same way to remove a large number of undesirable components.

UF, although not as extensively studied as methods of protein precipitation for the preparation of protein concentrates and isolates, has been applied successfully to protein sources such as soy, cottonseed, sunflower, rapeseed and fababeans (81, 82).

Solubilities of the proteins and of undesirable components will determine the conditions for the process of UF. The protein solubility of faba bean meal, for instance, is 85% in tap water without any addition of base, clearly facilitating the process of UF and minimizing the use of chemicals. Other protein sources may require different pH conditions.

A suggested flow diagram is given for the handling of oilseeds for oil extraction and protein purification (Fig. 1).

It should be mentioned that UF does not require a completely defatted material.

Serious mineral deficiencies in humans can be caused by high levels of phytic acid in the diet. Humans do not possess any phytase activity to destroy the chelating ability of phytic acid, thus diets containing a large portion of cereals and legumes will result in impaired absorption of some minerals. The following phytic acid contents have been observed for:

Soybeans	1.00-1.47% dry weight
Oats	0.79-1.01% dry weight
Barley	0.97-1.16% dry weight
Wheat	0.68-1.22% dry weight

These values were observed in 15 cultivars of soybeans, 19 cultivars of oats, 18 cultivars of barley, and 38 cultivars of wheat (83). Processing does not remove much of the phytic acid. In soybeans for instance, as much as 70% of the phytic acid present in the original soybean, remains in the concentrates and isolates. Environmental conditions seem to play an important role on the phytic acid concentrations. In oats, for example, cultivars do not seem to have a major influence as compared to environmental conditions (84).

A series of methods have been proposed for the removal of phytic acid. One of our main concerns however, is to minimize the use of chemicals. Removal of phytic acid, through the use of endogenous enzymes (phytases) presents some problems. In the case of soybeans, phytase levels are relatively low, aggravated by some degree of enzyme inactivation due to preliminary heat treatments. Nevertheless, authors such as Okubo et al. (1975) have obtained some positive results. Working with soybean meals, the authors found that when conditions are selected close to the optimum conditions for plant phytases (pH 5.5 and 55 C) sufficient phytase activity can be present to effect phytate removal. 90% removal of phosphorous was achieved with active phytase as compared to 74% removal when no phytase activity was present. Phytic acid was removed by ultrafiltration (UF)(85). UF presents a good alternative not only for low-phytate products but also for the removal of low molecular weight impurities. Conditions have to be provided, however, to promote dissociation of phytate-protein complexes. Authors such as Omosaiye and Cheryan (1979) have suggested that phytate removal should be carried out at pH 6.7. At this pH, phytic acid is almost completely water soluble. At lower pH (5.5), UF using hollow-fibers presents problems associated with protein instability which may result in plugging of the fibers (86). UF is a very desirable method in the obtaining of good quality protein due to the low temperatures involved and the mild conditions required for this process. Functional properties are expected to be consequently highly improved.

Removal of oligosaccharides such as stachyose and raffinose from oilseed meals is highly desirable due to the inability of humans to digest these materials. In soybeans, stachyose content is in the range of 5-8% d.b. and raffinose levels vary from 1-2% d.b. Although plant breeding has been suggested to eliminate the presence of these sugars, not much success has been achieved. Soaking of the oilseeds for long times at low pH (4.3) has been found to help to decrease the levels of oligosaccharides.

Washing of extruded products (water used for rehydration) can also help to lower the level of these sugars. Concentrates and isolates of oilseeds do not present a problem since a large portion of the carbohydrate components of the oilseeds have been removed. Ultrafiltration has been successfully used for this purpose and up to 96% of the oligosaccharides have been removed by two-stage ultrafiltration (87).

III. Summary

SCP, although very promising from nutritional and productivity points of view, presents the problem of safety. With the exception of yeast protein, other SCP sources have not been approved for human consumption. Furthermore, extensive processing is required, not only to obtain a product with good organoleptic and functional characteristics, but to remove traces of undesirable components.

Soy protein technology is unquestionably the most advanced for the oilseeds. However problems still remain with the soymeals, due to strong flavors, presence of undesirable hexoses and high levels of phytic acid. Most advantages that other vegetable proteins have from the point of view of functionality are lost upon extraction and processing.

Peanut protein presents the advantage that isolates are suitable for their use in beverages. Most other vegetable proteins present strong flavors and poor solubility, which make them undesirable for this type of product. Peanut proteins have also been found to be suitable in the preparation of simulated cheese.

Membrane processing seems to be an excellent alternative in the purification of proteins from undesirable components. Some research is still required in this area. The mildness of the process and the minimum use of chemicals are two of the most important features of this process. A series of novel protein sources such as rapeseeds, sunflower, SCP, etc. can be treated by UF. The presence of toxic and undesirable components and the harsh processes required for their removal have limited their use. The drastic conditions used, most times result in deterioration of their functional properties.

The use of protein blends for coextrudates or the production of other fabricated foods presents a good alternative to upgrade nutritional quality.

Extrusion presents perhaps the most suitable approach for the obtaining of meat and fish analogs or substitutes. A large number of products can be obtained by extrusion. Changes in formulation and process conditions will result in different product properties. Equipment requirements are minimum. However, a great deal of basic research is still required.

Chewy gel formations such as tofu-like products and sausage analogs present some potential as fabricated foods. Some basic research in the area is also required. Mechanization in the production of tofu-like products is still in a developing stage.

No attention has been paid so far to the area of carbohydrates. In the following sections this topic will be covered.

IV. Suggested Work

Research should be geared towards the production of high protein foods to replace meat, fish, and cheese. A list of suggested fabricated foods in order of priority is presented in Table 17.

One of the goals is to be able to obtain a variety of textural properties using a minimum number of ingredients by modifying formulations and process conditions. Soy protein, peanut protein, cereal protein (wheat and oats) and SCP (yeast) should be considered as starting raw materials. We consider that these would be the most suitable protein sources after an extensive study on their availability, nutritional quality, functional properties and processing required for their transformation from raw materials to food ingredients.

Basic research is needed to determine reactions and properties of novel proteins. Forecasting the functional properties of proteins in complex food sytems is not simple due to the high complexity of proteins.

Correlations between composition and processing variables and the microstructure of fabricated foods as affecting textural properties should be established.

Performance upon extrusion of partially defatted oilseed flours should be studied. It should be mentioned at this point that most extruded products have been made using defatted oilseed flours and protein concentrates and isolates. It has been shown that stretching of the protein molecules, a key issue in the production of meat analogs, is affected by other components in the system. Another factor of importance is the behavior of mechanically extracted oilseeds, which is expected to be different from the one for solvent extracted materials. Solvents do modify the properties of protein materials.

The use of protein blends as a way of preparing more wholesome foods, avoiding excessive amino acid fortification, should be one of our primary concerns. Protein blends should be geared to obtain an amino acid profile in the final product approaching that of casein. Characteristics of co-extrudates should be determined. Computer blending presents a very interesting technique leading to an increased efficiency in the use of proteins without the loss of functional properties, development of undesirable flavors and optimization in the degree of fortification (88, 89). Information on essential amino acid compositions, functional properties correlated to protein levels, requirements of crude protein content, etc. can be supplied to the computer to obtain optimum formulations. Critical parameters can be determined after some preliminary experiments.

High levels of phytic acid and hexoses responsible for the flatus problem in crude oilseed meals, are problems requiring some study. Enzymatic or chemical pretreatments may be required to minimize these two undesirable factors. UF is another alterative; perhaps the most suitable one to solve this problem.

As an alternative for obtaining improved protein materials, some consideration should be given to the area of coisolates. Coisolates present several desirable characteristics.

A. Improved amino acid pattern of the resulting mixture (90, 91).

B. Removal of undesirable components, such as hexoses and toxic factors, from the raw material.

C. Improved functional properties.

Modifications to the extrusion process for its adaptation to space colonies are needed once behavior of the raw materials is established.

Fortification should be considered in regard to mineral and vitamin content. Microencapsulation as well as surface application may be desirable approaches.

Studies on the acceptability of and tolerance to the long term ingestion of newly developed engineered foods must be conducted.

Once raw materials have been selected and processing operations have been chosen, the area of waste minimization and treatment must be considered.

Table 18 presents a preliminary list of research priorities based on the food supply scenarios.

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Table 1. Potential Food Supply Scenaria

I. Food Resupply.

All foods are generated on earth and periodically resupplied to the habitat.

II. PCELSS-no animals.

Most or all the vegetable food stuffs are grown on board. All food stuffs derived from animals are periodically resupplied from earth.

III. PCELSS-limited animal population.

All of the vegetable food stuffs are grown on board. Staples derived from animals (e.g., dairy products and eggs) are produced on board from a small animal population. Meat and fish are periodically resupplied from earth.

IV. CELSS.

All vegetable and animal food stuffs are produced on board. Vitamins and trace diet elements that are not contained in sufficient quantity by food stuffs are carried on board as diet supplement capsules.

Table 2. Potential Benefits of Engineered Foods (92)

- "Complete" infant formulas
- "Complete" diets for special uses
- Modify caloric density
- Specify ingredients and nutrients
- Improve dietary patterns
- Offset disadvantages of some foods
- Better use of protein sources
- Utilize by-products
- Eliminate naturally occurring toxicants
- Convenience foods: good nutrition
save time
- Uniform quality, palatability, and stability
- Meet needs of industrialized society
- Stretch colony food supplies
- Good nutrition at low cost

Table 3.

Protein Content and Amino Acid Composition of Selected Food Legumes and Cereals (19)

Food	Protein, %	Amino acid composition, % of total protein								
		Lys	Met	Thr	Trp	Ile	Leu	Tyr	Phe	Val
Soybean	34.9	6.9	1.5	4.3	1.5	5.9	8.4	3.5	5.4	5.7
Peas	23.8	7.3	1.2	3.9	1.1	5.6	8.3	4.0	5.0	5.6
Beans	21.4	7.4	1.0	4.3	0.9	5.7	8.6	3.9	5.5	6 1
Oats	14.2	3.7	1.5	3.3	1.3	5.2	7.5	3.7	5.3	6.0
Barley	12.8	3.4	1.4	3.4	1.3	4.3	6.9	3.6	5.2	5.0
Wheat	12.3	2.8	1.5	2.9	1.2	4.3	6.7	3.7	4.9	4.6
Rye	12.1	4.1	1.6	3.7	1.1	4.3	6.7	3.2	4.7	5.2
Sorghum	11.0	2.7	1.7	3.6	1.1	5.4	16.1	2.8	5.0	5.7
Maize	10.0	2.9	1.9	4.0	0.6	4.6	13.0	6.1	4.5	5.1
Rice	7.5	4.0	1.8	3.9	1.1	4.7	8.6	4.6	5.0	7.0
Ref (whole egg)	12.8	6.4	3.1	5.0	1.7	6.6	8.8	4.3	5.8	7.4

Table 4.

Tentative Nutrient Profiles Stipulated By FDA (93)

Proteins and nutrients per gram of protein requirements for nutritional equivalence in vegetable protein substitute foods.

Nutrient	Class 1 Breakfast meats, Lunch meats	Class 2 Seafood, Poultry, and meat other than in Class 1	Class 3 Eggs	Class 4 Cream Cheese	Class 5 Cottage cheese	Class 6 Natural cheeses other than those in Class 4 and 5
Vitamin A (IU)	13.00	13.00	91.00	146.00	—	39.0
Thiamine (mg)	0.02	0.02	0.01	—	—	—
Riboflavin (mg)	0.01	0.01	0.04	0.02	0.01	0.02
Niacin (mg)	0.30	0.30	—	—	—	—
Pantothenic Acid (mg)	0.04	0.04	0.22	—	0.02	—
Vitamin B_6 (mg)	0.02	0.02	0.02	—	0.01	—
Vitamin B_{12} (ug)	0.10	0.10	0.15	—	0.05	0.05
Iron (mg)	0.15	0.15	0.19	—	—	—
Magnesium	1.15	1.15	—	—	—	—
Zinc (mg)	0.50	0.50	0.22	—	0.06	0.24
Copper (ug)	24.00	24.00	14.00	—	—	—
Potassium (mg)	17.00	17.00	10.00	—	6.00	—
Calcium (mg)	—	—	4.3	9.00	4.00	28.00
Phosphorus (mg)	—	—	—	—	—	19.00
Vitamin E (IU)	—	—	0.15	—	—	—
Biotin (ug)	—	—	1.70	—	—	—
Folic Acid (ug)	—	—	—	—	1.00	—
Protein (% by weight)	13.00	18.00	13.00	9.00	14.00	24.00

Protein requirements refer to the percentage of protein by weight in the substitute product when formulated to resemble the traditional food.

Source: Dr. J. E. Vanderveen, Division of Nutrition, FDA, Washington, D.C.

Table 5.

TECHNICAL FEASIBILITY OF FORTIFYING CEREAL GRAIN-BASED PRODUCTS AS RECOMMENDED (94)

	[illegible]	Thiamine	Riboflavin	Niacin	[illegible]	Folic Acid	Iron	Calcium	Magnesium	Zinc	Comments
Flour											
Extended Shelf Life	[illegible]	A	A	A	[illegible]	B	A	A	B	B	Consumer acceptance problems indicated from preliminary results of extended storage studies at elevated temperatures and humidities.
Industrial (short shelf life)	A	A	A	A	A	A	A	A	A	A	
Farina	A	A	A	A	A	A	A	A	A	A	Consumer acceptance problems indicated from preliminary results of extended storage studies at elevated temperatures and humidities.
Corn											
Flour	A	A	A	A	A	A	A	A	A	A	
Meal	A	A	A	A	A	A	A	A	A	A	
Grits	A	A	A	A	A	A	A	C	A	A	Calcium addition should be no more than 300 mg/lb.
Rice	A	A	A	A	A	A	A	C	C	A	Addition of riboflavin may cause consumer acceptance problems. Ferric orthophosphate recommended as iron source. Calcium and magnesium addition might be possible by change in enrichment process to use of "synthetic kernel" technique.
Bread	A	A	A	A	A	A	A	A	A	A	Nutrient additions adjusted for levels of nutrients inherent in flour.
Soft Sweet Goods											
Cakes	A	A	A	A	A	A	A	A	A	A	
All Others	D	D	D	D	D	D	D	D	D	D	Would appear to be technically feasible based on results obtained on bread and cake. Confirmation through testing suggested.
Cookies and Crackers	A	A	A	A	A	A	A	A	A	A	Iron used at 40 mg/lb.
Pasta	A	A	A	A	A	A	A	B	B	A	Iron used at 40 mg/lb.
Refrigerated Doughs	D	A	A	A	D	D	A	D	D	D	
Frozen Products											
Unbaked	D	A	A	A	D	D	A	A	D	D	
Baked	D	A	A	A	D	D	A	A	D	D	
Prepared Mixes	D	A	A	A	D	D	A	D	D	D	

1. Key:
   A = appears to be technically feasible
   B = insufficient data to evaluate technical feasibility
   C = not technically feasible at present time
   D = no data submitted for committee review
2. Based on level of 16.5 mg/lb rather than NAS proposal of 40 mg/lb.

Table 6. Rank of Selected Crops in the United States According to Production of Calories and Protein per Acre (19)

Crop	Calories		Protein	
	1000 g	Rank	1000 g	Rank
Sugar cane	34,940	1		
White potatoes	10,518	2	290	2
Sugar beets	9,311	3		
Maize	8,462	4	216	3
Rice	7,019	5	146	8
Sorghum	5,355	6	177	4
Barley	4,020	8	111	9
Winter wheat	3,739	10	105	10
Soybeans	3,510	11	297	1
Beans	2,617	15	172	7
Peas	2,487	16	176	6
Rye	2,477	17	90	15
Oats	1,861	19	68	17

Table 7. Calorie and Protein Production of Selected Cereals and Food Legumes in the United States (19)

Crop	High state av yield, lb	Calorie content per lb	Protein content per lb
Cereals			
Maize	5359	1579	40.4
Spring wheat	1518	1497	63.5
Winter wheat	1800	1497	55.8
Rice	5242	1339	27.9
Sorghum	3556	1506	49.9
Barley	2545	1579	43.5
Oats	1818	1024	37.3
Rye	1635	1515	54.9
Legumes			
Soybeans	1920	1828	154.7
Beans	1697	1542	101.2
Peas	1613	1542	109.3

Table 8. Functional Properties of Soybean Proteins (95)

Property	Protein Form Used*	Food System
Emulsification		
Emulsion formation	F,G,C,I	Frankfurters, bologna, sausages
	F	Breads, cakes, soups
	I	Whipped toppings, frozen desserts
Emulsion stabilization	F,G,C,I	Frankfurters, bologna, sausages
	F	Soups
Fat absorption		
Promotion	F,G,C,I	Frankfurters, bologna, sausages; meat patties, simulated meats
Control	F,I	Doughnuts, pancakes
Water absorption		
Promotion	F,C	Breads, cakes, confections, simulated meats
Control	F	Macaroni
Retention	F,C	Breads, cakes, confections
	C	Meat patties
Texture		
Viscosity	F,C,I	Soups, gravies, chili
Gelation	F,C,I	Ground Meats
	I	Simulated ground meats
Shred formation	F,I	Simulated meats
Chip and chunk formation	F	Simulated meats, fruits, nuts, and vegetables
Fiber formation	I	Simulated meats
Spongy structure formation	I	Simulated meats, dried tofu
Dough formation	F,C,I	Baked goods
Adhesion	C,I	Sausages, luncheon meats, meat patties, meat loaves and rolls, boned hams
Cohesion	F,I	Baked Goods
	F	Macaroni
	I	Simulated meats
	I	Dried tofu
Elasticity	I	Baked goods
	I	Simulated meats
	I	Gels
Film formation	I	Frankfurters, bologna
Color control		
Bleaching	F	Breads
Browning	F	Breads, pancakes, waffles
Aeration	I	Whipped toppings, chiffon mixes, confections

*F,G,C, and I represent flours, grits, concentrates, and isolates, respectively.

Table 9. Protein Yields of Various Crops (17)

	Yield/kg crude proteins/ha per year
Wheat grain	550 kg
Sunflower	550 kg
Potatoe	600 kg
Rapeseed	700 kg
Field bean	800 kg
Soybean	850 kg
Mustard	1,800 - 2,000 kg
Alfalfa	2,000 - 2,500 kg

Table 10.
Protein productivity data for algae compared with other sources (29)

Protein source	Protein yield (kg dry weight/ha/year)
Spirulina platensis	24 300
Chlorella pyrenoidosa (Emerson)	15 700
Clover leaf	1 680
Grass	670
Peanuts	470
Peas	395
Wheat	300
Milk from cattle on grassland	100
Meat from cattle on grassland	60

Table 11. Desirable Properties of Microorganisms Used for Production of SCP(partly from Enebo)(23)

Composition of the organism:

- -High-protein content with high percentage of essential amino acids
- -Non-toxic
- -Highly digestible
- -Good taste
- -High content of nutrients other than protein
- -Fat and carbohydrate content of high quality

Other essential properties:

- -Rapid growth on simple media in submerged culture
- -Efficient energy utilization
- -Tolerance towards toxic compounds in the medium
- -Tolerance towards mechanical strains during the culture process
- -Resistance to contamination
- -Simple separation
- -Easy protein extraction
- -Minimum waste production

Table 12. Maximum Levels of Torula Yeast Which Could be Added to Various Prepared Foods[a] From the Standpoint of Acceptability (96)

Food Item[b]	
Soups	12[c]
Meat and fish casseroles	22
Sauces	25
Salad	16
Salad dressing	83
Vegetables	14
Cereals	13
Eggs	18
Stewed fruit	21
Puddings	17
Baked goods	26

[a]Klapka et al., 1958. Based on 191 days trial with 300 hospital patients.

[b]Each value represents the average of a number of food items within each of the listed categories.

[c]In percent of each tested.

Table 13. The essential amino acid content of some protein sources.

acid	Essential (FAO)	Scenedesmus obliquus	Chlorella	Spirulina maxima	S. cerevisiae	Candida utilis	C. lipolytica (gas oil)	Pseudomonas (methanol)	H. eutropha	Esso-Nestle protein (bacteria)	Whole wheat	Whole egg	Beef	Cow's milk	Soya meal	Ground nutmeal
sine	4.2	5.7	4.9	4.6	7.7	7.1	7.8	5.3	8.6	6.5	2.8	6.5	8.4	7.8	6.3	3.5
reonine	2.8	5.1	3.9	4.6	4.8	6.1	5.4	4.5	4.5	4.0	2.9	5.1	4.3	4.6	4.0	2.7
thionine	2.2	1.7	1.4	1.4	1.7	1.6	1.6	1.8	2.7	2.0	1.5	3.2	2.4	2.4	1.4	0.9
stine	2.0	0.6	0.8	0.4	–	0.4	0.9	0.3	–	0.6	2.5	2.4	1.3	0.9	1.8	1.5
yptophan	1.4	1.5	1.8	1.4	1.0	1.5	1.3	–	1.[illegible]	0.9	1.1	1.6	1.2	1.4	1.5	1.1
oleucine	4.2	3.8	3.1	6.0	4.6	6.0	5.3	3.9	4.6	3.6	3.3	6.7	5.2	6.4	5.3	4.1
ucine	4.8	8.4	6.8	8.0	7.0	9.1	7.8	7.0	8.5	5.6	6.7	8.9	8.0	9.9	7.7	6.0
line	4.2	5.7	4.8	6.5	5.3	7.3	5.8	5.9	7.1	4.5	4.4	7.3	5.5	6.9	3.5	4.9
enylalanine	2.8	5.1	3.5	5.0	4.1	5.3	4.8	4.2	4.0	2.9	4.5	5.8	4.0	4.9	5.0	5.0

[a]Expressed in grams per 16 g nitrogen.

Table 13A.

Amino acid composition of fungi, mushrooms, fish meal, and FAO reference proteins—g/100 g protein. (96)

Amino acids	FAO reference protein	Fungi	Mushroom	Fish meal
Arginine	—	4.3	7.85	5.0
Histidine	—	2.98	2.12	2.3
Isoleucine	4.2	3.52	2.70	4.6
Leucine	4.8	4.46	5.12	7.3
Lysine	4.2	5.53	3.84	7.0
Methionine	2.2	1.6	0.90	2.6
Phenylalanine	2.8	2.5	2.51	4.0
Threonine	2.8	3.34	2.98	4.2
Tryptophan	1.4	0.74	0.86	1.2
Valine	4.2	4.0	3.36	5.2
Cystine	2.0	—	—	1.0

Table 14. Methods for Texturizing Proteins

Fiber spinning
Extrusion
Chewy gel formation
Autoclaving coagulation
Pressure variation sponge formation
Non-spinning fiber formation
pH treatment of granules

Table 15. Tofu and Its Derivitaves (71)

	Fresh Tofu				Tofu Derivatives	
	Momen	Soft	Kinu	Packed	Aburage	Kori Tofu
Water Added (No. of Times)	10	7	5	5	10	15
Coagulant	$CaSO_4$	$CaSO_4$	$CaSO_4$ and/or GDL	GDL and/or $CaCl_2$, $CaSO_4$	$CaSO_4$	$CaCl_2$
Processing	Thorough elimination of whey	Elimination of whey	Coagulation of whole soybean milk without elimination of whey.	Cooked soybean milk is packed immediately after addition of coagulant and reheated. Whole soybean milk is coagulated.	Soybean milk is moderately heated and coagulated with thorough elimination of whey. Fresh tofu is fried in oil.	Soybean milk is coagulated with continuous stirring and eliminated whey. Fresh tofu if frozen at −20° C overnight, kept at 0 to 5° C for 2–3 weeks, thawed, and dried.
Chemical composition						
moisture (%)	86.8	88.9	89.4	90.0	44.0	8.1
crude protein (%)	6.8	5.7	5.0	4.5	18.6	50.2
crude fat (%)	5.0	3.8	3.3	3.2	33.1	33.4
ash (%)	0.6	0.6	0.6	0.6	1.4	2.8
Ca (mg %)	120.0	90.0	90.0	35.0	300.0	590.0
Texture	Hard, rough	Intermediate between Momen and Kinu	Soft, smooth	Soft, smooth, and fragile	Before frying fresh tofu for Aburage is harder than tofu for Momen. Rough, coarse Aburage is texturized and chewy.	Before freeze-drying, fresh tofu for Kori tofu is harder than tofu for Aburage. Coarse, lumpy Kori tofu is spongy, elastic, and chewy.

Table 16. Process and Equipment Design

A. Flexibility and versatility

B. Small scale of operations

C. Adaptation to habitat conditions

1. Lack of chemical and noise pollution
2. Reduced atmospheric pressure operation
3. Different "gravity" conditions
4. Utilization of solar energy and "hard vacuum"
5. Provision for "total recycling"
6. Area, volume and equipment configuration
7. Crew-size requirements

D. Adaptation to "remoteness" from earth industries

1. Maintenance and replacement of parts
2. Fail-safe operations
3. Simplicity
4. Minimize the utilization of chemicals

E. Provide capability for modification:

Provide for "the unexpected"

Table 17. Possible Fabricated Foods*

Food supply scenario II:

First priority

sausage links analog

bacon analog

fortified breakfast cereals (high protein cereals)

breakfast squares (high protein content)

beef analog

chicken analog

ham analog

fish analog

sausage analog

crabmeat-like spread and other spreads

imitation cheese

enriched pasta with fortified protein

instant soups

Second priority

fortified drinks (powder)

imitation drinks (soymilk, etc.)(powder)

scrambled egg substitutes

fruit analogs

Food supply scenario III:

Same as for food supply scenario II except for imitation drinks and scrambled egg substitutes.

Table 17. (cont.)

Food supply scenario IV:

restructured meats

fruit analogs

Some of the products listed under food supply scenario II can be used here to minimize animal protein consumption and to upgrade existing protein resources.

*Products on this list can be obtained from the same raw materials by using different formulations and process conditions.

Table 18 Potential Food Supply Scenarios

I. Food Resupply.

All foods are generated on earth and periodically resupplied to the habitat.

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III. PCELSS-limited animal population.

All of the vegetable food stuffs are grown on board. Staples derived from animals (e.g., dairy products and eggs) are produced on board from a small animal population. Meat and fish are periodically resupplied from earth.

IV. CELSS.

All vegetable and animal food stuffs are produced on board. Vitamins and trace diet elements that are not contained in sufficient quantity by food stuffs are carried on board as diet supplement capsules.

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 1.
FLOW DIAGRAM FOR OIL AND PROTEIN EXTRACTION FROM OILSEEDS.