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DEVELOPMENTS AND FUTURE TRENDS IN NON-ANIMAL SOURCES OF PROTEIN

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SUMMARY

Production of imitation meats made in the United States from soybean protein is expected to increase by 1985 to 10% of whole meat and up to 30% (as meat extenders) of comminuted meats. Since the demand for meat will increase faster than expansion of the substitutes, there will be a net increase in real-meat demand in that country. Imitation cow's milk is not yet in successful production, but predictions are that it will capture a substantial share of the market, as imitation cream and substitute mother's milk have already done. Soy protein will be replaced by other non-animal sources for formulating of new foods when Europe, Japan and other countries enter the field. Single cell protein (yeast), pure amino acids, or leaf protein may be the dominant sources by the turn of the century.

The imitation foods are not expected to solve the world protein problem because their cost is relatively high and production requires high technology. The best hope continues to be genetic manipulation of staple cereals for high yield, higher protein, and improved amino acid balance.

THE DEVELOPMENT of imitation animal foods in the United States will receive most attention in the discussion that follows because that country is a major market for animal proteins, and that is where the present trend in imitations started, and is expanding rapidly.

Non-animal proteins in competition with animal proteins may be listed as follows:

(1) Meat analogues: Imitation meat in which all the protein derives from non-meat sources.

(2) Meat extenders: Non-meat protein products to be added to comminuted or minced meat products up to a maximum of perhaps one-third of the protein. There is a two-way competition here—the non-meat with the meat, and milk versus soy protein as the extender.

(3) Substitute mother's milk: Infant formulae manufactured, usually from a base of cow's milk protein, but increasingly from soy protein isolates fortified with methionine. The soy based formulae are for use by infants subject to allergic reaction to milk protein. However, it is sur-

prising how many mothers are becoming anxious about their babies' allergies, real or supposed. The soybean milk preparation used in China, as well as the product made from peanut protein in India and called "Lact-tone", can best be catalogued as substitute mothers' milks, since they are used mainly for infant and very young child feeding.

(4) Imitation milk: Products formulated from ingredient parts to resemble and replace fluid cow's milk. This does not include filled milk which is simply cow's milk in which butterfat has been replaced by vegetable fat. In the United States fluid cow's milk is a standard and commonly used meal beverage for adults, and imitation milk would have to be accepted by adults. At present no truly imitation milk is on the market, although predictions indicate a major market penetration in about ten years time.

(5) New convenience foods: Foods which do not directly resemble an existing food but which may be used in place, or as a substitute, for a familiar food. Examples would include dry coffee whiteners to replace coffee cream, instant breakfasts which are really milk extenders, and a variety of protein-containing soft drinks and a variety of special dietary foods.

(6) Proteins as food additives: Protein concentrates are added to certain foods for technological reasons; milk proteins and soy proteins compete as additives to baked goods, breakfast cereals, processed meats and pet foods.

(7) Another form of competition would be one in which the nutritional quality and quantity of standard staple cereal grains are improved by genetic manipulation or fortification so that animal proteins become unnecessary in the diet for the health and wellbeing of population groups.

The concept of inexpensive meatless meat and other imitation animal food products has become headline news for a world that has just awakened to the existence of extensive human dietary protein deficiency in developing countries. Popular articles, and some technical ones, too, imply that new protein foods such as imitation meat and milk will solve the world protein problem. This probably is not likely. The manufacture of such foods requires a sophisticated technology which most developing countries do not yet have. The world protein problem is most likely to be solved by improvement of the staple cereal grain foodstuffs so that their consumption in a normal dietary pattern will supply all of the necessary amino acids in proper balance.

WORLD NON-ANIMAL PROTEIN PRODUCTION

The annual biosynthesis of non-animal protein is very high (Table 1). Agricultural production, including permanent pastures, produced 3,000 million metric tonnes as protein in 1970; this is equivalent to more than 2 kg per person per day. Then there is the protein produced by wild plants and forests. Many times more must surely be produced by plankton and weeds in the world's waters. In addition, there is the currently small but potentially limitless microbiological and chemical synthesis of amino acids and proteins.

TABLE 1: WORLD NON-ANIMAL PROTEIN SOURCES: 1970

	Million Metric *Total*	*Tonnes* *Protein*	*Protein* (*g/day*/caput)
(1) Agricultural crops*			
Cereal grains	1,200 × 10% =	120	90
Potatoes and yams	442 × 2% =	9	7
Pulses	44 × 9% =	4	3
Oil seeds	110 × 25% =	28	20
(2) Permanent pastures* (Area, 3,000M ha; protein yield, 1,000 kg/ha)			
Total protein from pastures		3,000	2,200
(3) Wild plants, forests, etc.			?
(4) Water plants and plankton			?
(5) Microbiological production of amino acids and protein			?
(6) Chemical synthesis of amino acids and proteins		0.01	—
Totals		3,160	2,320

*Source: FAO (1971). *Per caput* calculation based on 3,600 million people.

There is no lack of protein raw material and there is great opportunity for innovative application of technological and manufacturing skills to convert just a small part of this mass into acceptable, high quality protein foods. Of course these foods need not necessarily be created in the image of animal foods, but to do so facilitates acceptability and market penetration.

THE NUTRITIONAL QUALITY OF PROTEINS

Since imitation animal foods will be expected to equal the natural product in nutritional value (IUNS, 1971), it is helpful if the protein raw material has a good balance of amino acids to start with. As shown in Table 2 the

TABLE 2: ESSENTIAL AMINO ACID (EAA) CONTENT OF FOODS (g/16g N)

Food	*LYS*	*TRY*	*HIS*	*ISL*	*LEU*	*VAL*	*THR*	*AAA**	*SAA†*	*EAA Total*	*Reference*
Whole egg	7.0	1.5	2.4	6.3	8.8	6.8	5.1	9.9	5.8	54	(340)
Whole milk	7.3	1.4	2.9	5.3	9.9	6.4	4.2	9.8	3.5	51	(373)
Meat (beef)	8.9	1.1	3.4	4.8	8.1	5.0	4.6	8.0	4.0	48	(319)
Soy flour	6.4	1.3	2.5	4.6	7.8	4.8	4.0	8.1	2.6	42	(71)
Yeast (petro)	7.0	1.4	2.0	4.5	7.0	5.4	4.9	7.9	2.9	43	(390d)
Lucerne conc.	6.0	1.7	2.4	4.8	8.3	5.7	5.4	11.3	2.7	48	‡
Wheat germ	6.5	1.1	2.9	3.6	6.9	5.0	4.2	7.2	4.0	41	(24)
Rapeseed meal	6.3	1.7	3.3	3.9	6.9	5.3	4.1	7.2	4.5	43	§
Peanut meal	3.5	1.0	2.4	3.4	6.4	4.2	2.6	8.9	2.4	35	(57)
Cottonseed meal	4.4	1.3	2.7	3.3	5.9	4.6	3.3	8.1	2.8	36	(112)
Sunflower seed	3.6	1.4	2.3	4.3	6.4	5.1	3.7	6.3	3.4	37	(174)
Safflower seed	3.1	1.0	2.4	4.1	6.2	4.9	3.0	5.9	2.3	33	(166)
Potato	4.8	1.6	1.5	3.8	6.0	4.6	3.6	6.8	1.9	35	(36)
Wheat flour—70%	2.1	1.1	2.1	3.6	7.0	4.1	2.7	7.2	4.0	34	(28)
Rice	3.6	1.2	2.4	4.2	8.2	5.8	3.3	8.1	3.7	41	(16)
Rice—IR8	3.6	1.0	2.5	3.5	7.8	6.3	3.5	9.2	4.3	42	(17a)
Maize	2.7	0.7	2.7	3.7	12.5	4.8	3.6	8.7	3.5	43	(9)
Maize—opaque 2	4.2	1.3	3.5	3.2	8.4	4.9	3.3	8.3	3.1	42	(9a)

Data source: Recalculated to amino acids per 16g N from data in FAO (1970), with the food identified by the item number in parentheses.

*Aromatic amino acids (TYR plus PHE).

†Sulphur amino acids (MET plus CYS).

‡Hartman, *et al.* (1967).

§Average of items 1706 and 1709 in Harvey (1970).

items from soy flour to rapeseed are about equivalent to animal proteins except that soy, yeast, and lucerne are low in sulphur amino acids. Supplementation with methionine, which costs about 2 cents per 10 g, can correct this at little expense. However peanut meal and the non-legume oil seeds are also low in lysine and threonine and these are the critical shortfalls in the cereal grains that contribute two-thirds of the daily protein to two-thirds of the world's people.

If the cereal grains can be genetically manipulated to high yield, higher protein, and improved amino acid balance, the world will be a long step toward solving its protein problem. The composition of opaque-2 maize (Table 2) shows the possibility for other cereals. Even if this happens, the demand for animal foods (or their substitutes) probably will not diminish.

THE RETAIL PRICE OF PROTEIN

When the retail prices of animal proteins are expressed in terms of the protein they supply it is easier to understand the threat of substitutes. Table 3 shows that the price of 1 kg of pure L-amino acids in the proportions present in egg protein, when purchased in small lots from a

TABLE 3: RETAIL PRICES OF PROTEIN IN FOODS

Protein Source	*Protein Content* (%)	*Retail Price* *lb* ($)	*kg* ($)	*Price/kg Protein* ($)
L-amino acids* .... (as in egg)	89	—	48.94	55.00
Pork chop	13	1.00	2.20	17.00
Beef rib roast	16	1.10	2.43	15.15
Frankfurter	11	0.60	1.32	12.00
Fluid milk	3.5	—	0.27	7.73
Hamburger	18	0.55	1.21	6.75
Cheese	25	0.70	1.54	6.15
Chicken (fryers)	13	0.30	0.66	5.08
Soy flour, low fat	50	0.08	0.17	0.35
Torula yeast (food)	50	0.15	0.33	0.66
Yeast-petro (food)	50	0.18	0.39	0.78

Data sources: The protein contents are from *USDA Handbook, No. 8* (1965). Retail prices are approximate values obtained from *N.Z. Official Year Book,* 76th ed. (1971) for the U.S., from personal experience, or from Hammonds and Call (1970).

*Prices quoted in 1971 catalogue of the Sigma Chemical Co. (U.S.A.) for essential amino acids in whole egg protein pattern, and non-essential amino acids as equal amounts of glutamic and glycine.

United States chemical supply house, is only 3 times that of 1 kg of protein purchased as pork chop. Probably the amino acid mix would be the cheaper if supplied as food-grade rather than chemical grade and purchased in ton lots. The least cost of the animal proteins is about $5 per kg, while far below at 35 cents per kg is low-fat soy flour.

NON-ANIMAL PROTEIN SOURCES

It is not sufficient to produce a bland, inexpensive protein powder with a good balance of amino acids. Something must be done with it so that the housewife will recognize it as a food, will buy it at the local shops, and will serve it to her family for their enjoyment. In addition, many non-animal sources of protein contain toxins. Separation of the protein from the toxic material can be done either by genetic manipulation or by chemical processing. For example, rapeseed meal has an excellent balance of amino acids but cannot be fed readily to animals because it contains glucosinolates which enlarge the thyroid and inhibit growth. At DSIR Kantharaj and Hove (unpubl.) have prepared a rapeseed protein isolate by alkali extraction followed by acid precipitation. When fed to rats the isolate was nutritionally equal to casein and was free from glucosinolate.

SINGLE CELL PROTEINS (SCP)

During 1972 British Petroleum Ltd. will begin commercial production of "Toprina", a feed-grade yeast grown on petroleum fractions. Available estimates (Goldblith, 1967) for food grade yeast are given in Table 3. Annual production in BP's Scottish and French plants is expected to be 19,000 tons. This figure needs to be compared with the 500,000 tons of soybean imported into the United Kingdom in 1970. Europe and Japan would like to develop yeast production to free themselves from dependence on American soybean.

SCP, of which yeast is an example, have great potential. They have more than 50% protein of good quality. Production is free from agricultural vagaries such as weather and seasons, and they can be grown on a wide variety of inexpensive carbon sources. The growth rate and efficiency of growth are several orders of magnitude higher than crop production (Snyder, 1970). However, yeast has not yet been established as a commercial feed protein source, let alone as a significant raw material for food fabrication.

Much research and development need to be done. A major entry of yeast protein into the human diet must be assigned to the far future.

Fish Protein Concentrate (FPC)

The status of FPC has been reviewed by Holden (1971). Its failure can in large measure be attributed to the U.S. Food and Drug regulation which permits its sale in one-pound packages only. This has prevented its use by the food manufacturing industry, and without this market production of FPC is not economic. Perhaps countries other than the United States might become interested in FPC.

Leaf Protein Concentrate (LPC)

LPC has not yet advanced into human dietary use, although a feed-grade lucerne protein concentrate is being produced in the United States (Kohler and Bickoff, 1971). The long-range possibilities for human use are still as bright as previously described (Hove, 1969), especially since Hove, Lohrey and Allison (unpubl. data) have confirmed earlier reports that when supplemented with methionine LPC has a protein quality superior to casein; even without the methionine, the lucerne concentrate was found to be a very effective supplement to protein supplied by barley.

Soybean

To understand the developments in uses of soybean proteins it is necessary to review the battle between margarine and butter in the United States. Perhaps some lessons may be learned that can be applied to the coming struggle over imitation milks and meats. Margarine now has a two-to-one edge and at present trends butter will be a curiosity by 1985. Among the factors involved in the victory of the imitation over the established animal product were price; government regulations; uniformity of quality; technical characteristics; adaptation to market needs; convenience; storage and shelf life; health claims; nutrition; social status.

Of these factors price was the driving force but restrictive legislation was the key. When the laws against it were removed after World War 2, margarine won out. In a related but less known area, hydrogenated vegetable oil shortenings have about eliminated lard and beef drippings from baking and cooking use in the United States.

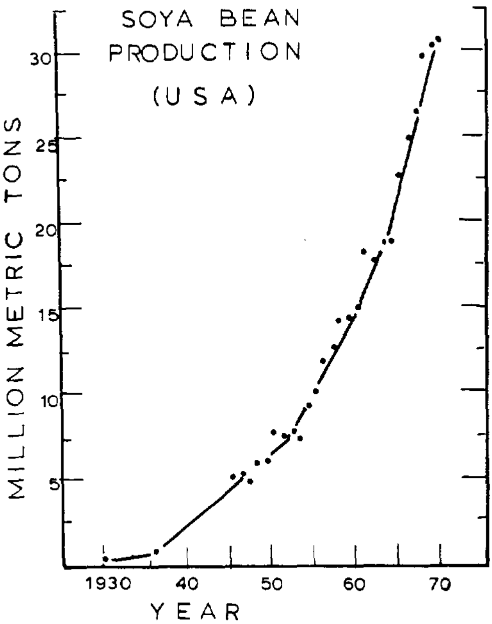

FIG. 1: *Soybean production in United States (FAO agricultural production yearbooks).*

A direct result of the twin victory for vegetable oil was a rapid expansion of soybean production to supply the needed oil (Fig. 1). In 1970 the United States crop was 67% of world production, China was second with 25%, and the rest of the world produced only 8% (FAO, 1971). As an indication of the size of United States production, its annual crop is equivalent to 9 g of protein per day for each man, woman, child and infant of the 3,600 million people in the world. This is more than one-third of the age-weighted average requirement (FAO, 1965).

Defatted soy meal has 50% protein of good quality, and has been the base of a revolutionized chicken and pig meat industry. Until now, its use in the diet of western man has been limited. Soy flour arouses no gustatory thrill. But with so much of it around, the food industry was impelled to find a way to use it in foods. After 20 years of research it has succeeded. The products now being produced will undergo continual change and improvement over the years.

FOOD FABRICATION FROM SOY PROTEIN

The food industry has become something of a manufacturing industry. The products of agriculture are mined for protein as though they were ores smelted for raw metals, which are then alloyed and fabricated into new foods on automated assembly lines. The industry does not care about the source of the protein as long as it is the least expensive to fulfil the technical, nutritional, and marketing requirements. A long list of new convenience foods are on the market. Many of these use the proteins of milk. but as soy proteins improve they are competing and gaining against the milk protein. Soy protein has an advantage of price at certain levels of fabrication, and it has some desirable technical effects such as fat- and water-binding, and prevention of shrinkage of comminuted meat products on cooking.

TABLE 4: SOY PROTEIN FOODS

Preparation	*Protein Content* (%)	*Price** ($/kg)	*Protein Cost* ($/kg)	*Production* (*1970*) (*M lb*)
Soy flour, low fat	50	0.18	0.35	500
Soy concentrate	70	0.48	0.70	33
Soy isolate	95	0.90	0.92	38
Textured				
Extruded	50	0.66	1.32	25
Spun	95	1.65	1.75	

*Wholesale prices to food processers.
Reference Walker *et al.* (1971) and Rakosky (1970, 1971).

The types of soy proteins are listed in Table 4. The concentrate is made by extracting out the sugars; the isolate is prepared by alkaline extraction of the protein followed by acid precipitation and spray drying. Texturizing is attained by one of two techniques: the isolate may be spun just as rayon synthetic fibre is produced; or a slurry of the flour may be extruded under high pressure and temperature with sudden release of pressure to form porosity. Either of the texturized products can be enmeshed with other proteins, fats, nutrients, flavours and colours. They absorb water to a meat-like texture and can be formed to resemble any animal protein food.

The spun product is more costly and is used for imitation meats, while the extruded product, still with some taste and flavour problems, is more suited as a meat extender to be mixed with comminuted meat products such as sausage, hamburger, frankfurters, chili con carne, enchiladas, lasagnas, tacos, scallopini, tamales, sukiyaki and veal birds.

GOVERNMENT REGULATIONS ON MEAT SUBSTITUTES

Success of a new food depends largely on the regulations pertaining to its use and labelling. An important ruling by the USDA Food and Nutrition Service (1971) now permits up to 30 parts of hydrated Textured Vegetable Protein (TVP) to be added to 70 parts meat in the Federal School Lunch Program. This regulation also set a nutritional standard for TVP (Table 5). A similar standard has been proposed by the combined food industry and is now under review by the Food and Drug Administration. The industry standard is more general. The name of the product is Texturized Protein Product (TPP), and approval is sought for the use of a wide range of raw material protein items in anticipation of the expansion of the techniques beyond soy protein. Included are all of the oil seeds as well as protein fractions from wheat and other grains.

Now that TVP has been approved for replacement of about one-third of meat on a protein basis and in such an emotionally charged area as the School Lunch Program, it may be anticipated that in time TVP will be cleared for addition at this level to all comminuted meat products. The existing regulations limit soy protein additions to meat to "sufficient for purpose", and the purpose is technical not nutritional. The level is defined as 2% of soy

TABLE 5: NUTRITIONAL STANDARD FOR TEXTURED VEGETABLE PROTEIN TO BE USED IN UNITED STATES SCHOOL LUNCH PROGRAMS

Nutrient %	*Minimum* (*dry basis*)	*Maximum* (*dry basis*)
Protein*	50	—
Fat	—	30
mg/100 g		
Magnesium	70	
Iron	10	
Thiamin	0.3	
Riboflavin	0.6	
Niacin	16.0	
Vitamin B6	1.4	
Pantothenic acid	2.0	
μg/100 g		
Vitamin B12	2.0	

Source: USDA Food and Nutrition Service (1971).

*The protein efficiency ratio (PER) of TVP shall be not less than 1.8 on the basis of casein PER at 2.5. The PER of the meat-TVP mixture shall be not less than 2.5.

isolate in sausage type foods and up to 12% of soy flour in meat balls.

Eventually the use of comminuted meats (primarily beef) will be one-third less than it might have been were it not for the soy protein meat extenders. And the beef that New Zealand sends to the United States is mainly used in the comminuted meat trade.

IMITATION MILK

In the developed countries of the world, imitation milk has already displaced more than 75% of a natural milk, namely infant formulae as substitutes for mother's milk. Here the food industry was not hampered by restrictive legislation nor required to label its product "imitation". Most of the formulae are still based on milk proteins, while about 5% are based on soy protein with added methionine (McIntire, 1971) on which infants do very well. In time this proportion may expand.

A similar displacement of fluid cow's milk has not occurred. For a time there was a flurry of interest, with imitation milk capturing 10% of the market in an isolated area. As a result, the Food and Drug Administration proposed a nutritional standard to ensure equivalence to the natural product. This was dropped when sales of imitation milk fell. The industry said that it could not make a milk with the required 3% protein without running into problems in taste and "mouth feel". Technical problems like this will surely be solved, but the success of future products may depend more on what actions are taken on the mountain of protective legislation surrounding milk. Perhaps the milk industry will itself enter the imitation milk production field, just as some of the big meat packing companies have become leaders in imitation meat production.

In a related area, imitation coffee cream (coffee whiteners) and imitation whipped cream (whipped toppings) have rapidly increased in production until in 1970 they made up close to 50% of the total market (McIntire, 1971). Hammonds and Call (1970) predict a continuing increase in the ratio of soy protein over caseinates in these foods.

HEALTH BENEFIT CLAIMS

When the soy-based substitute foods become better known (and improved in quality) certain promotional claims of health benefits may be expected. One will be for lower calories, since soy protein can duplicate the tenderizing action of high fat levels now used in sausage foods. A more serious claim will be that soy protein foods lower blood cholesterol. Hamilton and Carroll (1971) and Carroll (1971) have shown that rabbits fed soy-based diets had lower blood cholesterol than those fed casein or meat diets.

FORECASTS

Predictions on the volume of meat and meat substitutes to be used in the United States by 1985 have been made by Hammonds and Call (1970) and are condensed in Table 6. An important point is that the predicted increase in the use of substitute meats is less than the predicted increase in total demand for meat. Even if the use of substitute meats increases to one-third of the total market (instead of Hammonds and Call's 10%) by 1985, as may be predicted from the School Lunch Regulation, no more than half of the total increase of 26,000 million pounds will be met by the substitutes. The substantial increase in real

TABLE 6: PROJECTED VOLUME OF MEATS AND SUBSTITUTES BY 1985 IN THE UNITED STATES

Type of Meat	*Total Volume*		*Substitute Fraction*	
	1969	*1985*	*1969*	*1985*
	(*M lb*)		(%)	(%)
Fresh	17,560	34,700	trace	10
Processed	11,440	20,300	1	10
Total	29,000	55,000	0.5	10

Source: Abstracted from Hammonds and Call (1970) who assumed a 4% annual increase in meat demand.

TABLE 7: PROJECTED TOTAL VOLUME AND SUBSTITUTE FRACTION OF SOME ANIMAL FOODS IN THE UNITED STATES BY 1980

Food	*1969*			*1980*		
	Total	*Substitute*		*Total*	*Substitute*	
		Protein	*% of*		*Protein*	*% of*
	(*M lb*)	(*M lb*)	*Market*	(*M lb*)	(*M lb*)	*Market*
Meats	29,000	92*	0.5	45,000	640	7
Milk	62,000	—	—	78,000	188	10
Cream, coffee	485	12	32	730	23	60
Cream, whipped	55	0.6	50	100	2	62
Ice cream	4,970	4	6	6,400	8	9

Source: Abstracted and condensed from Hammonds and Call (1970).
*75% soy protein, 25% milk protein.

meat demand should be a comfort to beef exporting countries.

Predictions on volumes of a number of foods, including imitation milk, by 1980 are condensed in Table 7. There seems to be general conviction that imitation milk will enter the market, and that the future trend will be up. There are, however, no current trends to indicate this.

This discussion has been limited to the United States scene, for the near future, and in terms of substitute meat and milk made from soybean protein. The United Kingdom, Israel, Japan and other countries are now exploring their local markets for acceptability of meat analogues. How rapidly these advance may depend on the experience in the United States over the next decade, and on the suitability of yeast protein, amino acids, or other raw material protein sources to replace soybean protein in their manufacture. These countries would prefer to avoid the United States monopoly on soybean.

Predictions for the far future would be hazardous in the extreme. However, there seems to be no reason why non-animal proteins should not dominate the high quality protein foods market, in the developed countries at least, by the turn of the century and beyond.

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