The Probyte: A New Protein Unit System

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A new fundamental unit for protein is proposed and its use described. The unit is called a Probyte and is defined as one calorie composed of the eight essential amino acids required by the adult human in the gram-pattern of the protein of whole egg. A second term, Probit, accounts for the essential amino acids left over as fractional Probytes. A mathematical procedure is given for deriving the Probyte content of foods and diets, permitting simple addition of the Probytes and Probits from all sources. The use of the Probyte in terms of human requirements is described, as are the corrections for biological value, corrections for losses due to processing, and methods for setting a single protein standard in crop genetics research and pricing of commodities. It is estimated that 48 Probytes/day is the adult recommended dietary allowance, approximately the same as recommended in grams of high quality protein by the Food and Nutrition Board of the National Research Council. Because the Probyte has as its only dimension a calorie of essential amino acids, it is proposed for use in systems analysis, pricing policies, nutrition economics, and design of least-cost diets. Its use in systems models is illustrated.

Problems of food protein have occupied the attention of nutritionists for more than 50 yr, even though the linkage of protein to manifest deficiency diseases was first clearly shown less than 25 yr ago. Within the last 15 yr the scientific professions have built an impressive record of accomplishment in protein physics, chemistry and biochemistry, nutrition and malnutrition, and have begun to link plant genetics to nutrition and to extend their knowledge of the consequences of nutritional deficiency into the learning and behavioral fields. Now the frontier has reached economic and political considerations. By almost any measure, then, the nutrition field is young, at least the human branch as it concerns protein.

Typically, in a new and growing field, the investigators find themselves in need of new vocabulary and definitions and new units of measure to consolidate their knowledge. These are coined, proposed, and argued, and if accepted are incorporated into the science, and the field moves on. It has seemed to the authors that protein nutrition is at such a juncture; and herein we propose and describe a new unit to serve the needs of the many disciplines and activities concerned with protein.

Our proposal will be out of the ordinary, for the new unit should be broadly useful to all those who today desperately need to incorporate the findings of nutrition into their own activities, especially the agricultural geneticist, the agricultural and food economist, the food marketer, and the food policy maker.

BASIS FOR THE NEW PROTEIN UNIT

Our unit is designed to encompass the concept of nutrient *effectiveness*, displacing the practice of viewing nutrition in terms of needs. It is no longer necessary to begin with human suffering, as implied by King (1969), before we step in to apply methods of research to head off the possibility of further misery. During the course of developing our nutritional knowledge, it had indeed become common to speak in terms of the need for certain substances in the diet as though they were medical problems. We "prescribed" citrus fruits to prevent scurvy, cod-liver oil to prevent rickets, and greens to ward off mineral deficiencies. All this contributed to establishing a clinical attitude toward nutrients. In addition, because of the primitive state of our food industry a generation or so ago, many sources of nutrients were only seasonably available and were high in price. Hence "needs" took on the special significance of being expensive to fulfill, with illness the consequence of not meeting those needs, reinforcing still more the clinical and medical attitude.

Today we are in a different era. In this country, if nutrient needs are not met, it is for different reasons. Nutrients are not high in price, but the health costs associated with not having them are becoming ever higher. Our nutrient production, storage, processing, and distribution systems have enabled us to stop thinking of nutrients as needs, because significant need implies that misery or illness already exists. One of the first criteria of our proposed new unit, then, is to formulate it so as to measure effectiveness.

NUTRITIONAL EFFECTIVENESS AND FOOD

Effectiveness is a prime consideration in the field of economics. The economic distinction between food and nutrition has been seen by Muscat and Ber (1971) as analogous to the distinction between agriculture and health; the former is considered production, and the latter consumption. The distinction between protein and amino acids follows the same pattern; protein is considered production and amino acids are consumption. Human welfare is also considered consumption, and so the philosophy of nutritional need, like that of human welfare, is consumption oriented. On the other hand, the concept of nutritional effectiveness is production oriented, just as is protein. We believe a unit based on effective protein would tend to shift nutrition more toward the production side of the economists' equations and, thus considered, would bring nutritional values more frequently into national planning.

Food costs are measurable and are subject to economic analysis, but nutritional need is invisible except when physiologic needs are not met. It seldom commands a market price. In fact, except in the animal field where fast growth or some other nutritional criteria are used, one would be hard put to estimate effective demand for nutrients, or even for foods on the basis of nutrient content. Nutritional effectiveness is not the basis for consumer purchase, except perhaps in the avoidance of calories. Demonstrating this point, Patrick and Simoes (1969) found that in developing countries where needs are frequently not being met, least cost diets that could meet nutritional needs would be within income, whereas existing

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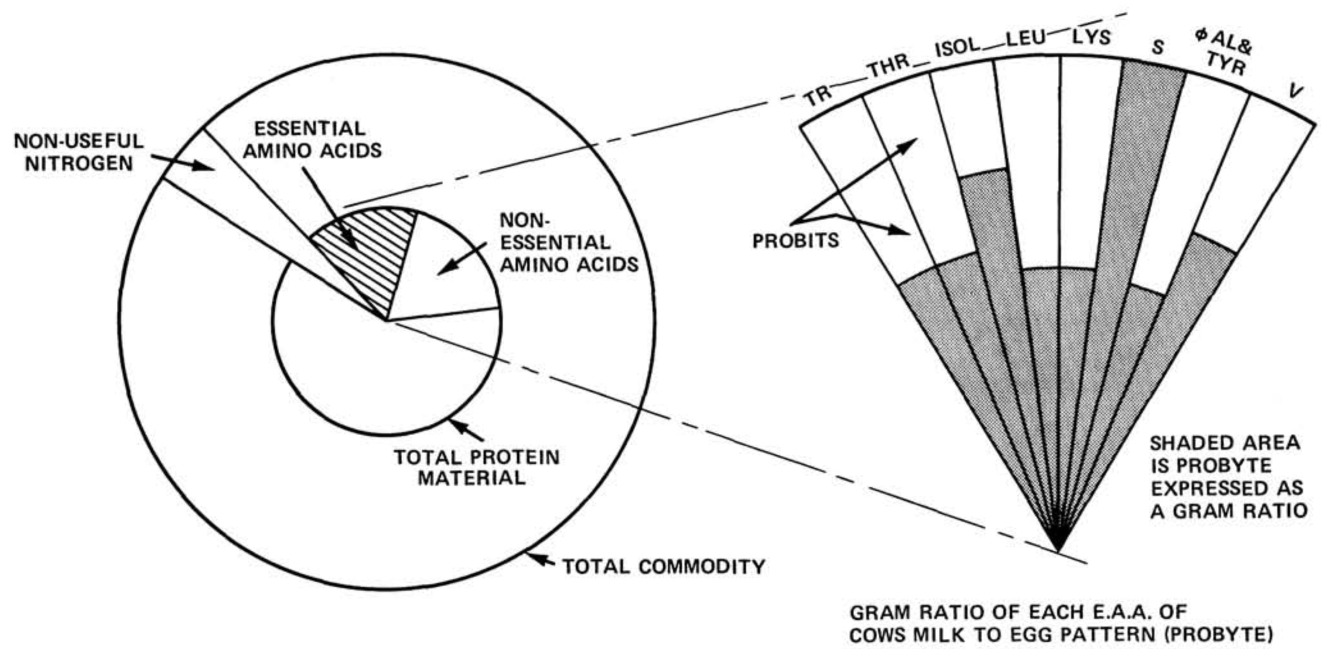


Figure 1. Commodity nitrogen-Probyte concept diagram for protein where sulfur amino acid is first-limiting

diets do not fulfill needs, and would cost 25% more if increased until they did.

Food, of course, supplies more than just nutrients which, in fact, are as invisible as nutrition itself. Beyond mere survival the customs surrounding eating have been unique to each cultural group of man through the ages. For this, among other reasons, the consumer is the one least capable of evaluating the nutritional effectiveness of his foods, and must depend for this mainly on suppliers and educators. Indeed, in our permissive U.S. society where single widely available foods could conceivably become the sole source of nutrients, we have a special need for new units of nutritional effectiveness—units that would make possible a more meaningful system of package labeling. Such units will take nutrition out of the consumption and human welfare orientation and into the area of production, and would thus move nutrition from the clinical syndrome position to the health investment category. To quote Hegsted (1970): "We must recognize that the American population, at least, is becoming increasingly dependent on foods which are already partially or wholly prepared. The things that sell foods are taste and appearance, flavor, and convenience. Not only is nutrition a hard thing to sell, but is becoming increasingly difficult to evaluate the nutritional quality of the food available. Many of the new foods are complex mixtures, and we often do not even know the composition of them. As the number of items available in the supermarket continues to increase, it becomes increasingly difficult to prescribe diets and especially difficult . . . to make the right choices or avoid making the wrong choices. The temptation to eat all of these foods is great. Indeed, this is what advertising is all about—it is aimed to tempt people to change their diet and try new materials."

Hegsted also predicts that the need for therapeutic diets will increase, as will the difficulty of selecting the right one. A new unit, oriented to products as well as to their production, will help both dieticians and physicians to simplify prescriptions, easing the patient's problem of adhering to the appropriate diet.

Since the basic nutritional unit is the calorie, we propose to expand its use into protein by developing an "effective" protein calorie. At present, protein data are expressed merely in weights or percentages. Even amino acid analyses retain the custom of expressing the data in terms of grams, listing the amino acids separately—a treatment that shows nothing of their biologic interdependence.

While we recognize the need to employ standard chemical, biochemical, and microbiological techniques, we propose two changes in handling the results: one, that the eight essential amino acids be packaged as a gram-proportionality pattern based on human metabolism; and two, that they be expressed in calories. The usual biological methods (for example, NPU) would be used to adjust the values. The Chemical Score Method of Block and Mitchell (1946–47) is such an adjustment.

Singling out the essential amino acids from food protein is not unlike the present practice of separating fat calories from carbohydrate calories in measuring the relative effectiveness of each to supply energy requirements. We all recognize that fats have other special functions besides their use for energy, just as some of the amino acids have special functions. It is also worth recalling that not all fats yield the traditional figure of 9 cal per g; this is only a useful convention for approximating calories of edible fats. Tributyrin, for example, yields only 6.7 cal per gram. Our unit is a calorie based on the abstract idea of a reference pattern of essential amino acids. We recognize that there is a caloric difference between considering, on the one hand, those amino acids linked by peptide bonds into protein coils and, on the other, our simple addition of amounts found by analysis. But the amount of bonding and steric energy is small, and the energy difference is also small between our grouping of essential amino acids and a grouping of all 20 amino acids when compared to the daily human need for energy. Therefore, we arbitrarily disregard these differences in formulating the unit of protein. We consider our pattern to have 4.1 kcal/g, the same as conventionally used for protein.

In designing a nutritional unit intended to have broad utility across several related disciplines it becomes necessary to assign such values as working bases. A very specific definition is called for, one with reasonably simple and traceable factual

Table I. Procedure for Finding the Probit Grouping of a Commodity

	Results							
Steps	**tr**	**thr**	**isol**	**leu**	**lys**	**s**	**pal + tyr**	**v**
1. List the egg essential amino acids mg/cal (Probyte):	7.1	24.4	30.0	42.0	33.3	27.6	47.1	32.6
2. List the mg essential amino acids/g N of commodity (whole fresh cow's milk):	88	278	295	596	487	208	633	362
3. Calculate and record (1)/(2) = g of milk N/Probyte[a]:	0.08	0.08	0.1	0.07	0.07	0.1327	0.07	0.09
4. Take max col of (3) times the values of (2) and record:	11.7	37.1	39.3	79.5	64.9	27.6	84.4	48.3
5. Subtract the columns (4) − (1):	4.6	12.7	9.3	37.5	31.6	0	37.3	15.7
6. Then divide each column (5) by (1) and record (Result is the group of Probits):	0.65	0.56	0.31	0.89	0.95	0	0.79	0.44

To find the number of Probytes per unit weight of commodity, take the maximum figure from line 3 Results above: 0.1327 g/ of milk N, which contains 1 Probyte + 1 Probit (0.65/0.56/0.31/0.89/0.95/0/0.79/0.44). Recalling that 0.1327 g of milk N is contained in 23.3 g of milk, therefore, 23.3 g of whole fresh cow's milk (wfcm) contains 1 Probyte + 1 Probit (0.65/0.56/0.31/0.89/0.95//0/0.79/0.44). So, 100 g of whole fresh cow's milk = 100/23.3 Probytes + 100/23.3 × Probits (wfcm) = 4.3 Probytes + 4.3 × Probits (wfcm).

[a] This line relates the milk to egg patterns so that the number of g of milk N needed to supply an equivalent amount as in egg of each of the essential amino acids is shown in its respective column. The largest value is the limiting amino acid, in this case the sulfur group.

Table II. To Determine the Characteristic Probits in a Commodity (Sorghum)

	Results							
Steps	**tr**	**thr**	**isol**	**leu**	**lys**	**s**	**pal + tyr**	**v**
1. List the egg essential amino acids mg/cal (Probyte):	7.1	24.4	30.0	42.0	33.3	27.6	47.1	32.6
2. List the mg essential amino acids/g N of commodity:	76	189	245	832	126	181	473	313
3. Calculate and record (1)/(2) = g of sorghum N/Probyte[a]:	0.09	0.13	0.12	0.05	0.264	0.15	0.10	0.10
4. Take max col of (3) times the values of (2) and record:	20.1	50.0	64.8	220	33.3	47.8	125.1	82.8
5. Subtract the columns (4) − (1):	13.0	25.6	34.8	178	0	20.2	78.0	50.2
6. Then divide each column (5) by (1) and record (Result is the group of Probits):	1.83	1.05	1.16	4.24	0	0.73	1.65	1.54

The maximum value of row 3 identifies the limiting amino acid. The nonlimiting essential amino acids defined as the Probit-values for the commodity in question (row 6).

Thus 0.264 g of sorghum N contains 1 Probyte + 1 Probits (1.83/1.05/1.16/4.24/0/0.73/1.65/1.54). Recalling 0.264 g of sorghum N is contained in 16.3 g of sorghum, therefore, 16.3 g of sorghum contains 1 Probyte + 1 Probits (1.83/1.05/1.16/4.24/0/0.73/1.65/1.54). So, 100 g of sorghum = 6.1 Probytes + 6.1 × Probits (1.83/1.05/1.16/4.24/0/0.73/1.65/1.54). = 6.1 Probytes + Probits (11.2/6/45/7.12/26.0/0/4.48/10/1/9.45).

[a] The maximum value of row 3 is the number of grams of whole sorghum nitrogen necessary in order that sorghum supplies at least as much of each of the eight essential amino acids as 1 cal of the essential amino acids of whole fresh egg (1 Probyte).

basis. Nutritionists have customarily done this. Protein in food is usually expressed as the analysis for nitrogen times a factor; for egg it is 6.25; for wheat it is 5.8, as described by Watt and Merrill (1963). This is a way of bringing analytical data into consonance with biological findings.

A unit based on a pattern of essential amino acids is relatively insensitive to differences in individual amino acid analyses. Also, in a pattern-based unit, it is easy to adjust for variables of protein utilization, variables of malabsorption, and concerns about nonessential nitrogen. It will be sensitive to analysis of the aggregate of the essential amino acids, but less sensitive to an error of analysis for a single amino acid since our pattern contains the sum of data from the analysis for eight amino acids.

We call the new protein unit the Probyte. The Probyte is defined to be 1 kcal of the hen whole egg gram-pattern of the eight essential amino acids required by the adult human. This yields an essential amino acid pattern calorie, nothing more. We propose using the FAO Nutritional Studies No. 24 (1970), upon which workers can base their calculations.

Because of pattern variations, some essential amino acids in proteins other than egg will be left over after all the Probytes are selectively withdrawn and counted. It is necessary, therefore, to have a subunit to account for these. This subunit is called the Probit. Because there are seven out of eight essential amino acids that could be left over, for ease in calculation we have specified that they be arranged in a given order, Probits (tr/thr/iso/leu/lys/s/pal + tyr/v). The calculation expresses Probits in terms of how much of the eight amino acids it would take to make another Probyte.

The Probyte, even though a calorie of the essence of protein, is independent of the level of essential amino acids in the protein. Simply because it is defined using the egg pattern does not imply that the high level of essential to nonessential amino acids in egg is necessary or efficient, since only the amount in 1 cal of the pattern is the basis of the definition.

Since our unit is based on standard nitrogen and amino acid analyses, it should be useful to illustrate some relationships by diagram, as in Figure 1. The outer total circle area represents the weight of commodity it takes to supply one Probyte. The inner circle represents the total weight of commodity nitrogenous material it takes to supply one Probyte. The hatched inner sector enlarged on the right represents the fraction of total nitrogen present in the commodity as essential amino acids, sufficient to supply just one Probyte plus the leftover Probits. These are expressed in ratio form, showing that for a commodity first-limiting in sulfur amino acids, as cow's milk is, all of the sample was needed to supply a Probyte calorie. The unshaded area represents the Probits left over. The actual amount of milk nitrogen it takes to supply one Probyte is calculated in Table I; in line three it is the largest number. The purpose of Tables I and II is to outline the mathematical procedure for extracting Probytes from total essential amino acids of a commodity, expressing the remaining essential

Table III. Probyte and Probit Content of Commodities

		A[a]		B	C	D	E	F							
								Probits per Probyte (dimensionless)							
		% Protein	g N/ Probyte	g of protein/ Probyte	Probytes/ 100 g of commodity	g of protein/ Probyte g of egg protein/ Probyte	cal commodity Probyte/ cal of egg Probyte	Trypto- phan	Threo- nine	Iso- leucine	Leucine	Lysine	Methionine and cystine	Phenyl- alanine and tyrosine	Va- line
Whole fresh egg	A	12.8	0.0762	0.462	28	1.00	1.00	0	0	0	0	0	0	0	0
Whole fresh cow's milk	B	3.5	0.130	0.827	4.2	1.74	2.65	0.64	0.56	0.75	0.93	0.92	0	0.74	0.73
Dried whole cow's milk	B	25.8	0.130	0.827	31	1.74	0	0.65	0.56	0.75	0.93	0.93	0	0.74	0.73
Human milk	A	1.2	0.149	0.947	1.3	2.00	0	1.23	0.71	0.26	0.96	0.96	0	0.34	0.30
Meat: medium fat beef	B	17.7	0.118	0.740	24	1.55	2.2	0.18	0.31	0.28	0.42	0.92	0	0.16	0.24
Fresh fish, all types	A	18.8	0.109	0.684	28	1.43	0	0.08	0.28	0.09	0.25	0.87	0	0.10	0.28
Dried cod	B	81.8	0.117	0.734	111	1.55	0	0.03	0.30	0.24	0.32	0.93	0.13	0	0.20
Beans (*Phaseolus vulgaris*)	A	22.1	0.232	1.45	15	3.03	3.36	1.06	1.35	1.02	1.62	2.13	0	1.37	1.03
Cheese (all type)	A	18.0	0.128	0.821	22	1.72	0	0.40	0.35	0.45	1.02	1.13	0	0.86	0.94
Corn flour (*Zea mays*)	B	7.8	0.187	1.18	6.6	2.47	9.05	0	0.91	0.81	2.62	0.02	0.34	1.65	0.82
Corn (Opaque 2)	C	10.3	0.141	0.883	12	1.85	5.10	0.62	0.37	0	0.95	0.30	0.34	0.61	0.40
Millet (*Pennisetum* spp.)	A	9.7	0.156	0.970	10	2.04	0	1.69	0.53	0.33	1.21	0	0.70	0.67	0.64
Rice, brown or husked (*on/za* spp.)	A	7.5	0.140	0.835	9.0	1.76	6.95	0.55	0.40	0.11	0.73	0	0.08	0.61	0.48
Rice, milled polished	A	6.7	0.147	0.875	7.7	1.84	0	0.76	0.25	0.29	0.81	0	0.23	0.58	0.63
Sorghum (*Sorghum* spp.)	A	10.1	0.264	1.65	6.1	3.46	0	1.84	1.05	1.17	4.24	0	0.74	1.65	1.58
Wheat flour (whole grain)	B	13.3	0.208	1.21	11	2.53	5.50	1.12	0.51	0.76	1.24	0	0.51	1.24	0.72
Wheat flour (white)	B	10.5	0.256	1.46	7.2	3.53	0	1.55	0.72	1.25	1.68	0	0.76	1.77	0.93
Cassava flour (*Manihot esculenta*)	B	1.6	0.255	1.58	1.0	3.30	0	1.93	0.77	0.48	0.55	0.95	0	0.57	0.47
Yam (*Dioscorea* spp.)	A	2.4	0.160	1.02	2.4	2.14	0	0.80	0.49	0.26	0.56	0.23	0	0.72	0.42
Taro (*Colocasia esculenta*)	B	1.9	0.138	2.21	0.9	2.75	0	2.42	1.52	1.27	1.77	1.28	0	0.46	1.40
Plantain (*Musca paradisiaca*)	B	1.1	0.228	1.45	0.76	3.04	19.2	0.81	0.45	1.45	0.85	0.97	0	0.39	1.61
Cassava leaves (*Manihot esculenta*)	A	7.0	0.159	0.980	7.1	2.07	0	1.03	0.88	0.58	2.00	0.83	0	0.96	0.71
Peanuts (*Arachis hypogaea*)	B	26.9	0.185	1.01	27	2.13		0.81	0.27	0.58	0.67	0.24	0	1.12	0.76

[a] References: A. F.A.O. (1970). B. Orr and Watt (1957). C. C.P.C. Int'l, Inc. Waltham, Mass. (1969). D. Burton (1965). Notes: 1. Probytes here not corrected for N.P.U. of commodity. 2. Column D is in fact the inverse of Block and Mitchell's "chemical score."

amino acids in fractional Probytes, that is Probits. In some commodities (Table III) the fractional Probytes for certain amino acids exceeds one, indicating that more than double the amount of it is present in relation to the amino acid first-limiting.

To find how to convert the Probyte calculations to an expression that describes the commodity in terms of Probytes and Probits (/) per unit weight, see the calculations in footnotes of Tables I and II. (When referring to the Probit grouping of a commodity or diet we have adopted the practice of following the Probits with (/) signifying it.) This shows the conversion of grams of milk nitrogen and of sorghum nitrogen in one Probyte to the quantity of Probytes and Probits (/) contained in 100 g of milk.

At this point it is worth restating that correcting for characteristics such as biological availability, malabsorption, or any difference between chemical analysis and biological observation of any specific protein is done by multiplying the Probytes and Probits (/) by the Chemical Score, the factor now routinely used for comparing biological results to chemical analysis. Indeed multiplying by the Chemical Score as a fraction can be used to correct the amount of Probytes and Probits (/) in each commodity or diet. Table V shows net Probytes in the last column after adjusting for biological characteristics (NPU).

Progress with analytical methods, as reported in Proceedings of the Nutrition Society (1970a,b), has been sufficient to assure minimum problems of reproducibility.

Describing effective protein in terms of Probytes and Probits (/) enables us first to center our attention on the Probyte when considering such things as the ideal pattern, the unavailability of amino acids, malabsorption, protein conversion in the human, standards of agriculture production and pricing, applied genetics research targets, and other matters where the quantity or percent of Probytes may be low. Then, when dealing with more than one food item, the groups of Probits (/) can be brought in to determine their complementarity. Each food commodity would have its own characteristic grouping of Probits (/), as would a synthetic amino acid. The Probits (/) of each commodity have a characteristic ratio of essential amino acids, like a numerical fingerprint. Now any number of commodities of foods can be combined by simply adding the amino acids of the characteristic Probits (/) and then transferring these Probits (/) to the Probyte score each time the combination sufficiently adds to the limiting

Table IV.[a] **Probyte Content of Total Diets**

	Guatemala		El Salvador	
	Rural	Urban	Rural	Urban
	Intake per person per day			
Food groups			grams	
Dairy products (assume fresh milk)	10	129	46	118
Eggs	4	6	6	21
Meat and fish	34	45	21	66
Pulses (assume beans)	58	64	60	48
Fresh vegetables (assume manioc leaves)	61	46	32	82
Fruits	23	33	1	34
Plantains	2	16	27	44
Starchy roots (assume manioc)	5	9	5	14
Cereals (assume corn)	494	290	326	244
Sugars	47	40	32	32
Fats	1	7	6	23
Calories	2243	1727	1666	1723
Total protein, g	66	53	48	52
Animal protein %	11	24	12	35
Probytes:				
a/direct	56.6	51.0	41.8	57.6
b/complementary	11.1	6.5	7.3	5.5
Total	67.7	57.5	49.1	63.1

The "complementary" Probytes are obtained by summing the Probits for the commodities listed, the value being that of the amino acid with lowest total. It assumes that food is eaten over a time span which is short enough to utilize the complementarity of the amino acids.

Equivalent grams of egg protein: (Probytes × 0.079)	31.3	26.0	22.7	29.1

[a] Except for Probyte calculations this data is reproduced with permission of Altschul (1965) and publisher (Proteins: Their Chemistry and Politics, Basic Books, New York, 1965).

Table V. Principal Sources of Probytes and Probits in a Central American Diet

		Probits									
	Calculation of no. of probytes (gross)	tr	th	isol	l	lys	s	pal and tyr	v	NPU	No. of Probytes (net)
Dairy products (assume fresh milk)	29 × 0.042 = 5.42	3.5	3.0	4.1	5.0	5.0	0	4.0	4.0	81	4.40
Eggs	6 × 0.28 = 1.68	0	0	0	0	0	0	0	0	94	1.58
Meat and fish	45 × 0.24 = 11.70	2.1	3.6	3.3	4.9	10.8	0	1.9	2.8	75	8.79
Pulses (assume beans)	64 × 0.15 = 9.60	10.2	13.0	9.8	15.5	20.5	0	13.1	9.9	48	4.61
Fresh vegetables (assume manioc leaves)	46 × 0.07 = 3.21	3.2	2.8	1.9	6.4	2.7	0	3.1	2.3	45	1.44
Fruits	33 × 0.001 = 0.03	0	0	0	0	0	0	0	0	0	0
Plantains	16 × 0.0076 = 0.12	0	0	0	0	0	0	0	0	0	0
Starchy roots (assume manioc)	9 × 0.01 = 0.09	0	0	0	0	0	0	0	0	0	0
Cereals (assume corn)	290 × 0.006 = 19.15	0	17.4	15.5	50.2	0.4	6.5	31.6	15.7	55	10.53
Sugars	40 × 0 = 0	0	0	0	0	0	0	0	0	0	0
Fats	7 × 0 = 0	0	0	0	0	0	0	0	0	0	0
Total	51.00	19.0					6.5				31.35

Probytes in diet: direct 51.0
complementary 6.5
Total 56.5

Lysine is the limiting amino acid in this diet. We can usefully add Probits of lysine up to the Probit level of the second-limiting amino acid, tryptophan, *i.e.*, 19.0 − 6.5 = 12.5 Probits of tryptophan can be usefully added and the diet would be richer by 12.5 Probytes. On a dietary basis one should also consider the effect of the different NPU's of the various dietary components.

Table VI. Effect of Errors in Protein Essential Amino Acid Contents

Essential amino acid	Egg: mg essential amino acids/g N	Egg: mg essential amino acids/Probyte	Faulty egg: mg essential amino acids/g N	Faulty egg: mg essential amino acids/Probyte
Tryptophan	93	7.1	93	7.5
Threonine	320	24.4	320	25.8
Isoleucine	393	30.0	393	31.7
Leucine	551	42.0	551	44.5
Lysine	436	33.3	436	35.2
Methionine and cystine	362	27.6	181	14.6
Phenylalanine and tyrosine	618	47.1	618	50.0
Valine	428	32.6	428	34.6
Total	3201	244.1	3020	243.9

Thus, a 50% error in the determination of the sulfur essential amino acid content of egg (*i.e.*, from 362 mg/g N to 181 mg/g N) results in a 5.7% change in the value of each of the essential amino acid's mg/Probyte.

amino acid (the zero column of the Probit (/) grouping). This is illustrated by Table III and in Central American Diets (Tables IV and V). Note that because the position of each amino acid in the Probit (/) group is always the same, it is not necessary to deal with the chemical name each time a calculation is made.

Analytic tables are not yet prepared so that this new counting system can be quickly applied, but when available it should be possible to assign economic values to the various Probits (/). For example, if a certain food is rich in a long residence-time amino acid, those Probits (/) would undoubtedly have a different value from the Probits of a commodity rich in the short-residence-time amino acid. This means the analysis has been discounted and an economic value placed on it, based on biological performance. We doubt that there is a single food or feed firm seriously interested in protein that does not already have computer programs similar to this counting system, but based on all the nutrients fed to the species.

What we are proposing would make such a counting system explicit and useful to human nutrition and to the many disciplines dependent on protein considerations through the adoption of a fundamental unit and subunit with which to calculate indices and correlations.

In recommending the adoption of the Probyte, we feel obligated to indicate the major effects that certain errors in the data formulating the unit would have upon its value and upon the interpretations based on it. Variations in the analytical values for any one of the essential amino acids would have the same effect on the Probyte content of a protein as would the selection of a reference pattern that differed in the content of only that amino acid. We have illustrated this by showing in Table VI the Probyte content of egg and the associated calculation assuming the sulfur amino acids were low in the analysis by 50% (181 mg/g N). If analytical errors of 10% are made in all of the essential amino acids, then the Probyte content of the food will be in error by a like amount, which is no different from the effect of errors at present. The analysis of the first-limiting amino acid will be most important to the accurate determination of the number of Probytes in a commodity.

Because each grouping of Probits (/) is individually characteristic of its source, there is an opportunity to develop value systems based on converting these Probit groups to Probytes. Thus a loss in the availability of an amino acid would reduce the number of Probytes and change the Probits (/). A loss in the biological value of the protein from digestibility, utilization, malabsorption, or from storage or cooking would reduce the number of Probytes and Probits (/) alike if losses were uniform across the amino acid spectrum. To correct for such losses, the quantity of Probytes and Probits (/) should be multiplied by the fraction representing the loss.

As mentioned earlier, for greater ease in using the Probits (/) we have employed some standard procedures. We list the eight essential amino acids in a standard order: Column 1 is always tryptophan (tr); 2, threonine (thr); 3, isoleucine (isol); 4, leucine (leu); 5, lysine (lys); 6, methionine and cystine (s); 7, phenylalanine and tyrosine (pal + tyr); and 8, valine (v). Then as a convention to aid in the calculation, we use the Probit (/) with its associated fraction of essential amino acids as follows: Probits (0.0/0.5/1.2/0.2/0.2/2.3/1.9/3.4/0.3).

With such a system, one can readily see which amino acid is first-limiting and how much is needed to cause two to the limiting. If that amount is used it of course adds that fractional Probyte to the total available. Using the above hypothetical grouping of Probits (/), it can be seen that adding 0.2 of the tryptophan would convert the above Probits (/) to: 0.2 Probyte plus Probits (0.0/0.3/1.0/0.0/2.1/1.7/3.2/0.1) 0.2 tryptophan is 1.46 mg. This times the number of Probits (/) per 100 g of protein gives the percent of tryptophan needed to fortify the commodity to the second-limiting amino acid.

DISCUSSION

Various Indices for Protein. It has long been known that both the amount and the nutritional characteristics of dietary protein are important considerations in protein adequacy. Miller and Payne (1961 a,b) proposed a method to bring these two factors together to form a simplified index. The scope of the resulting index is quite broad, spanning the many different analyses of food protein as well as their biological utilization characteristics. Recent work of Hegsted and Neff (1970) attacked the underlying assumptions of Miller but indicated there is continuing attractiveness to finding a way to deal with protein. Indeed, their finding (from slope-assay-ratio experiments) that the efficiency of protein utilization is constant over a wide range of animal growth rates suggests that an appropriate index of lesser scope could be both valid and applicable over a broad scale. At high levels of protein the data of the slope-assay-ratio determinations show wide scatter, which was interpreted to mean that factors other than protein quality or the quantity eaten are responsible for variations of protein efficiency. If such data on rats were applicable to humans, then an effective index might be of high validity in situations where protein levels are low and intake is limited. This would apply particularly in cereal or root-based diets of less developed countries, where less than optimum nutritional status and less than maximum growth is all too common.

Many workers in the field have dealt with and continue to study correlations between methods for measuring the protein quality of food commodities and fortificants. Among these methods are Determinations of Net Protein Utilization, Biological Value, Chemical Score, Protein Efficiency Ratio, Nitrogen Balance, Plasma Aminogram, and Blood Urea. A rich literature on some of these will be found by searching these headings by name. Because the methods and even the correlations do not provide simple indices, the workers have attempted to develop reference patterns of essential amino acids as standards against which foods and diets can be compared.

Recently, Cresta *et al.* (1969) reviewed and correlated the biological with the chemical methods, and concluded that not one of the reference patterns to date has given good correlations of one method with another. They suggest that to correlate amino acid patterns with the various methods, more than one pattern would need to be used. Their reason has been stated by others and is well known; *i.e.*, one pattern is more appropriate for methods measuring growth, and another pattern is more suitable for methods measuring maintenance. Many workers have also noted a high degree of variation in amino acid requirements of individuals, leading to the conclusion that methods, reference patterns, indices, and units ought to be more statistically based and less concerned with the metabolic reactions of the single subject. The amount of internal decomposition and re-use may far outweigh in importance the meal-to-meal variations of the dietary essential amino acids.

What is needed, we believe, is a fundamental essential amino acid unit adaptable to special situations and upon which various indices can be developed. And yet the rest of the dietary nitrogen, the nonessential nitrogen mentioned earlier, must be considered. Many workers have been concerned with the possible specific importance of the nonessential amino acids, and recently it has been put forth that even the need for essential amino acids beyond requirements is rather nonspecific, and can be classed as a need for "α-amino nitrogen." Patterns may be almost irrelevant when requirements have been met.

This conclusion takes into account the possibility of overloading the enzyme system, a situation which Peng and Harper (1970) found can occur with some amino acids because it is considered unlikely in diets based on basic food commodities used in moderation.

Other investigators have proposed as a standard a reference protein in a given amount based on total calories. In a study done for A.I.D., Bernstein (1969) suggested a reference protein containing 30% of essential amino acids in a modified FAO pattern with a standard intake level of 10% of the total calories. But such a standard combines many judgment factors, and it can be expected that adoption of any standards or indices encompassing major issues yet to be resolved is highly unlikely. The possible slighting of the needs of the elderly and of women of child-bearing age, as the above standard does, would be enough to call forth objections. The difficulties in developing standards and indices of human protein nutrition can be demonstrated by the work of Oomen (1970). He reports that in certain groups of root-eaters (sweet potato) in New Guinea, nitrogen-fixing bacteria may be supplying the equivalent of 10–15 g of protein per day, absorbed from the large intestine. The difficulty of setting fixed human requirements in the presence of such bizarre reports of human adaptability cannot be underestimated. We, therefore, decided early in our work to design a unit that could be adapted to various requirements.

Nutrition Decisions. Most of the malnutrition of the world can be blamed on the decisions of the adult members of the family, who either prepare foods of poor nutritional content, or allocate food poorly within the family, or grow food crops with poor nutritional qualities, or purchase foods without nutritional consideration. It is not enough to say that economic poverty is the cause of the nutrient scarcity that in turn causes malnutrition. We contend that basically poor decisions and thus poor policies bring about malnutrition, and that these conditions are sometimes superimposed upon the lack of resources. Making decisions requires alternatives. Having alternatives requires resources. Adults, who make the critical nutrition decisions, exercise alternatives in allocating limited resources. In most countries the young child has no options. On the other hand, better nutrition decisions are usually made when economic stress is lessened. In other words, there is a positive correlation between degree of undernutrition and level of poverty or lack of resources. The causal relation, however, is likely to be accidental, and not a consequence of any explicit decision to affect nutritional status.

Decision-making about food matters, even in developed countries, has yet to be based on considerations of nutritional efficiency. Certainly commodity pricing bears no relation to nutrition. It also seems that practically no home economic emphasis is applied to economic efficiency of nutrition, outside of institutional feeding situations. Esthetics and other considerations still seem to dominant adult decision-making the world over. But with technology now available, it should be possible to obtain nutritionally effective foods designed for cultural acceptability.

The Probyte and Probits (/), for the effective and potentially effective fractions of proteins, can make possible increased rational decision-making in the fields surrounding nutrition, without inhibiting the work of nutritionists in resolving the many issues on protein that are still in dispute.

Decisions on human requirements for many nutrients are still at issue among nutritionists everywhere, and probably will be for the foreseeable future. However, in spite of disagreements over details, both United Nations agencies and the U.S. Food and Nutrition Board of the National Research Council

Table VII. Procedure for Finding the Probyte/Probit Content of the F.A.O. Reference Protein Essential Amino Acid Pattern[a]

	Results							
Steps	**tr**	**thr**	**isol**	**leu**	**lys**	**s**	**pal + tyr**	**v**
1. List the egg essential amino acid mg/cal (Probyte):	7.1	24.4	30.0	42.0	33.3	27.6	47.1	32.6
2. List the mg essential amino acid/g N in FAO reference pattern:	90	180	270	306	270	270	360	270
3. Calculate and record (1)/(2) = g of FAO pattern N/Probyte:	0.1	0.13	0.1	0.137	0.12	0.10	0.12	0.12
4. Take max col of (3) times the values of (2) and record:	12.4	24.7	37.1	42.0	37.1	37.1	49.4	37.1
5. Probit grouping	0.74	0.01	0.24	0	0.11	0.34	0.05	0.14

From line three, the maximum value is 0.137, meaning that 0.137 g of FAO pattern N is required to provide 1 Probyte.

[a] Source: FAO (1970).

Table VIII. Human Requirements in Probytes (WHO, 1965)

Age	mg N/kg/day	Probytes kg/day	Probits/kg/day[a] ×(0.74/0.01/-0.24/0/0.034/-0.05/0.14)
1	148	1.08	1.08
2	136	0.99	0.99
3	134	0.98	0.98
4–6	130	0.95	0.95
7–9	123	0.90	0.90
10–12	114	0.83	0.83
Boys 13–15	110	0.80	0.80
Boys 16–19	102	0.74	0.74
Girls 13–15	110	0.80	0.80
Girls 16–19	100	0.73	0.73
Men	95	0.69	0.69
Women	95	0.69	0.69

[a] Note: If egg had been chosen as the FAO reference pattern the Probits (/) = 0.

Table IX. Comparing Maize and Opaque-2 Corn

	Maize	Opaque-2
Yield/kg/ha	4500	4050
Percent Protein	7.84	10.3
Probytes/ha	297,000	474,000

Added: First two limiting amino acids

Probit: (0/0.91/0.81/2.62/0.02/0.34/1.65/0.82) Maize
(0.62/0.37/0/0.95/0.3/0.34/0.61/0.40) Opaque-2

Added amino acids: 0.34 tr + 0.32 lys Maize
0.34 isol + 0.04 lys Opaque-2

Probytes added: 101,000 Maize, 161,000 Opaque-2

Percent tr added: Maize—0.34 tr × 0.71 g/Probyte × 6.6 Probytes/100 g

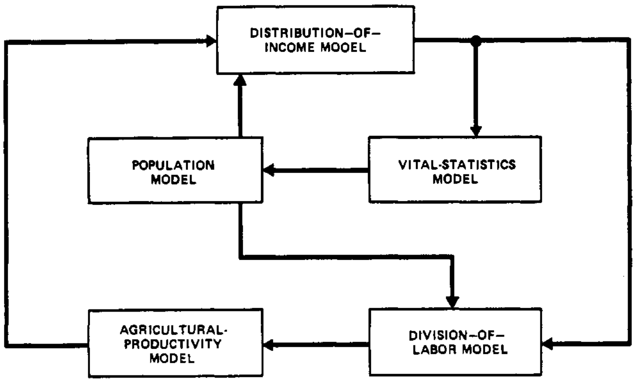


Figure 2. Major models in the farm sector simulation

have made important recommendations about requirements that can be quite usefully applied to considerations involving protein requirements, but still are far from settled. In the Food and Nutrition Board Recommended Dietary Allowances published in 1968, for example, requirements were put in terms of an "ideal" protein, but this protein was not defined. FAO (1970) and WHO (1965) have calculated requirements on a different basis, employing a reference pattern of amino acids. Table VII shows that with respect to egg the FAO pattern is first-limiting in leucine, and that the calculation shows the FAO ideal protein to contain 0.137 g of nitrogen per Probyte. Now referring to Table VIII, it can be seen that with requirements for ideal protein expressed in grams of nitrogen per day per kilogram of body weight, by age group, one can estimate the Probyte requirements of the adult of 70 kg to be 70 × 0.69 Probytes or 48 Probytes. The Food and Nutrition Board's "ideal" protein requirement for the 70-kg reference man is stated to have an egg essential amino acid pattern at the level of 25% of the total protein. The Probyte requirement here would be 35 g × 0.25 × 4.1 cal/g = 36 Probytes. But the Food and Nutrition Board assumes that an additional allowance for individual variability is needed equal to 30%, so the Probyte requirement becomes 36 + 0.3 × 36 = 48 Probytes. It is interesting to note that the requirements for essential amino acid calories (Probytes) are coincidentally about the same as for an "ideal" protein. Since most proteins are far from "ideal" the Probyte should give far more meaning to the importance of the essential amino acids of proteins.

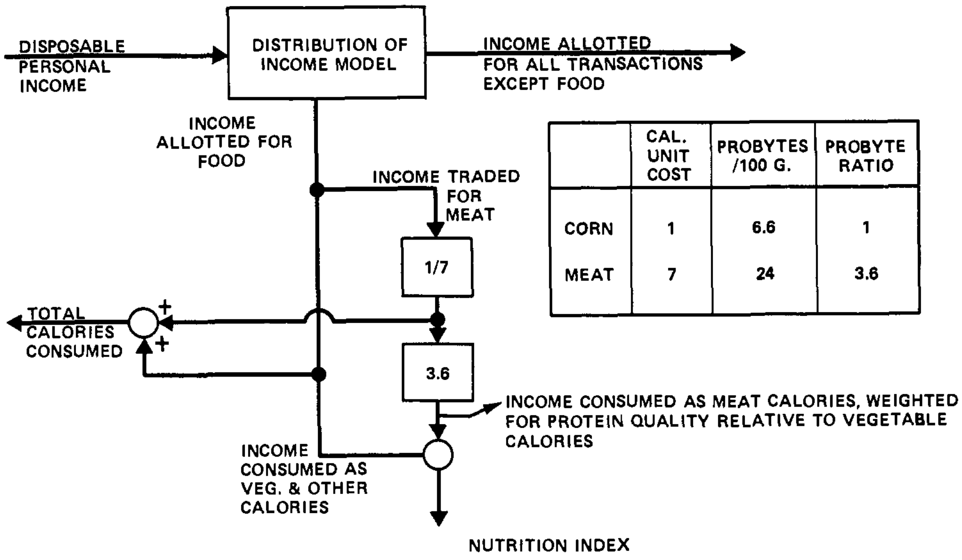
The Probyte and the Green Revolution. The full story on the negative as well as positive impact of the green revolution is yet to be unfolded. In the case of nutrition, it is likely that because of the newer high-yielding varieties, the decision maker has more food resources. Actually, he may have fewer nutritional alternatives. When yield goes up and a market or use cannot be found, the alternatives are to eat more and/or plant less. If the variety eaten is poorer in essential nutrients than the previous variety, as most of them are, then the consequences are poorer nutrient balance in the diet. On the other hand, if there is a market, all the growers move to fill the demand and the locally produced, less profitable but nutritious foods, such as pulses and specialty seed crops, may disappear from cultivation.

High-lysine maize represents a case where nutrition potential is improved, as illustrated in Table IX. However, because of the absence of such a unit as the Probyte in the pricing and marketing system, the improved grain may not enjoy the success it should. The yield of this variety is lower than those in use, although the Probytes are higher. Producers of animal feeds based on growth needs will undoubtedly find it economical, as shown by the difference in Probyte yield. Since most of the malnutrition in maize-consuming areas is Probyte malnutrition and not yield malnutrition, the nutrition potential of this new strain is not likely to be reached until either the market price reflects the Probyte improvement or until the yield and the Probyte production are together improved. The same effects will be observed in other basic genetic improvements, so limiting the impact of the green revolution.

Probytes and Nutrition Policy. Good protein is usually the most expensive nutrient in any country. This results from the extent of our daily requirements combined with the low productivity of effective protein food materials, further coupled with the need to process most of them more extensively than is necessary for other nutrients.

Suppose, however, in a developing country short of high quality protein, that an agricultural subsidy were offered for production of all food materials based on the per-acre production of Probytes. Thus, while a chicken industry requiring negligible land might claim a high production rate, it would have to base its Probyte output on the total inputs, and only the net Probyte production could be counted. The production of Probits (/) could also receive a subsidy, depending on the amount and potential to produce Probytes from them.

Under a Probyte pricing policy, it would be possible to gauge the importance of and even reverse the Swaminathan (1970) report of worsening nutrition brought on by converting from dry land farming to irrigated farming. When a rational change such as Probyte-based planning does occur, most of our agricultural and food economic tables will need to be modified to express protein in terms of nutritional effectiveness, Probytes and Probits (/). To assist policy makers, the economists, nutritionists, epidemiologists, dieticians, and educators could begin to express production, food balance, dietary requirements, clinical symptoms, and educational



	CAL. UNIT COST	PROBYTES /100 G.	PROBYTE RATIO
CORN	1	6.6	1
MEAT	7	24	3.6

Figure 3. Use of Probyte in determining nutrition index

materials in common units of effective protein. Beyond this the Food and Drug Administration could develop indices for estimating the suitability of nutritional advertising claims by scoring the foods in terms of Probytes and Probits (/).

Modeling Economics to Include Nutrition and the Probytes. Attempts to develop concept or systems models of economics to include nutrition as a distinct element have only recently begun to appear in literature. Perhaps the harbinger of these is the paper by Alan Berg (1967). Since it appeared, AID has stimulated research in the area, with the result that new preliminary concept models have been proposed, each taking a somewhat different perspective. Levinson and Call (1970) have taken a national economic development perspective; both Rulison (1970) and Oelhaf (1970) have taken the potential for interaction between nutrition and family planning as the basis upon which to build models. Cesario *et al.* (1970) proposed a model where nutritional status becomes the output.

Our own work in this field has led us in still a different direction—one based on the unit cell of decision-making. This research is continuing.

To handle the great number of variables involved in any social system or social change (*e.g.*, development) computerized simulation models are increasingly favored. Such models describe the interrelationships between large numbers of dependent, and usually fewer independent variables, in quantifiable terms. To the extent that the model accurately depicts a real situation, it can be said to be a good simulation model.

An example of this kind of model is a simulation model of the joining sector of a nonmechanized society developed by Daetz (1968). Figure 2 illustrates the relationships between different aspects within the joining sector, which is assumed to interact with a governmental sector and a merchant sector; the three sectors comprise the society. This model illustrates the utility of the Probyte to assess various alternative allocations of the principle factor in any joining sector, for example, crop output. In Figure 2 crop output is the output of the Agricultural Productivity Model, which then becomes input to the Distribution of Income Model.

In order to select rationally between alternatives, it is necessary to know the probable consequences of each alternative. In terms of diet it is thus necessary to know quality as well as quantity. Figure 3 describes the output of the Distribution of Income Model in more detail. Daetz has assumed that all animal protein consumed in the Agricultural Sector is obtained by trade with the Merchant Sector. He further assumes that the price of meat reflects the calorie conversion efficiency of livestock on the basis of work by Cepede *et al.* (1964). "On the basis of studies made in Western Europe, the international organizations devoted to food and agriculture claim that the caloric proportion involved is 1 : 7. That is, for every calorie of animal products seven calories of grasses or cereal grains will have been consumed by the animals."

Thus, by summing up the income consumed as vegetable products and that traded for meat (reduced to one-seventh of its original caloric content) Daetz was able to obtain total calories consumed. In order to obtain and index the quality of the diet, however, Daetz simply remultiplied his animal calories by 7. As can be seen from the table, however, the true protein value per calorie of animal products (in this case just meat) is 3.6, not 7.

These figures indicate that with these prevailing prices the Agricultural Sector would be nearly twice as well off in terms of the protein quality of its diet if it consumed all its food in cereal form, rather than trading it for animal products (subject, of course, to availability of other nutrients from nonanimal sources). Since proteins are generally recognized as inefficient sources of calories and animals are consumed primarily for protein, pricing might well be more reasonable on this basis. The Probyte provides a means of comparing nutritional protein quality between any number of products or diets.

A number of other economic approaches have been made to the problem of inserting factors for protein into economic tables and cost/benefit analyses. But as with modeling research, it seems to us, theb asic weakness leading to propositions of widely varying validity and to heroic assumptions is the nutritionists' lack of a single arbitrary but fundamental unit for protein nutritional effectiveness. The Probyte is such a unit. Apply to this all the factoring modifications that research in any field can devise and, like the vitamins and calories themselves, protein will become more accurately explicable to economists, planners, and modelers.

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Chemical Aspects of Updating Diet Quality

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The use of chemicals to improve the nutritional quality of foods began with the additions of iodine to salt to prevent goiter and vitamin D to milk to prevent rickets. Several hundred chemicals have been approved for use to improve the color, flavor, texture, keeping qualities, and nutritional value of food. This makes our food supply one of the most varied, palatable, convenient, and nutritionally adequate in the world. The outstanding example of the successful and economical use of chemicals to improve the nutritive value of foods is demonstrated by the enrichment of bread, flour, and other cereals. We must use chemical additives in increasing amounts and variety in order to make our food supply nutritionally adequate at the lowest cost in the face of the rapid population increase. Chemicals must be used under proper controls for safety and effectiveness. It can be anticipated that food mixtures, imitation foods, and meal substitutes in which chemicals are widely used are going to become increasingly useful and important in our food supply.

Although several hundred chemicals are used primarily to upgrade the quality and acceptability of many foods by improving their color, flavor, texture, and shelf-life, they also indirectly contribute to nutrition by making food more available, more convenient and more palatable. However, only a relatively few chemicals are used for the direct purpose of improving the nutritional value of food and this is a relatively new development in food science.

The use of various substances to prevent malnutrition, such as cod liver oil to prevent rickets, lemon juice to prevent scurvy, and fish oil concentrates to prevent vitamin A deficiency, goes back many years before synthetic nutrients became available. The use of synthetic or isolated chemical substances to improve the nutritional value of food was not possible until a number of important advances in our knowledge had occurred.

First, the nutrients had to be isolated, their chemical structure determined, and synthetic production worked out before they could be made available in sufficient quantity at a price which made the procedure commercially feasible. Even then a public awareness of their value in health had to be created, in order to make them acceptable and saleable.

The synthetic production of most of the vitamins occurred during the 1930's. At the same time, the knowledge of nutrition had to advance to a point where acceptable recommended dietary allowances for the various nutrients could be estimated in order that the proper quantity to use could be determined. The clinical diagnosis of the deficiency diseases

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