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THE COMPARATIVE MERITS OF ANIMAL AND VEGETABLE FOODS IN NUTRITION

Chairman: PROFESSOR R. C. GARRY, *Institute of Physiology, University of Glasgow*

Chairman's Opening Remarks

By R. C. GARRY, *Institute of Physiology, University of Glasgow*

Controversy concerning the relative nutritive merits of protein from plant and animal sources is of long standing. Our conception of the total quantity of protein required has also swung wildly from one extreme to the other. This scientific problem, intrinsically difficult in itself, has been, and still is, emotionally bedevilled by prejudice and sentiment.

Recent advances in biochemistry have given us a better appreciation of the ultimate composition of proteins from different sources, and have helped to explain and foretell the 'biological values' of different proteins. Nevertheless, we must not forget that we do not eat proteins as such, we eat food containing protein. And evidence is accumulating that the value of the protein may depend to some extent on the vehicle in which it is presented. The time is propitious for stocktaking, for a review of the past, for a forecast of the future. This is the purpose of our conference to-day.

Biochemistry of Animal and Vegetable Proteins

By G. R. TRISTRAM, *University of St Andrews*

Text not received for publication.

The Relative Nutritional Values of Animal and Vegetable Proteins for Animals

By K. J. CARPENTER, *Rowett Research Institute, Bucksburn, Aberdeenshire*

The classical method for the nutritional evaluation of the protein complex in individual foods or feeding-stuffs is to feed them, at a level of 10% protein, as the sole protein source in the otherwise adequate diet of young, growing rats. The material is then rated either by its digestibility and biological value (the proportion of the absorbed nitrogen which escapes excretion in the urine) or by the protein-efficiency ratio (the gain in weight of the rat per g. protein eaten). From an examination of published data for thirty-eight materials Block & Mitchell (1946–7) found a very high degree of correlation ($r = +0.84$) between the protein-efficiency ratio and the net protein utilization (digestibility × biological value).

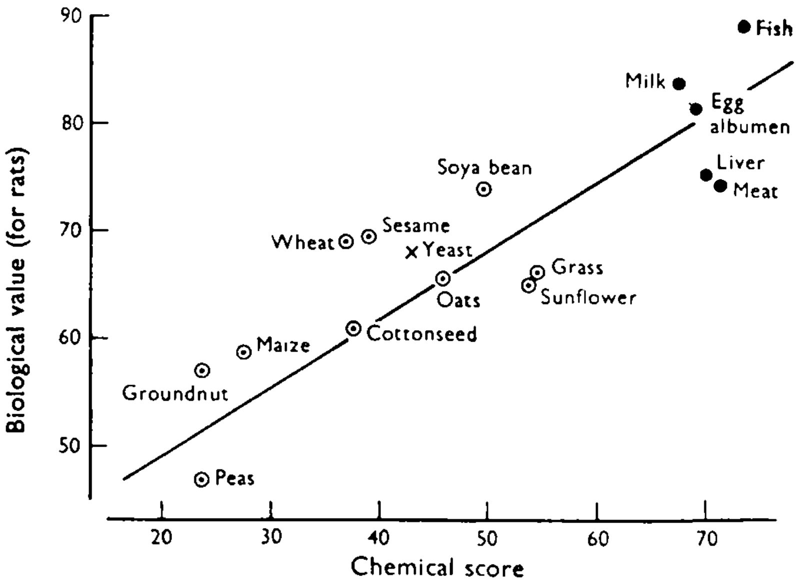

Fig. 1. Correlation diagram of the biological value and chemical score of sixteen animal (●) and vegetable (⊙) materials. (Data from Mitchell & Block, 1946; Bartlett, Henry, Kon, Osborne, Thompson & Tinsley, 1938; Harrison, Anderson & Pottinger, 1935.)

Figures of fair reliability are available for the essential amino-acid content of most common feeding-stuffs, and for these Block & Mitchell have calculated a chemical score in terms of whole-egg protein, which is almost wholly utilized by the young rat. This is obtained by calculating the content of each essential amino-acid in the protein (N × 6·25) of a material as a percentage of the concentration of the same amino-acid in whole-egg protein. As the limiting amino-acid is held to determine the value of the whole protein, the lowest percentage obtained is used as the chemical score.

In Fig. 1 some of the available data (mostly from Mitchell & Block, 1946) for the chemical score and biological value of materials of interest in animal nutrition are set out in diagrammatic form. Again there is a high degree of correlation between the two methods of evaluation. The data show the general superiority of the animal materials over those of vegetable origin. Only soya-bean meal, toasted to destroy the trypsin inhibitor it contains, is within the range of the animal proteins.

These figures for biological values would be invalidated if it were shown that the animal materials alone carried with them vitamins which affected the utilization of protein, and in which the rat was deficient.

Vitamin B_{12}-deficient rats have an increased requirement for methionine (Schaefer, Salmon & Strength, 1949) and the work of Bosshardt, Ayres, Ydse & Barnes (1946) suggests that utilization of dietary protein will be impaired. This vitamin is found in animal materials, but is absent from unfermented vegetables, as also from the basal diet used in the trials referred to. Nevertheless, the rats will almost certainly have carried sufficient reserves of vitamin B_{12} from their suckling period to prevent a deficiency in the short experimental period (Zucker & Zucker, 1948). This is confirmed by the biological values for the vegetable, as compared with the animal, feeds being at least as great as would be expected from the relative chemical scores of the two classes.

These rat experiments represent necessarily a great simplification of the practical problem of making up balanced rations at low cost. There remain the possibilities of less exacting requirements in later life (when a much greater aggregate of feed is consumed), mutual supplementation between vegetable proteins, and species differences.

Cattle and sheep

The ruminants, with the exception of the period when they are suckling (Blaxter & Wood, 1950), have an alimentary microflora encouraged by the dynamics of the digestive system to attack the feed for a considerable time. The micro-organisms have wide powers of synthesis. When urea is given as the sole source of nitrogen, all ten of the essential amino-acids are found in the rumen in approximately the same quantities as after feeding a good-quality protein (Thomas, Loosli, Ferris, Williams & Maynard, 1949).

It is not surprising, therefore, that for ruminants the proteins in the common feeding-stuffs, whether animal or vegetable, are generally similar in biological value (McNaught & Smith, 1947). Moir & Stewart (1947) showed that legume seeds low in the sulphur amino-acids were of low value in promoting heavy wool growth, but a requirement by sheep for dietary cystine and methionine has not yet been proved.

The major feed of both cattle and sheep is fresh herbage, which should meet their maintenance requirements for protein, and even sustain a moderate level of production.

Pigs and poultry

Pigs and poultry, both monogastric species, cannot tolerate the high level of fibre in a ration composed mainly of grass, and in practice the cereal grains and offals form the main source of energy in their rations. For poultry of all ages and for pigs (except during fattening), a mixture of cereals is deficient in protein. The practical problem is therefore to assess the relative values of animal and vegetable proteins as supplements to cereals for these two species.

So far, individual amino-acid requirements have been worked out only for chicks. Calculations suggest that of all the essential amino-acids only lysine and the sulphur-containing amino-acids, cystine and methionine, will be limiting factors in practical rations, and their concentration in sixteen feeding-stuffs (De Man, 1949) is shown diagrammatically in Fig. 2.

One criticism of experiments with supplementary proteins is that the results may apply only for the particular basal mixture used. However, the similar composition of the main cereals suggests that supplementary values should not differ greatly with the cereal mixture. This was confirmed when maize and wheat were tested separately with a series of fish meals and meat meals (March, Stupich & Biely, 1949).

The approximate percentages of lysine and cystine + methionine required in the protein of a chick ration containing 20% protein have been determined (Almquist, 1947) and are shown in Fig. 2. By analysis, the cereals should be deficient in lysine and border-line for the sulphur amino-acids, and this was confirmed for a wheat-protein preparation (Jeppesen & Grau, 1948).

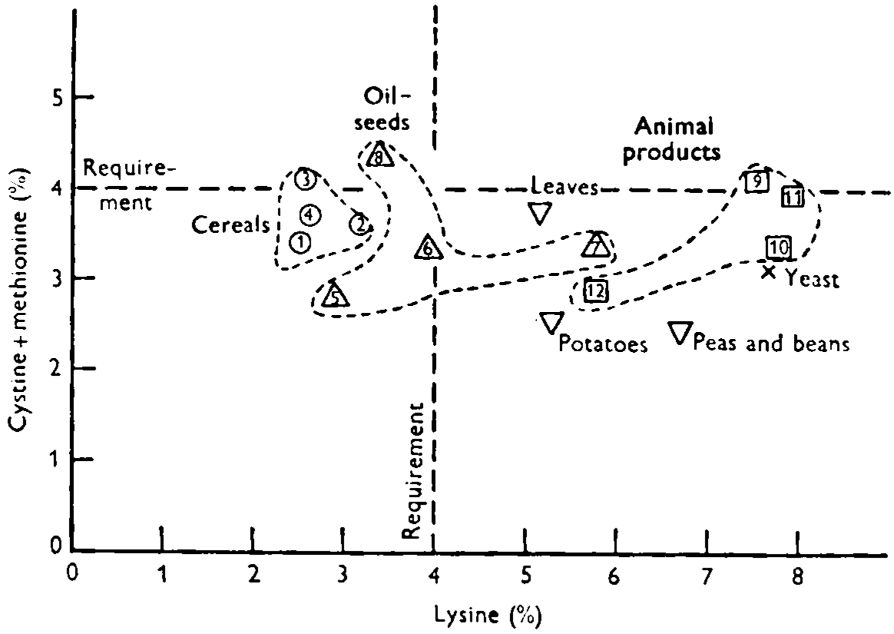

Fig. 2. Lysine and 'cystine + methionine' in the crude protein of sixteen feeding-stuffs, and the requirement of these amino-acids by the chick in an 'ideal' protein fed at 20% level. In each case the requirement is 0·8% of the total ration or, as shown here, 4·0% of the protein. (Data from Almquist 1947; De Man, 1949; and Grau & Kamei, 1950.) 1. Barley. 2. Oats. 3. Maize. 4. Wheat. 5. Groundnut. 6. Cottonseed. 7. Soya-bean. 8. Sunflower. 9. Fish meal. 10. Blood meal. 11. Skim milk. 12. Meat meal.

The common animal feeding-stuffs are generally higher in lysine than the vegetable feeds, and so appear better able to supplement the cereals. Soya-bean meal again appears to be outstanding among the vegetable proteins. Meat meal is inferior to the other animal feeds by analysis, and a large proportion of the lysine may also be unavailable to the chick (March, Biely & Young, 1950). The lysine of groundnut meal, though present at a low level, is mostly available (Carpenter & Ellinger, 1951).

There are some differences between the methionine content of feeds as estimated by chemical and microbiological methods (De Man, 1949), but it is clear that though some of both classes of supplements are deficient in the sulphur-containing amino-acids, no protein has a compensating excess.

Heiman, Carver & Cook (1939) have suggested a standard method of evaluating supplementary proteins for chicks, using a basal 8% protein ration of mixed cereals and vitamin concentrates. The supplements are added, for different groups, to give 3% additional protein. Their gross protein value (G.P.V.) is the extra growth obtained (in 2 weeks) divided by the supplementary protein eaten. The values are expressed as a percentage of that obtained for casein.

Table 1 shows the results obtained for a series of feeding-stuffs with the original method (Robertson, Carver & Cook, 1940), and with the crude-fibre level kept constant (Carpenter, Duckworth & Ellinger, 1951). The results for animal materials, and for extracted oilseeds are in good agreement with the expectations based on their amino-acid composition. The low value for cottonseed meal may be attributed to the presence of toxic material in the sample (Ingram, Cravens & Elvehjem, 1950).

Table 1. *Gross value* of protein supplements for chicks* (*casein* = 100)

(The figures are the mean values obtained with each feeding-stuff)

Supplement	U.S.† results	U.K.‡ results
Animal products:		
Casein	100	100
Herring meal	101	95
White fish meal	—	89
Dried skim milk	90	—
Meat meal	55	—
Oilseeds:		
Soya-bean meal	76	—
Groundnut meal	—	50
Cottonseed meal	25	—
Coconut meal	22	—
Herbage:		
Lucerne meal	37	27
Lucerne meal and 0·15 % cholesterol	—	70
Grass meal	—	55
Grass meal and 0·15 % cholesterol	—	58
Red clover meal	—	46

* For definition see p. 246.
† Robertson *et al.* (1940).
‡ Carpenter *et al.* (1951).

The first value obtained for lucerne meal was low, considering the promising analyses obtained for leafy materials. However, Peterson (1950) showed that lucerne contains a 'saponin-like' growth-depressant inactivated by the addition of cholesterol, and the G.P.V. for lucerne was greatly increased by adding 0·15 % cholesterol to the ration. Ordinary grass meal appeared not to contain this growth-depressant to any significant extent. The values for the leafy materials tested are still lower than for soya-bean meal, though amino-acid analyses suggest that they should be of approximately equal value. The analyses may be wrong, or alternatively the leaf proteins may be less digestible. Of the sixteen materials for which data from rat experiments are given in Fig. 1 above, all had a digestibility greater than 90 %, with the exception of grass meal for which the figure was 67 %.

If it is accepted that vegetable protein supplements are generally inferior to the animal ones, the problem is to determine how far the inferiority can be made up by giving the supplementary protein at higher levels.

Fig. 3, based on the results of three comparable chick trials lasting 4–6 weeks, shows the findings with herring meal and groundnut meal as supplementary proteins. The growth rates converge as the level of supplementation increases. The proportion, however, in which the two supplements have to be fed in order to produce any given growth rate is constant (in this instance 2 : 1). This would be expected if the requirement for the individual amino-acids remained constant within the range of protein levels used.

It has been shown by Grau & Kamei (1950) that the individual requirements for lysine and methionine increase when the protein level of the chick ration is raised to 30 or 40%. With a sufficiently unbalanced protein, additional supplementation should then make things worse rather than better. With groundnut meal, one of the poorer protein sources in common use, this does not occur, and the leeway can be made up by increasing the level (Fig. 3).

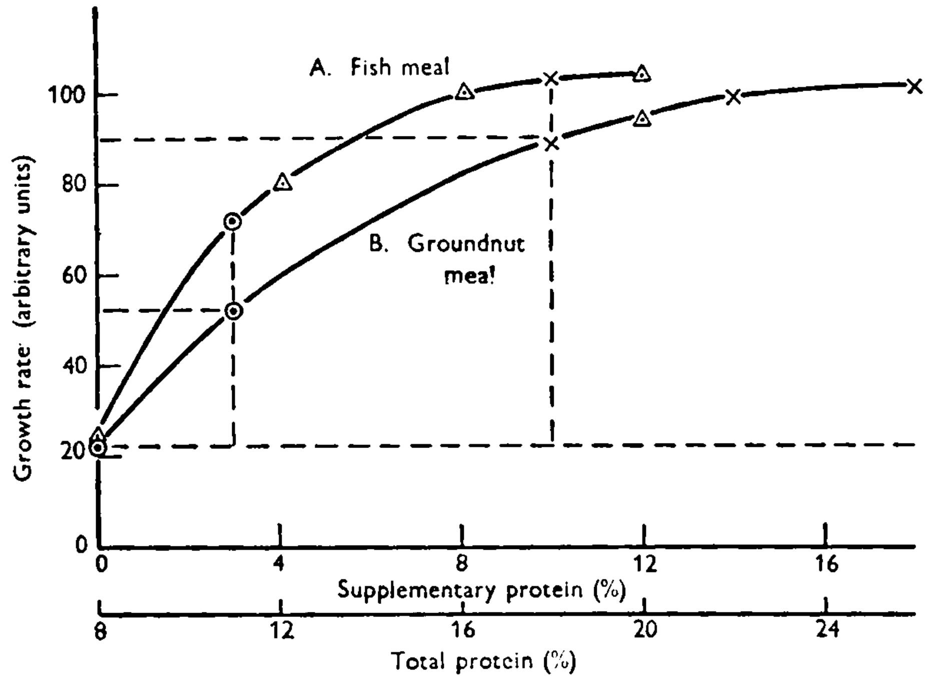

Fig. 3. Growth of chicks in the first 4–6 weeks of life according to protein level, and nature of protein supplement. Combined data from three experiments (Carpenter *et al.* 1951). △ = Exp. 1; ⊙ = Exp. 2; × = Exp. 3.

In practice, high initial growth rates are not an end in themselves, and we have found that a groundnut ration of normal protein level will finally produce a healthy bird at point of lay with the same feed-conversion efficiency as will a fish-meal ration giving a higher growth rate for the first few weeks (cf. Halnan, 1948).

In laying trials, with rations containing a total of 14–15% protein, fish meal has been replaced, without any significant differences resulting, by either soya-bean meal (Forrest, Biely & March, 1950), sesame meal (Hale & Bolton, 1948) or groundnut meal with palm-kernel meal (Temperton & Dudley, 1939–40). This contrast with the chick results could be due to a greater ability of the older animal to synthesize some of the essential amino-acids. A simpler explanation may be that the fish meal in the rations is in excess and could be reduced without effect, but that the level of the vegetable proteins could not be reduced.

General conclusions

Animal protein feeding-stuffs such as fish meals and dried skim milk are rich sources of vitamins, important for non-ruminant livestock. The recent introduction of condensed fish solubles, 'animal protein factor' concentrates from the antibiotics industry and synthetic riboflavin as alternative sources of these vitamins will provide a greater field for the use of otherwise suitable vegetable proteins which are not also potent sources of these factors. Research has shown that they are generally inferior to animal proteins, but that this may be made up for by feeding them at higher levels. Whether such a change is economically worthwhile will depend upon the cost of any extra vitamin supplements needed, as well as on the relative cost of the protein supplements themselves.

The use of vegetable proteins may be particularly important in the colonial development areas where fish meal and milk products are not normally available for pig and poultry feeding. Unfortunately, ordinary grass and leaf meals are high in fibre, and cottonseed meal contains a growth depressant. These limit their usefulness at present, but new processing methods may be worked out to overcome these difficulties.

I am indebted to Dr J. Duckworth for his help in the preparation of this paper.

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Conversion Factors for Vegetable and Animal Foods for Human Consumption

By K. L. BLAXTER (IN RECEIPT OF A SENIOR AWARD OF THE AGRICULTURAL RESEARCH COUNCIL)
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To translate animal and vegetable foods, meat, milk, eggs, cereals and vegetables, into terms of human consumption and then to discuss their adequacy in meeting the nutritional demands of man, necessarily involves decisions on common denominators. During translocation of crop or animal from the farm to the consumer many inevitable losses occur and, even in the hands of the consumer, further considerable, culinary, waste takes place. The first problem is, therefore, to decide on the unit to be used to assess this wastage. It could be a monetary one—the amount of food purchased for a given amount of money—or a unit of human endeavour—the amount of food produced per unit of man-power. Production per acre of agricultural land, however, is probably the most generally acceptable unit to use, and this I have chosen. The second problem is concerned with evaluation in terms of human needs. So far we have been concerned solely with protein supplied from vegetable and animal products, in some instances partly purified. We must also think in terms of dietary energy, essential vitamins, minerals and possibly as yet unidentified nutrients.

I have, therefore, considered requirements not only for protein but also for dietary energy, calcium, vitamin C, vitamin B_1 and vitamin A. As, however, most of the discussion on the differences between, or complementary virtues of, vegetable and animal foods revolves around their respective proteins, protein supplies from these two sources must be evaluated in terms of their ability to meet protein requirements. Biological values of single proteins have little practical value in this respect, since the biological value of the proteins of a mixture of two foods is not the arithmetic mean of the biological values of the proteins of the two foods determined separately (Mitchell, 1924). Even supplementation of the medium-quality proteins of wheat with the poor-quality proteins of gelatin results in a biological value of the mixture greater than that of the wheat proteins alone (Chick & Slack, 1945).

A solution to this difficulty is to express human requirements in terms of essential amino-acids. Requirements for amino-acids should be additive. Table 1 shows three estimates of the daily amino-acid requirement of man (Rose, 1949; Block & Bolling, 1945; Macy, 1943). It will be noted that the values given by Rose are considerably less than those given by the other authors. Rose's values, however, are double the requirement for the particular amino-acid necessary to maintain nitrogen equilibrium in young men, and as such are the only experimental values so far available. That they are approximately correct may be seen in Table 2, where the minimum requirements for particular proteins for the maintenance of nitrogen equilibrium have been expressed in terms of amino-acids. The amino-acid present in limiting concentration—lysine for wheat flour and methionine for milk proteins—is present in amounts almost

Table 1. *Recommended daily requirement of amino-acids for an adult human subject*

Amino-acid	Experimentally determined by Rose (1949)* (g.)	Calculated from analysis of diets: Block & Bolling (1945) (g.)	Macy (1943) (g.)
Tryptophan	0·5	1·1	0·9
Phenylalanine	2·2	4·4	4·2
Lysine	1·6	5·2	4·6
Threonine	1·0	3·5	3·2
Valine	1·6	3·8	3·2
Methionine	2·2	†	†
Leucine	2·2	9·1	9·6
Isoleucine	1·4	3·3	3·1
Histidine	Not required	2·0	1·6
Cystine and methionine	—	3·8	3·7

* Requirement taken as double the mean requirement necessary to maintain nitrogen equilibrium in a young adult male.
† See cystine and methionine.

Table 2. *Daily protein requirement for maintenance of nitrogen equilibrium in an adult human subject with basal metabolic rate of 1700 Cal./24 hr., expressed in terms of essential amino-acids*

Amino-acid	Proteins: Whole milk, 29·3 g.* (g.)	Wheat flour, 50·6 g.* (g.)	Mean requirement of amino-acid for nitrogen equilibrium (Rose, 1949) (g.)
Tryptophan	0·47	0·40	0·25
Phenylalanine	1·67	2·75	1·1
Lysine	2·19	0·90†	0·8
Threonine	1·35	1·35	0·5
Valine	1·93	2·50	0·8
Methionine	1·08†	1·50	1·1
Leucine	3·31	4·50	1·1
Isoleucine	1·81	2·25	0·7

* Bricker, Mitchell & Kinsman (1945).
† Limiting amino-acid in the nutrition of man when this source of protein used.

identical with those experimentally determined by Rose. These requirements do not allow for adult growth, loss of skin debris, growth of epidermal structures and minor changes of body form (Bricker, Mitchell & Kinsman, 1945; Hrdlička, 1936). Results of balance experiments have shown that this adult growth and loss of epidermal tissues is approximately 0·98 mg. nitrogen/basal Cal. of heat produced. This effectively doubles the protein requirement for mere nitrogen equilibrium. The recommended allowances of Rose, which are arbitrarily double the minimum, appear, therefore, to be quite suitable as standards of requirement, and better than those based on analysis of diets.

In Table 3 are listed the requirements of adult man for a whole year, based on Rose's estimates of amino-acid requirement, and the (U.S.A.) National Research Council's (1943) recommended allowances. Only tryptophan, lysine and methionine have been included in the estimates of requirement, as it seems unlikely that other amino-acids would ever be short.

Table 3. *Daily and yearly requirements of an adult human subject for certain nutrients*

Nutrient	Requirement	
	Daily	Yearly
Calories	3000 Cal.*	1·1 million Cal.
Tryptophan	0·5 g.†	182 g.
Lysine	1·6 g.†	584 g.
Methionine	2·2 g.†	803 g.
Calcium	800 mg.*	292 g.
Aneurin	2·0 mg.‡	730 mg.‡
Ascorbic acid	75 mg.*	27·4 g.
Vitamin A	5000 i.u.*	1·8 million i.u.

* (U.S.A.) National Research Council (1943). Recommended daily allowances.
† Rose (1949). Recommended daily allowances.
‡ Probably too high an estimate, especially for high-fat diets.

In the conversion of animal and vegetable crops into human food many losses undoubtedly occur as, for example, in the production of sugar from sugar beet and of flour from wheat. The losses of gross calorific value of the two crops are very considerable indeed, and Table 4 shows that large amounts of by-products are retained on, or sent back to, the farm, where they can be utilized by livestock. This point will be considered later.

The computed amounts of human nutrients produced per acre of land by animal and vegetable crops, disregarding for the present this return of by-products and their utilization by animals, are shown in Table 5. As we all know, wheat, sugar beet and potatoes are primary sources of dietary energy for the population, whereas animal products from a similar acreage supply only one-tenth to one-quarter as much. An acre of good agricultural land sown to wheat could supply the calorie needs of 2·4 people for a year, but could supply sufficient lysine for only 1·8, little, if any, ascorbic acid or vitamin A activity, and, without fortification of the flour with chalk, could supply the calcium needs of only 0·3 people. Except possibly for the lack of ascorbic acid in the egg, the utilization of the calories of the animal foods is not limited by the supply of amino-acids, calcium or vitamins B_1, C or A. Yet milk could supply the lysine needs of 4·1 people, the calcium needs of 3·6 and the vitamin A needs of nearly 2·0. In other words, the total nutritive value of the main vegetable crops is limited by their shortage of vitamins and, to a much lesser extent, of essential amino-acids, whereas animal crops provide a superabundance of these nutrients but a shortage of calories. What the housewife calls vegetables, i.e. green crops of various sorts, occupy a special position. They supply considerable excesses of vitamins A and C and in addition provide large quantities of essential amino-acids. Bulkiness limits their usefulness, since they do not supply a large number of calories. An adequate human diet can be planned from an arable acreage including a green crop, but it would not necessarily be palatable. A further point is that an entirely vegetable dietary for man is not necessary from the point of view of maximal production from our land resources, since by-products have to be utilized. This entails feeding to livestock the waste products of the food industry as well as the utilization of the straw, tops and unsaleable produce left on the farm.

Table 4. *Conversion of sugar beet and wheat crops into human food, direct products for human consumption from 1 acre of average farm land*

Crop	Total saleable produce	By-products: Retained	By-products: Returned to agriculture from factory	Processing losses	Total yield for direct human consumption: Weight	Total yield for direct human consumption: As percentage of total dry matter of whole crop
Wheat	Grain, 18 cwt.	Small corn, Seed corn } 1·5 cwt.; Straw, 1 ton	Miller's offals; part of screenings	Cleaning, 2%; Drying, 5%; Extraction, 25%	Flour, 850 kg.	50 (including straw)
Sugar beet	Beet (washed), 6 tons	Tops and crowns, 7 tons	Crude molasses; dried beet pulp	Sugar not extracted from pulp, 15%	Sugar, 750 kg.	29 (including tops)

Table 5. *Number of adult human subjects who can be supplied with 1 year's requirement of calories and nutrients from the vegetable and animal production of 1 acre of agricultural land*

Crop	Yield	Calories	Tryptophan	Lysine	Methionine	Calcium	Aneurin	Ascorbic acid	Vitamin A	By-products for stock feeding
Vegetable:										
Wheat	18 cwt.	2·4	2·4	1·8	2·1	0·3	3·8	0·2	0·1	Available
Sugar	6 tons	3·2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	Available
Potatoes	5 tons (ware)	3·3	1·7*	3·6*	—	0·8	7·7	24·7	0·1	Very little
Cabbage	20 tons	0·8	12·7	9·4	3·1	17·1	8·2	182·5	49·3	Very little
Animal:										
Milk	200 gal.	0·6	2·8	4·1	1·5	3·6	0·6	0·7–0·0	1·0–2·0	None
Pork and bacon	2 bacon pigs†	0·5	1·1	2·0	0·6	0·5	2·2	0·2	1·0	Available (cereal straw)
Beef	½ fattening animal	0·4	1·5	3·0	0·9	0·4	0·1	0·2	0·7–1·2	None
Eggs	2400 (20 birds)‡	0·2	1·4	0·8	1·5	0·3	0·5	0·0	0·7–1·2	Available (cereal straw)

* Based on analysis of isolated protein.
† Including purchase of 0·5 cwt. fish meal.
‡ Including purchase of 1 cwt. fish meal.
The following papers were consulted in constructing the table: Andross (1946), Booth, Carter, Jones & Moran (1946), Halnan (1944), Kon (1946*a,b*), Lampitt & Goldenberg (1946), Leitch (1944), Leitch & Godden (1941), Lockwood (1945), McCance & Widdowson (1946), Orr (1944), Pyke (1946), Watson & More (1942), Wood & Newman (1928).

Some crops leave little waste. Potato haulms are not edible under most conditions, and the only waste products are small unsaleable potatoes and a variable recovery of potato peelings in swill. To utilize these, the pig is normally used, and, as The Nutrition Society has often been informed, the pig is not a very efficient converter of food. Where cellulosic materials are available, the cow is the most efficient animal. Table 6 shows the

Table 6. *Contribution of animal products to the human-food production from 1 acre of land devoted to wheat or sugar beet*

(All results expressed in terms of the number of adults that could be supplied for 1 year from 1 acre)

Nutrient	Wheat: Direct (flour)	Wheat: Indirect (27 gal. milk)	Sugar beet: Direct (sugar)	Sugar beet: Indirect (134 gal. milk)
Calories	2·4	0·1	3·2	0·4
Tryptophan	2·4	0·4	0	1·9
Lysine	1·8	0·6	0	2·7
Methionine	2·1	0·2	0	1·0
Calcium	0·3	0·5	0	2·4
Aneurin	3·8	0·1	0	0·4
Ascorbic acid	0·2	0·1	0	0·5
Vitamin A	0·1	0·1–0·2	0	0·7–1·4*

* According to season of year.

Table 7. *Equivalent in terms of milk of the waste products from 1 acre of agricultural land of the sugar-beet industry*

	Starch equivalent (kg.)
7 tons tops, with 25% wastage, starch equivalent 8%	420
1·5 cwt. dried beet pulp per ton of washed beets = 9 cwt., starch equivalent 61%	274
Total	694

A cow requires 9300 kg. starch equivalent during her lifetime to produce 1800 gal. milk (rearing and 3 years' milking life)

So by-products from 1 acre sugar beet are equivalent to

$$\frac{1800 \times 694}{9300} = 134 \text{ gal. milk}$$

conversion of waste products from the wheat industry and the sugar-beet industry into human food. These calculations were based on the starch equivalent supplied by the by-products and the fact that the cost of rearing a cow and her production of 1800 gal. milk involves feeding her with 9300 kg. starch equivalent. The amount of milk produced from by-products is then calculated by proportion as shown in Table 7. The utilization of the waste products of these two crops by animals provides a very large additional supply of nutrients. With wheat, the milk produced from the bran and tail corn supplies almost sufficient lysine to make good the deficiency of lysine of the 75% extraction flour and more than doubles the calcium supply.

In conclusion, therefore, in dealing with the conversion of plants and animals into human food it is not with their comparative merits that we have to deal but with their complementary merits. An agricultural system devoid of livestock is not an efficient method of using our land nor is a system based in its entirety on livestock production.

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Economic and Statistical Aspects of Vegetable and Animal Foods

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In deciding what balance of vegetable and animal foods shall be available to the population of this country the relative nutritional and gastronomical values of the foods have to be weighed very carefully against what is economically practical. Though we know that it is possible to live and work on a diet containing only a very small contribution of animal protein and fats, most of us would probably work better and live more happily on a more mixed diet containing a larger amount of animal foods. The balance between the two types of food is largely determined by three factors: the acreage of land available for agriculture, the size of the agricultural labour force, and the extent to which we can rely on imported food. In this paper, I shall first indicate the relation of these economic factors to the physiological aspects of vegetable and animal foods, and then give some indication of how far home agriculture can be expected to make a greater contribution to our food requirements.

Physiological efficiency

Since to a considerable extent animals eat foods that could be utilized for human consumption or use land that could be cropped with cereals or potatoes, a measure of the efficiency of conversion of feeding-stuffs to human foods by animals is essential. There has been in the past some disagreement on the most appropriate measure to use; it will be as well therefore to consider first what is the best measure of efficiency and how it should be obtained. The yield of protein expressed as a percentage of the amount of protein fed has been widely used as an index of physiological efficiency; but this would only be a satisfactory measure if protein was the chief factor limiting further production. In fact, though lack of protein may be of major importance on some individual farms, particularly poultry farms, the livestock production in general is restricted not by lack of protein but by the available energy supplies. Sufficient protein for dairy cattle and other stock can be provided from home-grown foods and the ration of concentrates. The principal measures of efficiency that are of interest are therefore the ratio of proteins, fats, vitamins and other nutrients produced per unit of energy supplied in the feed. If the protein supplies of the population are critical, the first measure will be of greatest interest, but if fats are also short the ratio of the total energy produced (available to human beings) to the energy supplied may provide an adequate overall index.

In making assessments of this kind it is not sufficient to take the conventional allowances for maintenance and production for the adult animal. With the dairy cow, for example, allowance must also be made for the food required in the production and rearing of the calf up to the beginning of lactation, for maintenance during the dry period and for the food required to fatten her off when she leaves the dairy herd. On the credit side will be the milk produced in the course of, say, 5 years of productive life and the food value of the carcass. Similar calculations may be made for other types of livestock. These give the efficiencies shown in Table 1.

Table 1. *Efficiency of conversion of food by farm animals*

Kind of stock	Energy produced (as percentage of available energy in food): As protein*	As fat*	As carbohydrate*	Total: Present data*	Total: 1917 data†	Protein produced (as percentage of protein equivalent fed)
Dairy cows	3·7	11·1	4·6	19·4	15·0	23
Beef cattle	1·6	5·2	—	6·8	6·7	10
Sheep	1·3	7·5	—	8·8	10·4	11
Pigs	1·8	16·7	—	18·5	17·9	12
Fowls	3·0	6·7	—	9·7	7·7	32

* Quoted from Yates & Boyd (1949), except that revised values are given for sheep.
† Royal Society (1917).

Similar figures for total energy produced, prepared during the 1914–18 war (Royal Society, 1917), are also shown for comparison.

Though there are considerable differences in efficiency between the different farm animals, Table 1 shows that, regarded merely as converters of energy, all animals are decidedly wasteful. In round figures, it takes ten units of energy (available to the livestock), to produce one unit of energy available to human beings. On the energy : energy basis dairy cattle and pigs are outstandingly more efficient than the other livestock; on the protein : energy basis dairy cows again lead, closely followed by fowls. It will be seen from the last column of the table that the chief effect of the inappropriate protein : protein ratio is to overvalue the contribution of fowls relative to other live-stock.

Some economic considerations

There are important qualifications to be noted in using these purely physiological measures of efficiency. Farm animals, particularly herbivores, can utilize foods that are of no value to human beings. Beef cattle and sheep come out very low on each assessment; but to a considerable extent they are the product, as stores, of the hill and marginal land often unsuited to any other branch of farming.

Another qualification arises from the differences in yield/acre of the different crops, resulting in varying land requirements for the different forms of livestock. Estimates of yield/acre are given in Table 2. It is not entirely satisfactory to use

Table 2. *Yield in cwt./acre of available energy and protein from different crops*

Crop	Starch equivalent	Protein equivalent
Cereals:		
Grain	14	1·7
Straw*	2	0·1
Potatoes	28	1·3
Kale	27	4·2
Grass:		
First-grade ryegrass pasture	20–40	3·0–4·0
Second-grade pasture	13–19	1·8–3·0
Poor agrostis pasture	6–12	0·6–1·8
Rough grazings	0–5	0·0–0·5

* Assuming that three-quarters of the oat straw and one-quarter of the wheat and barley straw are utilized.

average values, since some parts of the country, owing to soil and climatic conditions, are more suited to one type of crop than another. The yield of grass is particularly variable, owing in part to these factors but mainly to variations in management; a series of estimated yields is shown to indicate the range. The relative yields of cereals and grass are of particular interest; they show that good grass in a suitable district can yield fully half as much again as cereals, and at the expense of less labour. Indeed it is possible by heavy nitrogen dressings for grass drying or storage to push up yields of grass very much further. Thus if grass can be made to yield twice as much as cereals the dairy cow will produce $2 \times 19{\cdot}4\%$, or nearly 40%, of the energy value of a cereal crop.

A third qualification to be noted in the data of Table 1 arises from the very different labour requirements of the different forms of livestock. Estimates of the man-hours/cwt. starch equivalent produced are shown in Table 3.

Table 3. *Labour requirements of farm animals and crops*

(Man-hours/cwt. starch equivalent produced)

	Direct requirements	Total labour requirements*
Animal:		
Dairy cows	24	30
Bullocks	12	15
Sheep	10	12
Pigs	5	23
Fowls	24	52
Crop:		
Wheat	3	—
Sugar beet†	8	—
Potatoes	7	—

* Including labour requirement for harvest and storage of feeding-stuffs.
† Assuming 12 % sugar yield.

Dairy cows have twice the labour requirements of bullocks, per unit of energy produced, and rather more than twice the requirements of sheep. Pigs, which Table 1 shows to be relatively efficient on the energy : energy basis, absorb relatively little direct labour, but most of their food has to be harvested and stored; moreover, the foods themselves are to a considerable extent directly consumable by human beings. The hen is expensive in direct labour, and in the main requires stored foods.

The second part of the table shows that for equal amounts of available energy produced the labour requirements for growing and harvesting cereal crops are far below the labour requirements for animals; the farm labour requirements of root crops are about half the total labour requirements for bullocks and sheep.

Sufficient has been said to show the limitations to which estimates of purely physiological efficiency are subject when we are considering the supplies of vegetable and animal foods from the wider economic angle. The construction of a table similar to Table 1 but in terms of economic efficiency would, however, be a formidable task. Thus we would have to balance the relative values of land units given by Table 2 against the labour units of Table 3; to these we would have to add similar complex problems affecting, for example, rent and capital. A simpler and more direct approach is possible by considering the selling price of the different livestock products. Within the country the prices of the different crop and livestock products, although fixed by negotiations between the producers and the ministries, are likely to bear sufficient relation to actual costs of production to form a rough overall integration of the different factors already discussed. The prices paid to the farmer in relation to the energy produced (£/cwt. starch equivalent) are shown in Table 4. On the basis of farmers' prices the cost of energy produced by the dairy cow is well below that from other livestock. At the same time, now that liquid milk supplies are adequate, it would be reasonable to expect any additional supplies to be converted into cheese or butter, thereby substantially increasing the cost per unit energy. Fowls and beef cattle, though expensive on the energy basis, come very close to milk on cost per unit protein. No allowance has been made for wastage or distribution costs, which will affect milk and eggs more seriously than meat, or for the value of hides and other by-products which will reduce somewhat the costs for cattle, sheep and pigs.

Table 4. *Cost of energy in vegetable and livestock products*

(£/cwt. starch equivalent, 1949–50 prices)

	Farmers' price	Import price
Animal:		
Dairy cows (milk)	8·8	—
Beef cattle	12·2	6·4
Sheep	13·8	6·8
Pigs	10·3	7·2
Fowls (eggs)	15·2	10·5
Crop:		
Cereals	2·0	1·9
Potatoes	2·8	—
Sugar beet*	2·2	—

* Assuming 12 % sugar yield.

Costs of energy from crops for human consumption are also shown in Table 4. No allowances have been made for processing of cereals and sugar beet, or for the high wastage of potatoes. In round figures, it appears that one unit of available energy from livestock is four to six times as expensive as a unit from crops.

As a matter of interest, import prices are also given in Table 4; the prices are comparable subject to the quality considerations in favour of the home product.

Current agricultural production

In the light of the foregoing discussion, it is of interest to consider briefly the amount and nature of the total food supplies of the country. In Table 5 are shown the energy

Table 5. *Energy equivalents of total available food supplies of the United Kingdom*, 1945*

	Acreage (acres × 10^6)	Starch equivalent (tons × 10^6): For man	For animals	Total
Home-produced foods:				
Vegetable: Tillage crops	13·8	3·2	5·7	8·9
Temporary and permanent grass	17·2	—	12·7	12·7
Rough grazing	17·3	—	0·9	0·9
Total	48·3	3·2	19·3	22·5
Animal	—	1·9	—	1·9
Manufacturing by-products	—	—	1·4	1·4
Imported foods (net imports):				
Vegetable	—	4·6 }	1·0	8·6
Animal	—	3·0 }		
Total	—	12·7	21·7	34·4

* Most of the estimates in the table are those given by the Central Statistical Office (1950), but some details are from unpublished data supplied by the Ministry of Agriculture.

values of home-grown foods going directly to human beings and to livestock; the table shows how the total supplies for man are divided between home production and imports and between vegetable and animal foods.

Home produce in 1945 supplied about 40% of the total energy requirements of the population, 25% coming direct from crops and 15% through the animal. The ratio of home production to imports was much the same for vegetable and animal sources. Although the output of home-produced animal foods was barely 40% of our requirements, the animals consumed 86% of the total energy available.

The quantity of vegetable foods for human consumption in 1945–6 was almost double the prewar figure, and this level of production has been maintained in the post-war period. The output of animal products has recovered from the low figures of the war years and in 1949–50 was a little above that of 1936–8; the reduction in pigs and sheep was more than outweighed by the increase in milk. There was a considerable reduction in the importation of animal feeding-stuffs. If allowance is made for this, the net output shows an increase over prewar values of one-third by 1945–6 and of almost one-half by 1949–50.

The arable side of our farms is in the main now running at a high level of productivity, and no large increases can be expected from this source without cutting into the large acreage at present devoted to livestock. Though greater efficiency appears to have been partly responsible for the increase in dairy production, there is no doubt that further increases in efficiency are possible. Since so large a part of our resources is devoted to livestock production, it is clear that the considerable increases that are possible in the productivity of grassland, together with better utilization of the fodder provided and better stock management, could lead to an appreciable improvement in human nutritional standards.

Although, as we have seen, it is quite common for well-managed grass to give 25 cwt. starch equivalent per acre, the estimated yield in Table 5 is no more than 15 cwt. starch equivalent per acre. The whole process of utilization of home-grown foods could also be made materially more efficient. Thus from Table 5 it may be calculated that only 9% of the energy value of foods supplied to livestock is returned in the form of animal products for human consumption; this indicates that the actual efficiency attained is 20–25% lower than the theoretical values given in Table 1.

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Nutritive Value of Vegetable Proteins and its Enhancement by Admixture

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Introduction

It is only since the beginning of the present century that different proteins have been accredited with different nutritive values. Previously, the proteins in a diet represented purely the necessary nitrogenous fraction, and were 'proteins' and nothing more. The conception of differing 'biological values' possessed by different proteins was founded on the experimental work of Max Rubner and his assistant Karl Thomas (1909). Their investigations and later those of Mitchell (1923–4) showed the differences existing in the amounts of different proteins which were required to maintain an adult human subject or animal in nitrogenous equilibrium or to support the growth of a young animal. The support of growth in the growing organisms is a more searching test for the nutritive value of a protein than the maintenance of an adult, and this criterion was adopted by Osborne and Mendel in their long series of investigations. (See Osborne, Mendel & Ferry, 1919). By their method the relative nutritive values of different proteins were measured by the weight increase of the experimental animal, usually the young rat, corresponding to the ingestion of a given amount of a protein, which provided the sole source of nitrogen in the diet. The different diets compared contained the same proportion of protein, which was less than the optimum amount in an otherwise complete ration and was thus the factor limiting growth. The ratio, $\frac{\text{g. weight increase}}{\text{g. protein ingested}}$, known as the P.E.R. or 'protein-efficiency ratio', has proved to be a useful measure of nutritive value.

A new approach has been developed from the knowledge of the chemical composition of proteins. As Osborne & Mendel (1914) said: 'The question of protein synthesis has now become a problem of the biochemical deportment of amino-acids.' Differences in nutritive worth have been found to correspond to differences in the amounts and relative proportions of the different amino-acids which they contain (see Mitchell & Hamilton, 1929), and the differences are particularly important as regards those amino-acids that are not synthesized in the animal organism, but must be supplied in the dietary proteins (Rose, 1938).

There are advantages and disadvantages in all the methods mentioned above for studying the nutritive efficiency of proteins (Chick, 1947) but, in general, the results obtained by the different methods have shown a satisfactory degree of concordance (Block & Mitchell, 1946–7).

Proteins of animal origin generally contain a more satisfactory mixture of amino-acids than those contained in vegetables, which are usually relatively poor in tryptophan

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and lysine, amino-acids essential for support of the growing animal. In a mixed diet, however, great advantage can be secured by an appropriate mixture of proteins from different foods, whereby a deficiency of an essential amino-acid in one may be corrected by an excess in another. This complementary action exists between many animal and vegetable proteins, and is well illustrated by the observation that mixtures of animal proteins from meat or milk with those from cereals have shown a growth-supporting ability not inferior to that of animal protein alone (see McCollum, Orent-Keiles & Day, 1939; Hoagland & Snider, 1927; Mitchell & Carman, 1926). The reason is obvious. Cereals are well supplied with most of the essential amino-acids, but are deficient in the essential amino-acid, lysine, which is relatively abundant in the proteins of meat or milk.

Examples of enhancement by admixture of the nutritive value of vegetable proteins

Beef tea and toast. An interesting example of such a complementary effect came under observation in the Division of Nutrition of the Lister Institute during a series of tests on the capacity of the proteins of some common foods to support the growth of weanling rats. The hot aqueous extract known as beef tea, from which the solid matter had been removed, was formerly recommended as a nourishing food for invalids and convalescents. In later years, however, it fell into disrepute, well-informed opinion arguing that all nourishment had been removed with the coagulated material and that the resulting beef tea was no more than a pleasant and stimulating drink. In experiments with weanling rats, fed on a ration in which the nitrogen was provided from beef tea, no weight increase occurred, even when the nitrogen was present to the extent of 3·6% (20 % 'crude protein') in the diet. When, however, in a diet containing only 2·2% nitrogen, one-quarter was supplied by the beef tea and the remainder by white flour, steady growth occurred and at a rate greater than when white flour alone supplied all the nitrogen (Chick & Slack, 1945). The effect was easily explained. About 70% of the nitrogen in the beef tea was in the form of gelatine, an imperfect protein lacking both tryptophan and cystine, both of which are present in satisfactory amount in wheat proteins. Gelatine, on the other hand, is rich in lysine, an amino-acid in which cereal proteins are notably deficient. This sparing action for protein is a well-known attribute of gelatine (see Lusk, 1928). Jellies and beef tea, taken with a little toast or bread and butter, can, therefore, be safely trusted to provide convalescents with a pleasant and nourishing snack.

Wheat fractions. Complementary action can be demonstrated also between the different vegetable proteins contained in different foods and sometimes in the same food. An example of the latter is the relation between the proteins contained in the outer layers (bran) and the inner portions (endosperm) of the wheat grain. A diet in which the protein was derived in equal amounts from the bran and endosperm of the same sample of wheat was found to maintain growth at a rate exceeding that which occurred on diets supplying an equal proportion of protein from either the bran or the white flour alone (Chick, Cutting, Martin & Slack, 1947). The supplementary action in this case is explained partly by the fact that the proteins of bran are richer in tryptophan and lysine than those of white flour (Jones & Gersdorff, 1923–4, 1925; Barton-Wright & Moran, 1946), but what the special contribution of the endosperm proteins may be is at present unknown.

Potato protein and non-protein nitrogen fraction. Another example of a complementary action between different nitrogenous materials in a single food is found in the potato. In this tuber the non-protein nitrogen, which amounts to about half the total, has a marked supplementary effect for the potato protein (tuberin). With diets of comparable nitrogen content, better growth was obtained when it was supplied by the whole tuber than when derived from the purified potato protein (Chick & Slack, 1949). The non-protein fraction, as contained in potato sap from which the protein had been separated by heat coagulation, was incapable of promoting any weight increase in the experimental animals, but was found to have a markedly stimulating action when combined with wheat gluten, a protein which has the lowest nutritive value of the mixture of proteins present in wheat. With a diet containing 20% gluten (on dry weight) as source of protein, the average weight increase of weanling rats was 6·5 g. weekly over a period of 7 weeks. When one-quarter of the gluten was replaced by an equivalent amount of nitrogen from the non-protein nitrogenous fraction of potato sap, the growth rate was nearly doubled, to an average weight increase of 11·5 g. weekly. In this instance no explanation has been found in terms of amino-acid supplementation. Only about one-fifth of the non-protein nitrogen of the potato consists of amino-acid nitrogen, and analyses of this fraction have not shown an excess of any essential amino-acid that might so greatly improve the nutritive value of wheat gluten (Slack, 1948).

Cereals and soya-bean meal. Perhaps the most impressive instance of supplementation between vegetable proteins is shown by mixtures of cereal proteins with those of the soya bean, where the mutual advantage gained is great enough to produce a nutritive value comparable with that of milk proteins. In experiments with young rats on diets containing about 10% of protein derived from white wheat flour or soya flour or milk, the figures for the protein-efficiency ratio were found to be, respectively, 0·83, 2·14 and 2·84. When, however, the 10% of protein was supplied by a mixture of soya and white flour proteins in equal amount the protein-efficiency ratio was about 2·0 and about equal to that corresponding to a similar mixture of soya and milk proteins (Hove, Carpenter & Harrel, 1945; see also Jones & Divine, 1944).

A preparation of soya flour and malted cereals was produced by Caprino in Rome in 1944 and found to be an acceptable food for young children at a time of great milk scarcity. In the expectation that such foods might find useful application in Central Europe in the period following the recent war, the Division of Nutrition of the Lister Institute acceded to the request of the relief organization of U.N.R.R.A. to make an experimental study of such foods. To our surprise we found that a diet containing a mixture of soya flour, malt extract and white flour, in which these ingredients supplied, respectively, 56, 34 and 10% of the total protein, was about equal in growth-supporting value to a diet in which the same amount of total protein was provided entirely from milk (Chick & Slack, 1946). Following this result, similar combinations of soya and cereals have received extensive trials in Germany since the end of the war, which are described by Dean (1949, 1951). The particular value of soya in these combinations lies in the unusually high proportion of lysine contained in its proteins. Its presence can make good the deficiency of this important amino-acid in the proteins of the cereals and in most other vegetable proteins that have been investigated. When the results of trustworthy analyses are available of the proteins of other legumes and of root and other vegetables, sources may be found of proteins as rich in lysine as those of soya. At present we seem to be dependent on some admixture of soya in any attempt to produce a food of high nutritive value from vegetable products alone.

The animal protein factor

It would appear, therefore, judged by the practicability of providing a satisfactory supply of essential amino-acids, that it is possible to replace animal proteins in a human diet by an appropriate combination of vegetable proteins. On these grounds alone, there would seem to be no scientific basis for the conviction, widely held, that a certain proportion of animal protein is necessary in a human diet, a conviction which will be strengthened by the evidence Dr Wills has collected in her work among undernourished young children in tropical and sub-tropical countries (Wills, 1951).

The question, however, arises whether the need for animal protein may not, in fact, be the need for some special nutrient, some animal protein factor, not itself of a protein or amino-acid nature, which is usually found to accompany the protein in animal foods.

Cary and co-workers described experiments in which young rats receiving a diet containing 25% protein (5% from yeast and 20% from casein) failed to grow normally if the casein had been purified by successive extractions with hot alcohol (Cary, Hartman, Dryden & Likely, 1946; Hartman, 1946). Normal growth was, however, secured by addition of various animal foods or of a small amount of liver extract, but the necessary factor was not present in yeast, or in the cereals, legumes and root vegetables investigated. The essential nutrient in liver extract was later found to be identical with the anti-pernicious-anaemia principle now known as vitamin B_{12} (Hartman, Dryden & Cary, 1949).

The presence in the ration of a source of vitamin B_{12} also has been found essential for satisfactory nutrition of poultry and hatching of their eggs (Ott, Rickes & Wood, 1948; see also Stokstad & Jukes, 1949; Snell & Wright, 1950).

Vitamin B_{12}, now regarded as identical with an essential 'animal protein factor', is known to be capable of storage in the animal organism, and it is probable that mothers that have been fed on a generous mixed diet may transmit substantial reserves to their offspring. It is significant that, in order to demonstrate the need of weanling rats for this nutrient, Cary and his colleagues found it necessary to deprive the mothers during the period of lactation. In the experiments described above, with weanling rats fed on diets containing combinations of vegetable proteins, the mothers had received an excellent mixed diet up to the time of weaning their young, and the fact may explain the lack of evidence in these tests that the young animals had need of any 'animal protein factor' in their ration.

Whether the previous diet of the human mother may influence the capacity of the human baby to subsist on a purely vegetable diet for a given period after weaning is a point of interest worthy of study.

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* Given in original as Gartman, obvious misprint,

The Clinical Picture in Children Fed after Weaning on a Predominantly Vegetable Diet

By LUCY WILLS, *late of McCord's Zulu Hospital, Durban, and the Royal Free Hospital, London*

Introduction

The clinical findings in infants and children fed after weaning on predominantly vegetable diets is the subject of this paper; my experience has been chiefly with the African, so most of the space will be devoted to a description of the syndrome of malignant malnutrition, kwashiorkor, or fatty liver disease of infants as Waterlow calls it, as seen in the Bantu race. It must be understood that this syndrome, which I take to be the extreme expression of the ill-effects of such diets, is not limited to the African; it is seen in all races, and Czerny's 'Mehlnährschaden' is probably the same condition in European children.

A study of populations living on diets consisting predominantly of carbohydrates suggests that there are three very constant ill-effects on the body. The first is on the haemopoietic organs; children and adults are either anaemic or have a tendency to develop an anaemia, generally macrocytic, when under stress. The second effect is on the liver; the lack of protein in the diet is associated with the development of fatty livers in children and with a high incidence of cirrhosis and malignant disease in the adult. The third effect which apparently results partly from the lack of protein itself and partly from the impaired liver function is a shortage of suitable protein so that the body has to call on its own supplies, as is shown by muscular wasting and by an abnormally low level of serum albumin; with the last is associated a tendency to develop oedema. Further, unless the diet contains a suitable mixture of vegetable products, there is often a high incidence of deficiency states due to inadequate supplies of the vitamins of the B_2 complex, skin lesions being especially frequent.

The clinical material studied

The material studied consisted of thirty-six consecutive cases of kwashiorkor admitted to McCord's Zulu Hospital, Durban, under the care of Dr Frank Walt (Walt, Wills & Nightingale, 1950). The diagnosis was based on what we considered to be the essential clinical signs: anorexia, wasting particularly of the muscles which might be masked by oedema, an enlarged liver, and oedema associated with low values for serum proteins. Skin lesions, though not essential for diagnosis, were present in most of the cases.

The children varied in age from 3 months to 6 years. The histories, always unreliable, were depressingly uniform: the baby had been breast fed and then weaned on to a standard diet of *samp* (Kaffir corn) and mealie-meal porridge; no fresh milk or only minute quantities, no meat, eggs or fish and only the very occasional green vegetable. Generally, the mother said that the child had been well until a short time before when there had been an attack of diarrhoea followed by oedema. Sometimes there was a history of several previous attacks, and one atrophic case gave a history of severe oedema which had cleared up some time before admission.

The cases were of two types: the commoner was the oedematous, many of the children having gross oedema with anasarca; a few, six in all, were of the second type, and were in the last stages of wasting. These atrophic cases were the most severe; they were seen to pass from an oedematous condition to an atrophic one while under observation, and there seems no doubt that the atrophic state is the terminal stage of the disease. Most of the patients had diarrhoea on admission. Examination showed oedema to be present in thirty-two of the thirty-six cases; in thirty it was associated with an enlarged liver, which we assumed to be related to the existence of fatty infiltration (Pls. 1 and 2). Skin changes were very striking in the majority of the patients, though a few had clear skins. The hair was reddish brown, there was hyperpigmentation associated with areas of depigmentation, and often there were terrible sores and angular stomatitis. Except in one extremely anaemic child, the urine contained no albumin. Unlike Trowell's cases (Trowell & Muwazi, 1945), tropical diseases were absent; there was no case of hookworm infection.

Haematological examination showed that all the children were suffering from a moderate normochromic, normocytic or slightly macrocytic anaemia, except in three cases, two fatal, where the anaemia was very severe. The serum proteins were of particular interest; they were estimated as a routine by the copper-sulphate method with use of Hoch's formula, $P = 364 (S - 1{\cdot}006)$, where P is the protein concentration in g./100 ml. serum and S the apparent specific gravity of the serum (Hoch & Marrack, 1945), and also by the biuret method. The mean value for total serum proteins on admission was 4·5 g./100 ml. with range from 3·5 to 5·6 g./100 ml.; in seven instances only, including two of the atrophic ones, was it over 5·0 g./100 ml. The low values for total serum proteins were due to decrease in the albumin fraction, the globulin values being normal. On treatment the rise in the protein level was extremely rapid; it often started on the 2nd day, and by the 16th–20th day the mean level was 7·0 g./100 ml., a value agreeing closely with that of 7·1 g./100 ml. found in a control group of healthy Bantu children.

Three patients were clinically jaundiced, and two of them died within 24 hr. of admission with grossly enlarged and fatty livers.

Findings at autopsy

Limited post-mortem examinations were made on the four fatal cases, two of each type. In all of them the liver showed gross fatty changes; in the two oedematous ones, both under 2 years of age, the organ weighed 1 lb. and 1 lb. 2 oz., respectively. One of the atrophic cases had a small liver, suggestive of early cirrhosis. The pancreas showed no pathological changes. Two of the patients had died from terminal bronchopneumonia, the other two apparently from liver failure.

Treatment

The treatment was very simple. We argued that the children were dying of protein starvation and excess carbohydrate, and that with such fatty livers administration of fat was contra-indicated, so we decided to force-feed them with *maas*, which is curds made from skim milk, and with *maas* only, to which, after a week, skim milk powder was added; later a full mixed diet supplemented with extra milk was given. Improvement was rapid in most cases. After a few days a marked diuresis set in resulting in a rapid loss of weight which was followed by a steady gain. The diarrhoea generally ceased in a few days with no other treatment. The liver gradually decreased in size. The serum proteins increased steadily but the blood count fell slightly at first and then rose slowly, the results being similar to those observed by Altmann (1948) and by Walters, Rossiter & Lehmann (1947) in returned Indian prisoners of war. The last workers showed the fall in the red-cell level to be due to an increase in plasma volume. If a similar increase in plasma volume explained the fall in red-cell level in our cases, the rate of protein regeneration must have been even more striking than the figures suggest, as we never observed a fall in serum protein level once treatment had begun.

The crude death rate in our series was 11%, or 2·8% if all deaths within 24 hr. of admission are excluded as was done by Altmann (1948) in his calculation of death rate. The latter figure may be compared with a corrected value of 20% for Altmann's series and of 6% for the series of cases treated with hog's stomach by Gillman & Gillman (1946). The death rate for oedematous cases was low in Altmann's series and in ours, being 4·5 and 3·3%, respectively. It is the atrophic cases that are so fatal, and the number of such in any series will determine the death rate in that series.

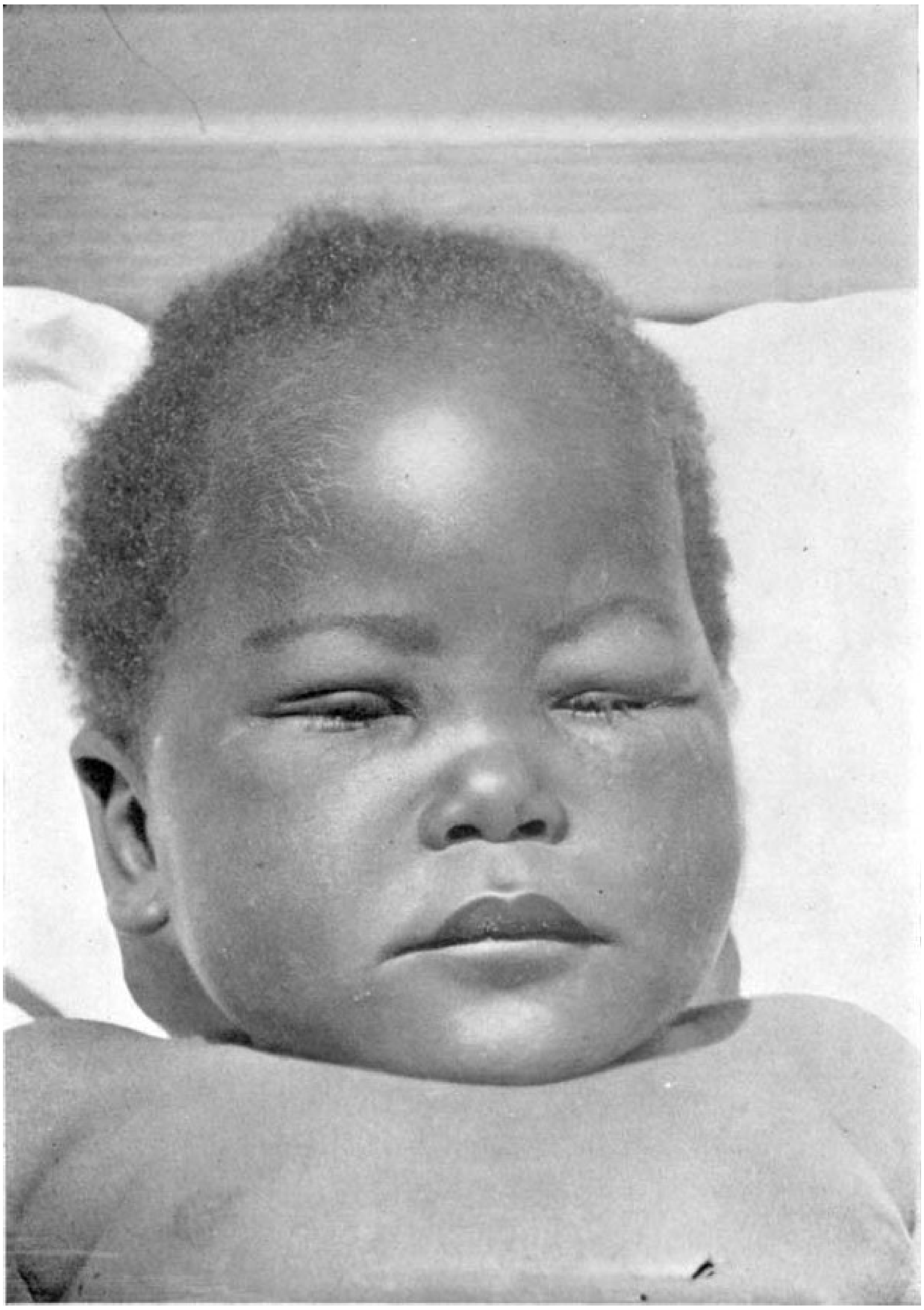
Discussion

In my opinion the essential causative factor in this condition is associated with a deficiency of animal protein. That animal protein rather than vegetable protein is essential is not proven, but the evidence in favour of its being so is suggestive. The syndrome occurs in many lands with varied national diets, the common factor in all being a lack of animal protein and an excess of carbohydrate in the diet, and very frequently, though not invariably, a rather low supply of calories. Whipple and his colleagues in their classical experiments showed that for protein regeneration, animal proteins favour the formation of serum albumin, and vegetable protein, with the exception of soya-bean protein, that of serum globulins (McNaught, Scott, Woods & Whipple, 1936). Milk is the best known curative agent.

If the liver lesion is the primary one and a deficiency of protein the essential causative factor, it is natural that lipotrophic factors such as methionine and choline should have been considered as possible curative agents. Gillman & Gillman (1945) and Waterlow (1948) used the substances with no success. Vitamins, too, have been tried and found wanting. Milk is the basis of successful treatment.

Taylor & Chhuttani (1945) studied the incidence of anaemia among Indian troops of whom 17,000 were meat eaters and 1188 were vegetarians, all living under good conditions, with a low sick rate. The men had been on army rations for 2 years. They had received the same basic rations which yielded about 3000 Cal. and 80 g. vegetable protein but the meat eaters received an additional ration of 6 oz. fresh mutton with bone daily, the vegetarians one of 4½ oz. tinned milk 3 times a week, and ¾ oz. ghee and 3 oz. atta or rice twice a week, but the milk was frequently not taken. The incidence of anaemia severe enough for admission to hospital was at the yearly rate of 58·5/1000 for macrocytic anaemia among vegetarians, and of 2·6/1000 for normocytic or microcytic, hypochromic anaemia among meat eaters. The difference was even more striking in the incidence of anaemias with red-cell counts of 2 millions or less or a haemoglobin value below 5·8 g./100 ml.; among vegetarians the rate was 24·7/1000, and among meat eaters 0·16/1000. Anaemia, especially macrocytic anaemia, is one of the most constant findings among peoples who depend for their protein on vegetable sources. Indian troops on active service had a far higher incidence of anaemia than British troops exposed to the same risks of malaria and other tropical diseases: the meat eaters suffered as well as the vegetarians, since their meat ration, which had to be fresh owing to supply difficulties, might reach them only once a fortnight (Marriott, 1945). Indian prisoners of war suffered even more severely from macrocytic anaemia, as their diet was extremely poor, often completely vegetarian and low in calories.

The evidence for the occurrence of protein deficiency in adults on predominantly vegetable diets is more circumstantial. It is idle to look in adults for the same syndrome as in children, since the adults of those populations where the incidence of malignant



malnutrition is high in the children will themselves have suffered the same stresses in their infancy. One could expect, therefore, that the liver lesion would progress in any individuals who had failed to recover completely from malignant malnutrition in infancy. In the children's departments of the hospitals in the West Indies and South Africa, one sees small patients, generally boys, with every grade of liver damage from an enlarged hard liver to the final stages of advanced cirrhosis. In those countries and in India routine post-mortem examinations and hospital records provide the evidence of a very high incidence of cirrhosis and carcinoma of the liver; the incidence is far higher than among Europeans and the lesions occur at a much earlier age. True malignant malnutrition also is found among adults, and Trowell & Muwazi (1945) quote a figure of 10% of all admissions to the Uganda Medical School Hospital at Kampala.

The clinical picture in populations weaned on to and existing on diets predominantly or almost entirely of vegetable origin includes underdevelopment, poor physique, anaemia, liver damage associated with cirrhosis and malignant disease, abnormal values for serum proteins with a tendency to develop oedema, and often all the signs and symptoms of vitamin B_2-complex deficiencies. Given a diet with an inadequate supply of calories derived mainly from one or more staple carbohydrates and with little or no animal protein, and malignant malnutrition will appear with all its sequelae. That adequate calories from mixed vegetable staples can prevent the syndrome and give maximum health has yet to be demonstrated.

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EXPLANATION OF PLATES

Pl. 1. Bantu child, aged about 18 months, with the oedematous form of kwashiorkor, showing severe generalized anasarca and moderate skin lesions.

Pl. 2. Head of same child as in Pl. 1. Note pale, scanty hair and severe oedema of face.

Both plates by the courtesy of the Senior Pathologist, Central Pathological Laboratory, Durban, South Africa.

The Nutritional Adequacy of a Vegetable Substitute for Milk

By R. F. A. DEAN, *Department of Experimental Medicine, University of Cambridge and Medical Research Council*

The problem of supplying a substitute for milk can be resolved into the separate problems of finding substitutes for the various components: minerals, carbohydrate, fat, protein and vitamins.

The supply of minerals seems to be the easiest to deal with. Sodium must always be added to a vegetable diet, calcium nearly always, and iron usually. Carbohydrate forms the greater part of most plant foods, soya being a notable exception, and here the problem is to alter the carbohydrate into a form that is easily digestible. There are many vegetable sources of easily absorbed and well-tolerated fats. The fat requirements of man are unknown. It may be necessary to supply small quantities of unsaturated fatty acids, but fats can be synthesized in the human body, even by children. The chief importance of dietary fats seems to lie in their high calorific value and, since most vegetable foods are bulky in proportion to the calories they provide, the inclusion of fats is usually an advantage. The vitamins of milk are seldom regarded as among its most important constituents, and I want to be excused from discussing most of them. Dr Chick (1951) and Dr Wills (1951) have emphasized the importance of protein, and I am going to discuss principally the possibilities of replacing the proteins of milk.

Fairly convincing evidence could be brought forward, from what we can deduce of the food habits of our prehistoric ancestors, from the pattern of our dentition, from the comparatively recent establishment of agriculture, to show that through the ages the proportion of animal protein in the diet of man has undergone considerable reduction. Now we have a disease, kwashiorkor, malignant malnutrition, which may be the result of the reduction of the animal protein to below the minimum compatible with life, at least, with life at a time of rapid growth.

There can be few races or even individuals who exist on diets that are exclusively vegetable in origin. There must surely be only a handful of vegetarians who deny themselves or their children milk or cheese or an unfertilized hen's egg. Some races, who are obliged by scarcity to live on a vegetarian diet, eat meat in an orgy on the rare occasions when they can get it. Others add insects, ants, caterpillars and locusts (dried locusts are 50% crude protein) to their diets when they can, especially when there is no meat or fish available. It is probable that if the whole, not merely the largest items, of the diet of any race of fine physique were analysed, it would be found to contain a set of amino-acids resembling more or less closely that in milk protein, or in the protein of meat or fish.

It seems then that we are being ambitious if we attempt to provide a good diet from none but plant sources. In spite of this, I intend to confine myself to the problem of feeding young children on such diets. My own experience has been mostly with children. They probably exaggerate the adult's need for amino-acids (just as the rat, which grows even more rapidly, exaggerates the child's needs), and we know how great is the necessity of providing a cheap and adequate transitional diet, to fill the gap between breast milk and the adult diet. In this country we use for this purpose large amounts of cow's milk and increasing amounts of cereals. Is it possible, in less fortunate countries, to do without the milk? Has anyone succeeded so far? Success must have been achieved, but there are very few reliable scientific records. Most of them, as Dr Chick (1951) has said, related to diets which included soya-bean products. Tso (1928, 1929) reared a few children in the 1st year of life on diets in which soya milk, and a small amount of egg, provided the protein. The children throve, but had to be given extra calcium if rickets was to be avoided. Lane (1931) weaned a pair of twins on to a truly vegetarian diet at the age of 5 months, using a milk made chiefly from soya, almonds, peanuts and wheat flour. These children also throve, and continued to do so for the whole period of observation, which lasted nearly 3 years. The experiments of Rittinger, Dembo & Torrey (1935) are well known. They fed infants on various soya milks with satisfactory results, and could not detect any improvements when they added a little dried skim milk. One of these experiments was an apparently unrecognized trial of protein supplementation; a malt syrup was used to supply carbohydrate, but may have supplied also 20–30% of the total protein. Cereals were added to the diets of most of the children at the age of 12 weeks. Soya milks have been given also to Indian infants, and have in some experiments been thought not far inferior to cow's milk, but the reports of the experiments have always been given in an incomplete form, so that the weight gains cannot be properly assessed. Soya preparations are used extensively in the United States for feeding children who cannot tolerate cow's milk, but when Stoesser (1944) tried one of the most widely advertised of these preparations, his results were very poor. The food caused gastro-intestinal upsets in most of the children, and it was obviously unsuitable for use as a permanent diet. We can only hope it has been improved by now.

Willemin-Clog (1930) investigated the use of sunflower-seed meal in infant feeding, and had a fair measure of success, although she noticed that sunflower as the only source of protein was not, apparently, adequate for more than a few weeks. One of her collaborators (Ribadeau-Dumas, 1946) has more recently expressed the opinion that the vegetable proteins are best considered as 'milk-sparers', although a mixture of rice, barley and sunflower was a valuable food for children.

Dr Chick (1951) referred to mixtures of malted cereals, barley and wheat, with soya which she found could produce good growth in rats. I have already given this Society a survey of the results of our use of similar mixtures in child feeding (Dean, 1949). Our first discovery was that there were unexpected and very important difficulties in the way of manufacture. One whole batch of mixture which we thought had been made in the same way as Dr Chick's most successful mixture had to be abandoned because it caused diarrhoea. To-day, I am going to give some additional details of our use of more successful mixtures. In these, 25% of the protein was derived from barley, 5% from wheat and 70% from soya. In Dr Chick's best mixture of these three ingredients, 34% of the protein was derived from barley, 10% from wheat and 56% from soya.

Our two mixtures were exactly the same except that one of them (mixture B) contained soya that had been steamed only long enough to remove the bitter material, whereas the other (mixture C) contained soya that had been steamed for 100 min. to remove also the trypsin inhibitor.

The children, who were between 1 and 2 years old, and were living in a rather overcrowded orphanage, were divided into two equal groups. One was given a simple diet, semolina, vegetables (mostly potato), butter, and some bread, supplemented by cow's milk; and the other group had the same basic diet supplemented by one of the cereal-soya mixtures. The milk and the mixtures were made into a pudding with the semolina. All the children were liberally provided with vitamins A, D and C, and we made sure there was no shortage of calcium.

In the milk group, about 33% of the calories were obtained from fresh whole milk, but in the other group about 50% of the calories came from the cereal-soya mixtures. Of the total calories in the milk diet 11% were protein calories, and of these 60% were derived from milk; in the cereal-soya diets, 13% of the total calories were protein calories, and 70% of these came from the mixtures. The results of the trials are given in Fig. 1. Trial 1 lasted 16 weeks, and trial 2, 8 weeks. The periods are short, but we

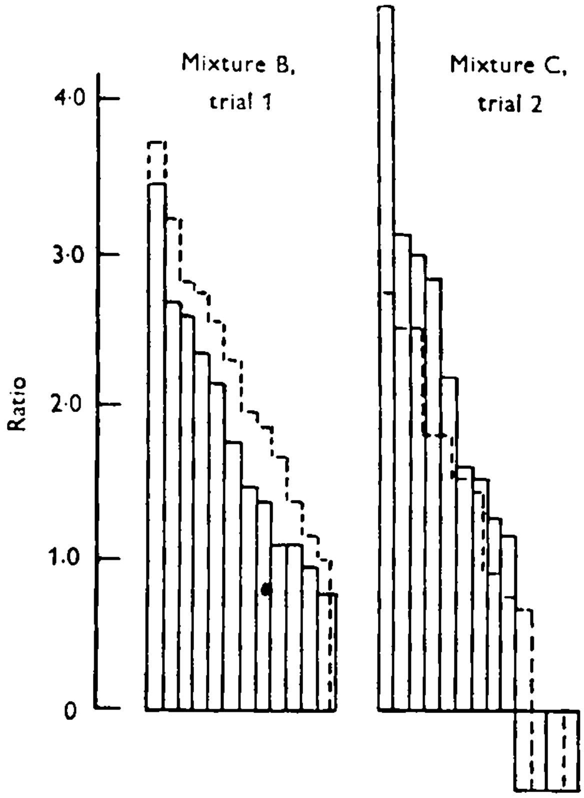

Fig. 1. Ratios of actual to standard weight gains of individual children given cereal-soya mixtures B (in trial 1) and C (in trial 2). The dotted lines indicate the ratios of the children in the contemporary control groups, who were given a diet containing fresh whole milk.

were quite sure that during these periods the children on the cereal-soya diets had no animal protein of any kind. Nearly all the children exceeded the standard gain in weight. There was an epidemic of infective diarrhoea in trial 2 which affected children in both groups. Some of the trouble, however, may have been due to mixture C. We were unable to find the exact cause, but it was probably over-heating during the spray-drying process used for large-scale manufacture. Trial 2 and some later trials made us decide that the removal of the trypsin inhibitor increased the nutritive value of the soya. The approximate amounts of the essential amino-acids in the mixtures, and in the complete diets were calculated from the data of Block & Mitchell (1946–7). When the amounts were compared with the amounts of the same amino-acids in human milk, on the basis of equal amounts of total nitrogen, the differences were small, but the essential amino-acids represented about 63% of the total nitrogen in the human milk, and only 47% of that in the cereal-soya mixtures. This was one reason why we found it necessary to give a higher proportion of protein in the cereal-soya diets than in the milk diets.

It seems justifiable to conclude that if the mixture of amino-acids is suitably adjusted, a diet entirely of plant origin can give excellent results, at least for short periods, in the feeding of children. Dr Chick's (1951) work on young rats is, in fact, applicable to young human beings.

We have sought to extend the scope of our work to other plant materials, and, following Willemin-Clog's example, we have studied sunflower-seed meal, which is a rich source of protein and seems a useful alternative to soya. The soya bean is not universally available, and it cannot, for instance, be grown well in this country, whereas sunflowers can. We have also, not entirely by chance, taken an interest in maize. Sunflower protein contains twice as much of both lysine and tryptophan as maize protein, and we have found that rats grow excellently on various combinations of sunflower and maize, especially if a little yeast is added to the diets.

The success of these experiments has made us speculate on the possible cause of kwashiorkor. We know the disease can be cured by milk. It appears also to have been cured by various other substances which contain animal protein, serum given intravenously, liver and hog's stomach. Does the disease occur because of amino-acid deficiencies in the diet, a single or multiple deficiency of one or more of the amino-acids I have mentioned or of some other, and is it cured by proteins which contain large amounts of those amino-acids? There is another, and quite different, possibility which also has occurred to us as a result of our experiments. We were anxious to find out if our cereal-soya mixtures were improved by the addition of vitamin B_{12}. It is not present in soya or in any of the cereals we have used in our child-feeding experiments. When we added it to the cereal-soya mixture B, we found that it had an effect on the growth of rats as beneficial as the addition of quite considerable amounts of milk protein, and we hope to have an opportunity in the near future of demonstrating a similar effect in children. There is a further point worth consideration. Vitamin B_{12} has not been demonstrated in maize, but it is, I believe, to be found in all those substances which can cure kwashiorkor. This may be merely a coincidence, but a trial of vitamin B_{12} seems to be indicated, not only on these empirical grounds, but because the vitamin is believed to be of importance in transmethylation and therefore in the utilization of lipotrophic substances such as choline and methionine.

We think we have evidence enough to show that it is possible to evolve diets containing protein exclusively from plant sources, which will successfully rival diets containing fair amounts of animal protein. This circumlocution is preferable to the use of the term 'milk substitutes', because so many diets do not contain milk. We are really only at the beginning, however, of knowing how best to apply our experience. There are many diverse factors that have to be taken into account. They include variations in the amounts of amino-acids in our raw materials, depending on the strain of wheat or yeast, for instance, or the method of cultivation of rice; alterations in biological value caused by heating and by the reactions between amino-acids and sugars, reactions which may escape detection by the ordinary methods of analysis; variations in the methods of preparation of foods which may impair digestibility and cause loose stools, as our mixture C did; differences introduced by the necessary jump from the laboratory or 'pilot' scale of production to the full factory process, and all the time we must remember that economic necessity forces us to prepare our new foods in the simplest and cheapest way, and as far as possible from materials locally available.

We cannot be experts in all the sciences simultaneously involved. We rely on the co-operation of the paediatricians, the biochemists, the agriculturalists, the cereal chemists, the educators, the administrators, even the politicians.

We know there are millions of undernourished children. We believe they could be better nourished if we used our plant resources more perfectly. We must find means of translating our belief into fact.

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