The Direct Use of Plant Materials by Man

By F. WOKES, *Ovaltine Research Laboratories, King's Langley, Herts*

It is indeed fitting that to-day's meeting should be held at the Rowett Research Institute, which is so closely linked with the name of Lord Boyd-Orr. His masterly surveys of the world food problem and its intensification by soil erosion and by increases in world population, provide the necessary background to the problems we have been discussing here.

Sir John Russell, in his presidential address to the British Association (Russell, 1949), emphasized the close relationship between land, diet and world food supplies, when he pointed out that the average area of land per head available for food production throughout the world was expected by A.D. 2000 to fall to 1 acre, or only two-thirds of the area of 1½ acres per head required at British yields to give the British prewar dietary (Table 1). Sir John, in a personal communication, kindly provided the

Table 1. *Areas of food-producing land required for different diets** *(after Russell, 1949)*

Diet	Acres/head
Prewar British	1½
Vegetarian with milk	¾
Vegetarian with no milk	½
Average area expected to be available for food production in A.D. 2000	1

* Calculation based on British yields.

following estimates of the average areas per head needed for different diets: three-quarters of an acre for a vegetarian diet including some milk, as in northern India, half an acre for a vegetarian diet including almost no milk, as in parts of China.

The low yields per acre for beef and mutton account for the high cost of our imported meat, an economic factor that is already modifying the British diet considerably. The poor conversion factors are much improved when we turn from meat to eggs and milk. Direct utilization of plant food by man does not include dairy produce but, in practice, it is very difficult to exclude all animal food from the diet. There are in this country at present over 100,000 registered vegetarians, and probably 98 or 99 % of these consume some dairy produce, providing about two-thirds of the usual intake of animal protein amongst non-vegetarians.

Nutrients supplied by a vegetarian diet

Vitamin C. Widdowson (1947) has suggested that the diet of vegetarian children tends to be deficient in vitamin C, protein and calories. Vitamin C may have been a misprint for vitamin D, since her results on the nutritive value of a week's prewar diet of seven vegetarian children, summarized in Table 2, showed the vitamin C value to be 108 %, but the vitamin D value to be 75 %, of that of normal children's diet. Adding to these results her data on another thirteen children living in a residential nursery school in Kent where they received no meat, gives an average vitamin C intake for the twenty children significantly above the normal. Findings in a week's prewar experiment on 118 vegetarian children and adults and a week's postwar experiment on about fifty vegetarian children and adults (Wokes, 1952) showed them to be receiving sufficient vitamin C.

Table 2. *Nutritive value of prewar diet of seven vegetarian children* (*Widdowson*, 1947)

Constituent	Nutritive value as percentage of normal *	Constituent	Nutritive value as percentage of normal*
Vitamin A	105 ± 8·3	Calcium	124 ± 17·4
Carotene	155 ± 31·6	Iron	90 ± 8·8
Vitamin B_1	104 ± 12·4	Total protein	74 ± 9·0
Vitamin C	108 ± 15·3	Animal protein	69 ± 10·0
Vitamin D	75 ± 5·9	Calories	83 ± 7·2

* Value with its standard deviation.

Vitamin D. The prewar consumption of dairy produce by vegetarians probably supplied much less than the full requirement of vitamin D (Wokes, 1941). This deficiency is not completely eliminated by the synthetic vitamin D now being added to certain foods (e.g. nut butter, cereal products). It would be interesting to discover how much vitamin D is obtained by vegetarian babies and young children through the action of sunlight on provitamin D.

Vitamin A. Vitamin A supplies also are complicated by the possible use of precursors. For children old enough to take greens or other vegetables containing provitamin A, no difficulty arises. Babies, if artificially fed, usually depend on fish-liver oils for making good deficiencies of vitamin A in their diet. Exclusion of all animal food necessitates recourse to provitamin A, of which a perfectly satisfactory source for babies does not yet seem to be available in this country, although it could no doubt be found. Red palm oil, for example, is widely used for this purpose in the tropics. Synthetic vitamin A also may soon be available in sufficient quantities.

Vitamins of the B complex. Kodicek's (1942) suggestion that a vegetarian diet might tend to be deficient in nicotinic acid has not yet proved to be correct, at least as far as this country is concerned, where vegetarians obtain from the use of wholemeal or high-extraction flours, as well as from other sources, sufficient extra nicotinic acid to make good the amount they lose by not eating meat. However, nicotinic-acid deficiencies may be encountered in other countries with diets based on cereals or pulses deficient in this vitamin. Oats and certain varieties of maize and soya usually contain much less than the minimum nicotinic-acid content of 4 μg/Cal. recently recommended by the Committee on Nutrition set up by the British Medical Association (British Medical Association, 1950). Even greater deficiencies are found in the riboflavin content of barley, maize, oats, rice, wheat and certain varieties of soya, which may be less than half the B.M.A. Committee's minimum of 0·6 μg/Cal. During World War II riboflavin-deficiency symptoms occurred in Japanese P.O.W. camps with diets with a riboflavin content of about 0·4 μg/Cal. and were in some cases ameliorated by using sprouted beans, according to an official report by Willimott (Wokes, 1952). Sprouting or germination of seeds, staple cereals and pulses increases the contents of nicotinic acid and riboflavin to different degrees depending on the germination energy involved (Klatzkin, Norris & Wokes, 1949), a fact which throws light on the long-established Eastern custom of sprouting such seeds before eating them. Vitamin B_{12} will be considered later.

Iron. Widdowson's study of the prewar diet of seven vegetarian children showed it to contain only 90 % of the normal amount of iron. This deficiency has, however, been largely eliminated by the use of flour containing a higher proportion of germ, which also helps with the supplies of various trace elements.

Energy. Results obtained by Foote & Eppright (1940) and Widdowson (1947) showed on the whole subnormal calorie intakes in vegetarian children above the age of 5. Below this age they did not differ significantly from the normal. This change at the age of 5 may be explained by the findings of Wakeham & Hansen (1932) that the average basal metabolic rate of vegetarians begins to fall when they have been vegetarians for 5 years, and eventually comes to a level about 10 % below normal.

The heights and weights of vegetarian children were found to be normal by Wakeham & Hansen (1932). Sibly (quoted by Wokes, 1952) also claimed average normal increases in height and weight in boys in one of the houses at a public school in which the diet has been vegetarian since 1909, the animal-protein content (all from dairy produce) providing about 3 % of the total calories. Data on the athletic performances (e.g. swimming, cross-country running) of the vegetarian boys, which apparently show them to be equal to the non-vegetarian boys in the same school, are being submitted to statistical analysis. It is hoped also to examine statistically the athletic records of members of the Vegetarian Cycling and Athletic Club.

Animal protein. A recent survey (Wokes, 1952) of the animal-protein intakes in different countries since 1939 shows that these have fallen considerably in many European and Asiatic countries. Whereas in North America, Uruguay and the Argentine, Australia and New Zealand the average intakes of animal protein now provide 5–8 % of the total dietary calories, in most west European countries this percentage lies between 4 and 5. In eastern Europe it is usually between 1·5 and 3, and in India and the Far East it falls below 1, and may be less than 0·5.

Economic and political factors may lead during the next few years to some smoothing out of the dietary differences between the East and the West which, in view of the diminishing area of land available per head for food production, will almost certainly necessitate further reductions in the European intakes of animal protein. Hence the experience of eastern nations who have been living for generations on very low intakes of animal food may provide useful information to the western nations facing possible reductions in their intakes of animal food. Some information of value may also be obtained from the experience of persons in this country who have been experimenting for a number of years with diets containing little or no animal food.

Protein requirements of adults

There is a good deal of evidence that adults can maintain health and activity for years on intakes of animal protein providing not more than 3 % of the total dietary calories. Similar results were obtained by McCance & Widdowson (1946) in shorter experiments, lasting 14–15 weeks, in which the corresponding percentages were 1·6–2·8 for three men, and 3·9–5·1 for two women, some of the animal protein being obtained from dairy produce and some from meat. As regards protein intake and muscular efficiency, Wishart (1934) showed in experiments on a racing cyclist who had been a vegetarian for 20 years that almost as good results were obtained with diets containing no animal protein as with diets in which as much as 18 % of the calories came from animal protein, all from dairy produce (Table 3). However, each of these diets was consumed only for 3 days.

Table 3. *Effect of animal-protein intake on external work by a vegetarian racing cyclist (from Wishart's (1934) data)*

Protein intake (g/day)		Percentage of calories from animal protein	Total external work (kgm × 10^3) in	
Animal	Total		6 h 24 min	8 hr 10 min
0	39	0	272	344
0	112	0	289	357
0	208	0	270	—
		Mean	277	351
191	228	16	297	381
184	213	18	289	377
		Mean	293	379

A number of adult vegetarians, in this and other European countries, have been trying during recent years to live on a diet containing no animal food. Some of them have succeeded in adhering to this drastic regime for a considerable number of years, apparently with no ill effects. The health and activity of others appeared satisfactory during the first few years of abstinence from animal protein, but after this weakness of the limbs frequently began to develop, with severe spinal pains. These deficiency symptoms do not seem to have been encountered by Germans living on diets quite low in animal protein (Members of the Department of Experimental Medicine, Cambridge, and Associated Workers, 1951). Until more is known about their cause, there would seem to be definite risks in attempting to live for prolonged periods on diets containing no animal protein, especially whilst food shortages place difficulties in the way of obtaining a sufficient variety of unprocessed foods, such as fruit and nuts. Interesting results have recently been obtained by American workers using a diet of rice and fruit providing no animal protein and only about 25 g vegetable protein daily. The body-weight, after dropping rapidly during the first few months, became steady at a lower level, when the average nitrogen balance was no longer negative. The diets have been recommended for the treatment of hypertension, but need to be maintained for much longer periods before their nutritive value can be established (Peschel & Peschel, 1950).

Protein requirements of children

The crucial test of any diet is whether it will give satisfactory results in the production and rearing of children, as well as permitting suitable growth and development and adult activities throughout the normal span of life. Records are available of families in which the members for several generations have eaten no animal food except dairy produce, their intakes of animal protein usually providing between 2 and 4 % of the total dietary calories (Wokes, 1952). Since these intakes permitted satisfactory growth of children, protein supplies must have been adequate, even although this has not been duly confirmed by nitrogen balances.

Still lower intakes of animal protein occurred in Widdowson & Dean's (1948) nutritional study, extending over a year, on German children who were given unlimited amounts of bread (with vitamin supplements) which provided 75 % of the total calories, the remainder being derived mainly from vegetables. Each child received 250–500 ml. milk per week, so that the animal-protein intake provided less than 1 % of the total calories. This study demonstrated the possibility of securing excellent growth and health on very little milk and little animal protein (McCance, 1948).

Comparison of human and cow's milk

During the early stages of lactation there is a sharp fall in the protein content of both human and cow's milk, which can be seen more clearly if it is plotted against the logarithm of the age of the baby or calf. Allowing for the shorter span of life in the cow, the rate of fall is similar in both species. The final level reached is 16–20 % in the cow as compared with about 8 % in the woman, both expressed on the calorie basis. This difference of protein levels, which is probably related to the more rapid rate of growth of the calf, means that bottle-fed babies living on National Milk are receiving much more protein than they would obtain from their mothers' milk. In many proprietary baby foods the protein content of cow's milk is reduced in different degrees by admixture with malted cereals. If cow's-milk proteins are equal in biological value to human-milk proteins, they should promote satisfactory growth in babies when supplied at the same level as in human milk, i.e. providing about 8 % of the total calories. This was shown to be possible in experiments carried out a few years ago under the supervision of Prof. Andersen of Copenhagen, at the Dronning Louise Hospital and Ordruphøj Nursery (private communication). Satisfactory growth was obtained in babies 0–8 months old deriving nearly the whole of their calories from a specially modified cow's milk in which the proteins provided only about 8 % of the total calories. Moreover, there was no significant difference in the rate of growth when the protein content was raised to about 13 % (on a calorie basis).

Vegetable substitutes for cow's milk

The shortage of supplies of cow's milk in many parts of the world has led to many attempts to devise satisfactory substitutes. These have usually been based on soya, although almonds and other nuts of high protein content have sometimes been used for this purpose. Soya beans have for many generations supplied the basis of suitable foods for babies and young children, as well as adults, in the Far East, particularly northern China and Manchuria. However, experiments on soya in India and in Europe have on the whole given less satisfactory results, the addition of some milk usually being found necessary (Aykroyd & Krishnan, 1936–7; Dean, 1949). This failure to obtain completely satisfactory growth with milk substitutes entirely free from animal protein may be due to (*a*) unsatisfactory amino-acid mixtures, (*b*) denaturation of the proteins during processing, (*c*) presence in soya of the trypsin inhibitor, which may interfere with the digestion and assimilation of the protein, or (*d*) deficiency of the vitamin B complex.

Differences in amino-acid composition between soya and human milk can be smoothed out by admixture of the soya with suitable proportions of cereals (Wokes & Klatzkin, 1949). Denaturation changes can be reduced to a minimum by processing in vacuo. The trypsin inhibitor can be eliminated by means of germination enzymes, using malted cereals and soya as the raw materials. But the malting must be carried out in such a manner as to secure adequate development of the enzymes as well as of the vitamin B complex. If such precautions are not taken these milk substitutes may be definitely deficient in riboflavin. This deficiency can be particularly serious in very young babies because of the need for high levels of riboflavin in the earliest weeks of life.

The animal protein factor

Recent experiments on various animal species have shown that plant proteins give better growth and development if supplemented with the animal-protein factor, which appears to be closely related to vitamin B_{12}. As far as human diets are concerned, evidence of the need for this factor is still unconvincing, experiments on American children having given varying results (Wetzel, Fargo, Smith & Helikson, 1949; Downing, 1950). This may be due to the presence of stores of the vitamin in the body tissues when the experiments began. Such a difficulty might be overcome by choosing as experimental subjects the babies of mothers who have abstained from animal food not only whilst breast feeding the babies but also for some months before the babies were born. The breast milk of such mothers should have a very low content of the animal protein factor. Their babies are often found to have allergies to dairy protein which may be associated with asthma and cause much difficulty in experimentation.

In examining the results of these experiments on milk substitutes it should be borne in mind that the rate of growth in children on diets very low in animal protein is often below normal, according to records kept over a number of years by my colleague Dr Cyril Pink. Nevertheless, such children are usually able to maintain satisfactory activity and development without increase in their animal-protein intake. In such instances the rate of growth may need correlating with other criteria when the nutritive value of the diet is assessed.

In conclusion, the opinions of Lord Boyd-Orr and Sir John Russell (1949) indicate that the problem we have been considering here is ultimately concerned with the future of the human race. In the short space at my disposal only brief reference could be made, in fairly general terms, to a few of its more important aspects. The results so far obtained are affected by so many factors that they will need repeating over and over again before conclusive findings, that are statistically significant, can be reached. Nevertheless, in spite of many failures and disappointments, the work is important enough to ensure that the necessary refinement of experimentation will sooner or later be secured. The generous help and encouragement of my friends and colleagues lead to the hope that our faith in the future of mankind will eventually be justified.

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