Trace nutrients
4*. Iodine in British food

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1. The amounts of iodine in nationally representative samples of prepared and cooked groups of foods and in a wide variety of individual foods and food products were determined colorimetrically. The amounts of erythrosine, a red food colour containing 577 mg I/g were also determined in selected foods and diets by high-performance liquid chromatography.

2. The average British diet was calculated to provide 323 μg I/d but only 255 μg if two fruit samples containing large amounts of glacé cherries were discounted. Of the total, 92 μg was derived from liquid milk. Meat and meat products provided 36 μg and cereal products 31 μg, but fresh fruits and sugars, vegetables and beverages provided little I. Fish and fish products, though rich in I, contributed only 5% to the total intake.

3. Milk was the most variable as well as the most important individual source of I. Summer milk samples contained 70 μg/kg and winter milk 370 μg/kg on average. Milk products, including butter and cheese, and eggs were also rich in I.

4. Some processed foods contained erythrosine, particularly glacé cherries and some pink or red confectionery items, biscuits, cherry cake, canned strawberries and luncheon meat. However, none of these are major foods in the average household diet and erythrosine would therefore contribute little more than 10 μg I/d to most diets.

5. The average daily intake of I was lower than in similar studies in the USA, but was twice the provisional UK recommended intake. This study provides no evidence that I intakes in the UK could be too low or too high for health.

There is little information on I intakes or their adequacy in Britain. In 1969 the Department of Health and Social Security (1969) suggested that an intake of 150 μg/d was adequate for health, but stated that earlier recommendations of 150 μg for children or 100 μg for adults were unlikely to be met without the iodization of salt; and only 2·5% of table salt is iodized in this country even now. Their report also stated that much more information was needed, and without this no further recommendations have been made (Department of Health and Social Security, 1979).

Goitre is, however, now rare in Britain. Historically, it has been associated with specific regions such as Derbyshire where, even in the 1960s, 6·6% of a population of women showed signs of thyroid enlargement (West Derbyshire Medical Society, 1966). Their intakes of I were not known. In West Germany there is still concern that the average intake, calculated to be 80 μg/d, is not high enough to prevent goitre (Hötzel *et al.* 1976), but in contrast there is growing concern in other countries that intakes may now be too high for health (Stewart & Vidor, 1976; Fisher & Carr, 1974). In particular, cases of thyrotoxicosis which have been diagnosed in Tasmania have been attributed to a rapid rise in the I available from a number of foods and particularly from milk (Stewart & Vidor, 1976), while in America, although thyroid disorders due to excessive intakes are rare (Talbot *et al.* 1976), intakes by infants, toddlers and teenagers have been estimated from 'total diet' studies to be as high as 395 μg, 368 μg and 958 μg/d respectively (Harland *et al.* 1980), and are increasing (Park *et al.* 1981).

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There have been few reports on the I content of foods since 1952, when the Chilean Iodine Educational Bureau (1952) reviewed the subject, and since then analytical methodology has improved considerably (Fisher & Carr, 1974). American foods have been studied (Vought & London, 1964; Harrison *et al.* 1965; Fisher & Carr, 1974), but in Britain only milk (Broadhead *et al.* 1965; Alderman & Stranks, 1967; Dodd *et al.* 1978; Kingwill *et al.* 1979) and fish (Broadhead *et al.* 1965) have been studied in any detail. There have also been changes in the British diet, especially the decline in the consumption of fish which is the richest natural source of I (Chilean Iodine Educational Bureau, 1952), from 30 g/d in 1952 to 20 g/d in 1980 (Ministry of Agriculture, Fisheries and Food, 1954; 1982).

For these reasons a reassessment of I intakes in Britain was required, and I has therefore been included in the Government's evaluation of trace nutrients and other minor constituents in the British diet. The results are presented in this paper, together with a preliminary indication of the amount of the red food colour erythrosine (Erythrosine BS; EEC food additive number E127; US Foods, Drugs and Cosmetics (FD & C) Red no. 3) which contains 577 mg I/g and may break down to contribute some physiologically-available sources of I (Vought *et al.* 1972; Knowles *et al.* 1974; Chan, 1975; Draper, 1975; Sharp, 1976).

METHODS

Food samples

The average daily intake of iodine was estimated from the food samples collected for the Ministry of Agriculture, Fisheries and Food's 'total diet' study between 1977 and 1979. The organization of this study and the foods included have been described in detail elsewhere (Buss & Lindsay, 1978) but, in brief, Home Economics and Food Science departments in colleges throughout Great Britain and Northern Ireland bought specified amounts of some seventy major foods in local shops and prepared and cooked them as for eating; the foods were then combined into groups for analytical convenience. For the present study, ten colleges provided thirteen sets of samples, with between two and five colleges participating in each quarter. The colleges were in Aberdeen, Edinburgh, Glasgow, Liverpool, Shrewsbury, Sheffield, Ilkley, Brighton, Torquay and Cookstown (Northern Ireland), and were thus geographically reasonably representative of the United Kingdom as a whole.

In addition, a range of 184 different kinds of individual foods was bought in London and analysed. These were chosen mainly because they are major items in the British diet, or because the Chilean Iodine Educational Bureau (1952) indicated that they might be rich sources of I. Many processed foods were included, some because of American evidence that they can be richer sources of I than non-processed foods (Kuhajek & Fiedelman, 1973; Fisher & Carr, 1974) and some because they could contain erythrosine.

Elemental I from seawater is deposited onto soil at rates varying from 3·8 to 10·0 mg/m^2 per year depending on the annual rainfall (United Kingdom Atomic Energy Authority, 1975). This may be taken up by plants at rates dependent on pH and on the amounts of calcium and organic matter in the soil (Whitehead, 1975). To determine whether the I content of plants was in any way affected by rainfall and local environment in Britain, selected samples of vegetables were obtained from market gardens in Boston (Lincolnshire), Cambridge, Preston and Truro. A number of foods were also analysed both raw and cooked to investigate the extent of any losses of I on cooking.

Analytical methods

All analyses were carried out by the Laboratory of the Government Chemist. The analytical method for total I has been published in detail elsewhere (Moxon & Dixon, 1980), but, briefly, each foodstuff was treated with potassium carbonate (300 g/l) and zinc sulphate (100 g/l) solutions, evaporated to dryness and then heated for 90 min at 550° in a covered crucible. After cooling, more zinc sulphate solution was added and the procedure repeated. The ash was extracted with water and, after centrifugation, a representative fraction was diluted to a known volume and mixed with potassium thiocyanate (0·23 g/l), ferric ammonium sulphate (0·163 M in 3·76 M nitric acid) and sodium nitrite (20·7 g/l) in an AutoAnalyzer. The reduction in colour due to the reaction of ferric thiocyanate with nitrite in the presence of iodine as a catalyst was measured at 450 nm after 20 min.

Where appropriate, erythrosine was analysed by a method which has also been published in detail elsewhere (Boley *et al.* 1980). The colour was extracted from the food with a liquid anion-exchange resin dissolved in butan-1-ol. Where irreversible binding of the colour to a food had occurred during processing, it was released by a preliminary enzymic digestion. Erythrosine was re-extracted from the resin phase into aqueous solution, followed by purification and concentration on a polyamide column. The final eluate was concentrated and examined by high performance liquid chromatography. Erythrosine was separated from other colours by paired-ion chromatography on a reverse phase column with cetyl trimethylammonium present in the mobile phase as counter ion, and determined quantitatively at 510 nm. Because of some discrepancies in the results, the total I content of each of the samples which had been analysed for erythrosine was determined in triplicate and the mean is presented.

RESULTS

'Total diet' study

The I contents of the 'total diet' samples are shown in Table 1, and the average daily intake of I calculated from them was 323 μg. The range of 'intakes' between the colleges varied from 116 to 1051 μg/person per d. Two colleges, however, provided fruit samples which contained more than 20 g glacé cherries, which contain approximately 34000 μg erythrosine/kg (equivalent to 19400 μg I/kg). If these two fruit samples were omitted, then the average daily I intake fell to 255 μg/person (Table 1). The cereals, meat, fish and fruits

Table 1. *Iodine content of 'total diet' samples and estimated average daily intake, 1977–1979*

Food group	I content (μg/kg) Mean	Range	Estimated wt of food eaten* (kg/d)	Estimated intake of I (μg/person per d)
Cereals	140	50–280	0·23	31
Meat	240	70–580	0·15	36
Fish	750	320–1440	0·02	15
Milk	230	50–550	0·40	92
Fats	220	80–420	0·08	17
Root vegetables	80	< 20–280	0·18	15
Other vegetables	80	< 20–260	0·11	8
Fruit and sugars†	550	< 30–3800	0·17	93
Beverages‡	20	< 10–120	0·12	16
Total			1·46	323

* From Buss & Lindsay (1978).

† Two of the fruit and sugar samples, which included more than 20 g glacé cherries, contained 1700 and 3800 μg I/kg. The mean concentration of the remaining eleven samples was 150 μg/kg (range, < 30–440), which would have provided 25 μg I towards a total of 255 μg.

‡ For calculation of the intake from this food group, see Wenlock *et al.* (1979).

Table 2. *Iodine content of selected foods in Britain*

(Individual values are given for up to three different samples of the same kind of food; otherwise the mean and range are presented with the no. of samples in parentheses)

	I content (μg/kg)	Erythrosine content (μg/kg)	Erythrosine I content (μg/kg)
Cereal products:			
Bread			
White (6)	60 (< 50–100)		
Hovis	220		
Wholemeal	< 50, < 50, 70		
Malt	270		
Currant loaf	290		
Rolls, white	190		
Flour, white, plain; self-raising	100; 100		
Macaroni; spaghetti, boiled	< 20; < 20		
Rice, boiled	50		
Crispbread	150		
Porage oats, boiled	< 30		
Cornflakes	100		
Biscuits			
Assorted	150	—	—
	5410	2300	1300
Raspberry cream	2170	6100	3500*
	5340	2100	1200
Neapolitan wafers	31000	20000	11400
Cakes and pastries:			
Fruit cake	1530	230	130
Cherry cake	1780	500	300
	6800	2400	1400
	14800	10200	5800
Battenburg cake	110, 120, 150		
Strawberry and vanilla iced cake	40		
Cherry cheesecake	110, 400		
Cherry slices	4900	1700	1000
Bakewell slices	2400	1700	1000
Swiss roll (6)	120 (50–230)		
Strawberry sponge cake, jam rings, jam tarts, jam doughnuts (8)	100 (20–260)		
Canned sponge, frozen sponge products (4)	180 (40–420)		
Trifle (4)	60, 110, 340		
	1780	1300	740
Pie fillings (5)	70 (30–100)		
Cake mixes	50, 120, 200		
Dessert mixes (9)	< 200 (all < 200)		
Meat:			
Beef, stewing steak	60		
Lamb, New Zealand; English	20; 90		
Pork, leg	30		
Bacon (raw and cooked) (11)	110 (50–170)		
Ham, canned	60, 170	—	—
Chicken, broiler, raw; roast	100; 50		
Liver, lamb and ox, raw and cooked (9)	120 (< 60–300)		
Kidney, pig and ox (6)	120 (< 30–280)		
Meat products:			
Sausages, beef and pork, raw and grilled (4)	40 (30–70)		

Table 2 (*cont.*)

	I content ($\mu g/kg$)	Erythrosine content ($\mu g/kg$)	Erythrosine I content ($\mu g/kg$)
Beefburger, raw and grilled	< 30, < 30		
Corned beef	50, 180, 200		
Salami			
Danish	5060	9300	5300*
Other (6)	150 (50–280)		
Polony	2150	1500	860
Garlic sausage	510	—	—
Luncheon meat	1690	700	400
	2000	—	—
	2150	1200	680
	5420	5200	2960
Chopped ham and pork (6)	200 (80–320)		
Pork pie; veal and ham pie; veal, ham and egg pie; cornish pasty (10)	80 (30–230)		
Sausage roll	60, 130		
	1270	1400	800
Scotch egg	120, 180, 210		
Meat pastes (6)	330 (140–660)	—	—
Fish and fish products:			
Cod fillet, fresh or frozen, raw or cooked (5)	740 (540–1200)		
Haddock, raw; grilled	1200; 2100		
Plaice, raw; grilled	100; 130		
Fish fingers, raw or grilled (5)	1120 (720–2290)	—	—
Kippers, grilled	860		
Tuna, canned	300		
Salmon, canned	850		
Salmon paté	1020		
Salmon spread	5970	3200	1800
Salmon and shrimp spread	4260	2400	1400
Salmon and butter spread	920		
Dressed crab spread	2390	—	—
Lobster paté	5570	1300	750
Milk and milk products:			
Liquid milk, summer (9)	70 (50–110)		
Liquid milk, winter (14)	370 (290–500)		
Condensed milk	740		
Evaporated milk	110		
Cream	< 20		
Yoghurt, natural	420, 840		
Yoghurt, fruit (6)	480 (360–530)		
Cheese, Cheddar (4)	420 (200–580)		
Cheese, processed	290		
Eggs	510, 540		
Oils and fats:			
Butter (5)	380 (230–490)		
Margarine, hard	230		
Margarine, soft	270		
Lard, cooking fat, suet, cooking oil (4)	60 (< 50–110)		
Vegetables:			
Potatoes, raw or boiled (5)	30 (< 10–80)		
Cabbage, raw or boiled (5)	20 (< 10–40)		
Broccoli, raw or boiled (4)	20 (< 10–50)		
Carrots, raw (4)	20 (< 10–70)		
Cauliflower, spinach, runner beans, broad beans, peas (fresh or frozen), tomatoes, onions and mushrooms (10)	20 (< 20–40)		

Table 2 (*cont.*)

	I content (μg/kg)	Erythrosine content (μg/kg)	Erythrosine I content (μg/kg)
Peas, canned	130		
Baked beans	20, 30		
Red cabbage, pickled	40, 80		
Fruit and nuts:			
Apples; oranges; bananas	< 30; 20; 80		
Apricots, canned	70		
Grapefruit, canned	< 20		
Fruit juices	50		
Fruit salad, canned	610		
	640	—	—
	1800	300	170
Cherries, canned	21200	3500	2000
Cherries, glacé	36000	34000	19400
Cherries, cocktail	180	—	—
Strawberries, canned	9000	4700	2700
	11700	8300	4700
Olives, stuffed	30, 70		
Almonds	100		
Peanuts, raw	< 20		
Peanuts, roasted	220		
Peanut butter	30		
Confectionery:			
Sweets, assorted	4800	2100	1200
Strawberry sweets	100, 100		
	4400	10300	5900*
	8200	23000	13000*
Chocolate, assorted, plain	1420	1900	1100
Chocolates, assorted, milk	940	550	330
Miscellaneous:			
Salt	440		
Salt, iodized	31000		
Infant formula	800, 1300		
Infant cereal; rusks	320; 290		
Infant food, canned	80		
Tea, infusion	< 10		
Coffee, instant	50		
Beer	80		
Milk shake, dry	320		
Iced lolly	30		
	70, 140	—	—
Mousse, chocolate	360		
Caramel dessert	330		
Jam (8)	70 (40–150)		
Soup, canned	160		
Soup, canned, condensed	50		
Soup, dried	740		
Gravy cubes	440		
Yeast extract	490		
Mayonnaise	350		
Salad cream	110		

* Foods in which the I calculated from the erythrosine content was greater than the experimentally determined iodine.

samples from seven of these colleges were also analysed for erythrosine. Again excluding the fruit sample which was rich in glacé cherries, the mean intake of I from this source was 11 μg with a range from 0 to 13% of the total I intake.

The main, but at the same time the most variable source of I was liquid milk which contained from 50–550 μg/kg. On average it provided 92 μg I/d (36% of the total). The meat and meat products group contributed a further 36 μg/d and the cereals 31 μg/d. Fish provided only 15 μg/d because of the low level of consumption, while the fats and oils, beverages and vegetable groups were normally insignificant sources. None of the colleges used iodized salt in the cooking of any of the samples, but the addition of just 1 g iodized salt would have added 31 μg to the average intake of I (Table 2).

Individual foods

The results of the analyses of a wide variety of fresh and processed foods are summarized in Table 2. As expected (Chilean Iodine Educational Bureau, 1952) the richest natural sources of I were among the fish and fish products, all of which, apart from plaice and tuna, contained more than 500 μg I/kg. Eggs were also rich in I, as were winter milk, condensed milk, yoghurts, butter and Cheddar cheese, all containing on average more than 300 μg/kg. The various meats and meat products, other than those containing erythrosine, contained less I, as did fresh fruits, vegetables and most cereal products. The limited influence of region upon the I content of fresh vegetables is illustrated in Table 3. Some of the processed foods appeared to be very rich sources of I, but this was usually due to the presence of erythrosine or because the product was in a dry or concentrated form.

Table 3. *Iodine content (μg/kg) of raw vegetables grown in different areas of Britain*

	Boston	Cambridge	Truro	Preston
Potatoes	20	< 10	< 10	80
Cabbage	< 10	< 10	< 10	40
Broccoli	< 10	20		50
Carrots	10	< 10	70	10

DISCUSSION

The average intake of iodine calculated from the total diet samples was 323 μg/person per d, but there were wide variations and this mean was raised by the inclusion of glacé cherries in two of the fruit group samples. The average intake in Britain is therefore more likely to be of the order of 250 μg/d (Table 1) of which little more than 10 μg would be derived from erythrosine itself. This intake is substantially more than expected by the Department of Health and Social Security (1969), or than the earlier estimate of 80 μg/d made by the Chilean Iodine Educational Bureau (1952) who multiplied the I concentrations in foods by the amounts of food available in British homes in the 1940s. Much of the increase was due to the increased contributions from milk (92 μg/d compared with 14 μg) and meat and eggs (36 μg/d compared with 7 μg), but there were also substantial increases from all other groups of foods except for fish; the contribution from the latter decreased from 28 μg/d (35% of the total) to 15 μg/d (5% of the total) because of the decline in fish consumption.

Although the Department of Health and Social Security (1969) provisionally recommended an intake of 150 μg/d for all population groups, the current American recommended intakes ((US) National Research Council, 1980) are more specific and vary according to age and body-weight. Based on these recommendations and the projected population of the UK for 1979 (Office of Population Censuses and Surveys, 1976), the weighted average recommended intake for the British population as a whole would be 142 μg/person per d. The average intake estimated in the present study was approximately twice this value. Nevertheless it was low compared with the intake by American adults of 958 μg/d, calculated from recent American 'total diet' studies (Harland *et al.* 1980), or 550 μg/d if that value is reduced to allow for the fact that the American diet was taken to provide 16·3 MJ (3900 kcal)/d while the British 'total diet' samples provide 9·4 MJ (2250 kcal)/d. Previously measured intakes among women and children in America averaged 128 and 360 μg/d respectively but ranged from 58 to 830 μg/d (Vought *et al.* 1972), while intakes in an American hospital averaged 206 μg/d (Vought & London, 1964). A more recent study of Swedish pensioners gave average intakes of 318 and 246 μg I/d for men and women respectively (Abdulla *et al.* 1977).

Although this study provides no evidence of deficiency, it is also unlikely that the intakes are too high for health: the (US) National Research Council (1980) considers that intakes of up to 1000 μg I/d are safe for adults, and we are unaware of any evidence that thyrotoxicosis is a problem in the United Kingdom.

The main individual sources of I in our study were milk and its products, and especially winter milk which contained five times as much I as summer milk. These concentrations of I were in agreement with other recently reported values in Britain (Dodd *et al.* 1978; Kingwill *et al.* 1979). The I content of milk is known to be affected by supplemental animal feeds, by iodized salt blocks and by the use in dairying of iodophors as disinfectants, sanitizers and in mastitis control (Fisher & Carr, 1974; Dodd *et al.* 1978; Hemken, 1979). Alderman & Stranks (1967) noted that the concentration in winter milks in the UK was elevated by the feeding of proprietary dairy concentrates and this has been confirmed by Dodd *et al.* (1978). Although the use of iodophors could also have raised the levels of I, Dodd *et al.* (1978) showed that the increases from iodophors in the milk from thirty UK herds were smaller than either the differences normally found between the individual herds or those occurring as a result of the seasonal changes in the herds' diets. They concluded that the normal iodophor application in UK dairying was unlikely to be an important factor in human nutrition. Even smaller effects have been reported from the use of iodophors in New Zealand (Sheldrake *et al.* 1980), and there have been similar conclusions in the USA (Fisher & Carr, 1974; Cantor & Most, 1976; Hemken, 1979; Harland *et al.* 1980; Hemken *et al.* 1981). Cheese and other milk products (except cream) were also rich in I in our study (Table 2), for I is known to be carried over from milk during cheese making (White & Moghissi, 1971).

Eggs also contained high levels of I. The values in Table 2 (more than 500 μg/kg) were five times the average value given by the Chilean Iodine Educational Bureau (1952) and double their highest value. High concentrations have also been found in America where it was concluded that this was the result of the then widespread use of I-rich concentrates derived from fish meal in the feeding of intensively laying hens and broiler fowl (Vought & London, 1964; Marcilese *et al.* 1968). The I content of broiler chicken (100 μg/kg) was seven times higher than that given by the Chilean Iodine Educational Bureau (1952) but the feeding system under which the birds were reared is unknown.

With these exceptions, our values for the I content of individual foods were generally within the ranges quoted by the Chilean Iodine Educational Bureau (1952). In particular, fish were confirmed as very rich sources, while the quantities in fresh fruit and vegetables were, as before, very low. Furthermore, there was no evidence of any significant variation in the I content of vegetables with the region of the country (Table 3). Cooking was found to have some effect on the I content of foods, but these foods were mostly so low in iodine that this would be nutritionally unimportant. Thus beef and pork sausages, beefburgers, bacon, chicken and fresh vegetables, some samples of which contained less I after cooking, all contained less than 100 $\mu g/kg$ when raw. Conversely, the fish and offals which were richer sources of I either lost none or gained, in some instances, up to double the concentration of I on grilling, presumably due to the preferential loss of water.

Some processed foods were extremely rich in I and in most instances this was because of the presence of the red food colour erythrosine (Table 2). In contrast to America (Kuhajek & Fiedelman, 1973; Fisher & Carr, 1974), cereal products were otherwise poor sources of I because potassium bromate and not potassium iodate is used as a flour improver in Britain and because iodized salt is not used. The products containing erythrosine included glacé cherries and cakes containing them; some pink or red biscuits and confectionery products; canned cherries, strawberries and fruit salad; Danish salami, luncheon meat and polony; and some fish spreads. The I content of this erythrosine was calculated and in four instances was higher than the experimentally determined total I content; this was thought to have been because the food samples were not homogenous. In most of the other foods which contained erythrosine, there was a substantial amount of I besides that present in the extracted colour itself, and was presumably in the form of breakdown products of erythrosine. Whether or not the I in these products is physiologically available is the subject of further experiments.

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