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Studies on the composition of food

5.* The chemical composition of eggs produced under battery, deep litter and free range conditions

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1. The nutrient content of battery, deep litter and free range eggs from domestic hens under systems of management typical of those used in the commercial production of eggs was studied from January to March 1968.

2. Monthly samples of eighteen eggs, supplied by six centres, were homogenized, freeze-dried, ground and stored at −15°. Their contents of moisture, nitrogen, amino acids, fats, fatty acids and cholesterol, ash, sodium, potassium, calcium and iron, thiamin, riboflavin, nicotinic acid, pantothenic acid, folic acid, vitamin B_{12}, tocopherols and retinol were determined. The mean values for eggs from each system, each centre and each quarter of the year were calculated.

3. For many nutrients, no significant difference between systems was detected; the greatest variations occurred in the content of some vitamins. Free range eggs contained more vitamin B_{12} than deep litter or battery eggs and more folic acid (*Lactobacillus casei* assay) than battery eggs. Differences in tocopherol and cholesterol contents were complicated by system-by-centre interactions. There were also small differences in calcium and iron contents.

4. Riboflavin, folic acid (*Lactobacillus casei*) and vitamin B_{12} were the only nutrients which were observed to vary with the time of year in the eggs from all systems of management. Major differences were found in the vitamin content of eggs from different centres.

5. Though the differences in vitamin B_{12} and folic acid contents which result from the different systems of management are of little significance in an average mixed diet, they would be measurable for some individuals who may depend on eggs as an important source of these nutrients.

The management of the laying hen has undergone widespread changes with increasingly greater emphasis being placed on intensive management systems. The essential features of such systems, which are designed to improve the efficiency of egg production, are the maintenance of the birds indoors, where for the whole of their adult life their environment, food and activities are closely controlled. In the battery system the birds are kept in the confined space of a cage, whereas in the deep litter system flocks of birds are kept on the floor in pens and so have more freedom of action but little choice of environment or food. On the contemporary free range system, the birds are provided with a formulated ration, but in addition have free access to grass. Changes in the proportions of birds kept under these systems between 1956 and 1971 are shown in Table 1.

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Table 1. *Laying fowls on agricultural holdings in England and Wales: percentage distribution by main systems of management (after Orton, 1971)*

System	1956	1962–3	1970–1
Free range	43·8	21·0	5·8
Battery	14·8	27·0	84·6
Deep litter and others	41·4	52·0	9·6

A benefit of these changes has been that the real price of eggs has decreased and egg consumption has increased. Information obtained by the National Food Survey showed that between 1956 and 1971 average egg consumption in all households increased by 4·6% to 4·55 eggs per person per week. Eggs make a useful contribution to the daily intake of vitamin D, retinol, riboflavin, iron and protein in the average household diet (Ministry of Agriculture, Fisheries and Food: National Food Survey Committee, 1973), and for the elderly they can be a particularly important source of some essential nutrients such as protein, iron and vitamin D (Exton-Smith & Stanton, 1965). The extent to which the iron in eggs is absorbed is dependent on the other components of the meal; it has been shown, for example, that the addition of orange juice increases absorption (Callender, 1971).

It is, however, a popular view that eggs produced by modern intensive farming methods are nutritionally inferior or less wholesome than those produced by traditional methods. Major differences in the composition of eggs produced by different management systems are not to be expected since egg production would cease before this occurred. Nevertheless, egg composition may be influenced by a number of factors such as age and breed of bird, and diet, and many of these effects are well documented (Cruickshank, 1940–1; Cravens, Sebesta, Halpin & Hart, 1943; Petersen, Lampman & Stamberg, 1947; Romanoff & Romanoff, 1949; Arroyave, Scrimshaw & Tandon, 1957; Marion, Nordskog, Tolman & Forsythe, 1963). There is, however, little published information on the comparative composition of eggs obtained under different systems of management (Coppock & Daniels, 1962; Krieg, 1961, 1963; Jones, 1968).

In view of this, and because of the widespread public interest in the effects of modern farming methods, the investigations described in this paper were undertaken. By analysing samples of battery, deep litter and free range eggs from birds under systems of management typical of those used in the commercial production of eggs in this country, we have attempted to obtain values which are broadly representative of the eggs obtained by the consumer. The main investigation was spread over a period of 15 months from January 1967 to March 1968, the samples being supplied on a monthly basis from six centres in different areas of the United Kingdom. Thus it was planned that some additional information on seasonal variation and variation in egg composition between centres would be obtained.

Apart from the prime interest in the chemical composition of eggs, another important aspect is the effect of management systems on the physical characteristics of eggs. This is of special significance to the food industry since egg is used in a large number of food products and the physical properties of eggs are major factors in determining the

Table 2. *Sources of eggs used in the study*

Centre*	Period of supply†	Management system‡	Breed of bird
A	Q1, Q2, Q3, Q4, Q5	FR	Light Sussex and Light Sussex × Leg bar
		DL	Leg bar × Light Sussex
		BA	Light Sussex
H	Q1, Q2, Q3	FR	Rhode Island Red
		BA	White Leghorn (Shaver 288)
L	Q1, Q2, Q3	DL	Rhode Island Red × Light Sussex (Thornber 404)
		BA	White Leghorn (Nickchick)
S	Q1, Q2, Q3, Q4, Q5	DL	White Leghorn (Hyline 935)
		BA	White Leghorn (Shaver 288)
T	Q1, Q2, Q3	FR	Light Sussex
		BA	Light Sussex
Y	Q1, Q2, Q3, Q4, Q5	DL	Rhode Island Red × Light Sussex (Sykes H_3)
		BA	Rhode Island Red × Light Sussex (Sykes H_3)

* See below.

† Q1, Jan.–Mar. 1967; Q2, Apr.–June 1967; Q3, Jul.–Sept. 1967; Q4, Oct.–Dec. 1967; Q5, Jan.–Mar. 1968.

‡ FR, free range; DL, deep litter; BA, battery.

quality of the product. Measurements were therefore made of the physical characteristics of eggs produced under different management systems; the results of these investigations will be reported elsewhere.

EXPERIMENTAL

Sources of eggs

It would have been desirable to obtain eggs from commercial producers, but this proved to be impossible in practice because of the difficulties in controlling such an experiment. It was arranged, therefore, for eggs to be obtained from farms attached to agricultural institutes and colleges where laying flocks were maintained under commercial conditions.

The co-operating centres and details of the sampling periods, the management systems and the breeds of bird used at each centre are shown in Table 2. The following abbreviations are used for the centres: (A) West of Scotland Agricultural College, Ayr; (H) Hampshire County Farm Institute, Winchester; (L) Kesteven Agricultural College, Grantham, Lincolnshire; (S) Harper Adams Agricultural College, Newport, Shropshire (January–September 1967), and British Egg Marketing Board Poultry Husbandry Experimental Unit, Newport (October 1967–February 1968); (T) Loughry Agricultural College, Co. Tyrone, N. Ireland; (Y) Yorkshire (West Riding) Farm Institute, Askham Bryan, Nr York.

The periods covered by the survey were: January–March 1967 (first quarter); April–June 1967 (second quarter); July–September 1967 (third quarter); October–December 1967 (fourth quarter); January–March 1968 (fifth quarter).

Table 3. *Composition/kg of the rations given* ad lib. *to the laying hens at each centre* (A–Y)*

Nutrient	A	H	L	S	T	Y
Nitrogen (g)	26·5		26·2	26·1	26·6	26·0
Fat (g)	32·1	Normal	29·5	27·6	31·1	30·0
Fibre (g)	35·8	commercial	29·6	26·8	34·3	31·0
Calcium (g)	27·0	laying	30·2	25·1	26·0	28·4
Phosphorus (g)	8·0	ration	7·0	7·8	7·7	6·8
Sodium (mg)	2·9		3·0	3·5	3·0	2·6
Potassium (mg)	4·7		4·0	4·9	4·8	4·5
Iron (mg)	16·3		10·5	18·5	17·4	16·0
Magnesium (mg)	4·1		3·5	4·0	3·7	3·9
Thiamin (mg)	3·7		3·4	3·6	3·9	5·5
Nicotinic acid (mg)	47·8		54·9	52·1	45·0	67·0
Riboflavin (mg)	4·3		3·8	4·0	3·8	5·5
Folic acid (mg)	0·5		0·4	0·5	0·4	0·4
Vitamin B_{12} (μg)	2·2		3·3	3·4	2·1	3·3
Vitamin E (mg)	25·5		25·4	23·1	27·5	23·1
Vitamin A (μg)	2610		2415	2750	2975	2545

* See p. 187.

The experimental design was largely dictated beforehand by the facilities available and the prevailing general management conditions at each centre. Thus all six centres provided battery eggs, four centres deep litter eggs and three centres free range eggs; no control could be exercised over the rations and breeds used at each centre. At centres A, H and L, breeds differed between management systems.

Method of feeding

Since ration formulation is a major influence on egg composition, the calculated composition of the rations used at each centre is shown in Table 3. The diets which were the normal laying rations used at each centre were home-mixed and there was some variation in composition between centres, especially with regard to vitamin content. At any particular centre, the birds kept under each management system were given the same ration and the formulations were unchanged throughout the experiment. No drugs were used routinely in the rations.

Sampling procedure

Eggs were sampled at monthly intervals. Ninety eggs for each system at each centre were taken randomly at the beginning of each month and packed according to normal commercial practice into egg boxes. The boxes were all stored together in one place (at 12·8°) for about 2 weeks in conditions which approximated to those used by the British Egg Marketing Board, the storage time being based on their advice as to the average age of eggs when purchased by the consumer. After storage a dozen eggs were removed for determination of physical properties, and approximately thirty eggs were dispatched to the laboratory of the Government Chemist for chemical analysis. Centres A, S and Y provided eggs throughout and H, L and T for only the first three quarters of the experiment. On a few occasions some of the centres did not provide a sample.

Preliminary treatment and storage of samples

From each monthly sample, consisting usually of thirty eggs, the contents of eighteen were weighed, homogenized by stirring and then freeze-dried to reduce the moisture content to a low level. The freeze-dried material was weighed, ground, and stored at −15°. At quarterly intervals bulked samples representing eggs of the different systems of husbandry at each centre were prepared by mixing the monthly samples on the basis of equal weights of liquid egg. The bulked samples were then stored at −15°, until required for nutrient analysis. Preliminary studies showed that the procedure described had a negligible effect on the concentration of the nutrients examined.

Analytical methods

Moisture. This was calculated from the loss in weight on freeze-drying and the moisture content of the freeze-dried solids, determined by drying 2 g at 100° for 4 h.

Nitrogen. Total nitrogen was determined by the Kjeldahl method of the Association of Official Analytical Chemists (1970), except that the distillate was collected in boric acid. Protein is expressed as nitrogen × 6·25.

Amino acids. Freeze-dried egg was extracted in a Soxhlet apparatus with light petroleum (b.p. 40°–60°) for 2 h to remove fat. Defatted egg (200 mg) was hydrolysed with 5 ml 6 M-hydrochloric acid for 16 h at 125° in an evacuated sealed tube. The liberated amino acids were subsequently determined by ion-exchange chromatography on an autoanalyser. Cystine and methionine were determined on pre-oxidized samples by the method of Moore (1963); tryptophan was determined after alkaline hydrolysis by the method of Miller (1967). Results were corrected for hydrolytic losses.

Fat. The acid hydrolysis method of the Association of Official Analytical Chemists (1970) was used.

Fatty acids. Lipids were extracted with a methanol–chloroform mixture and separated into triglyceride and phosphatide fractions by elution of the 'chloroform' lipid extract through a silicic acid column (Hanson & Olley, 1963). Fatty acids were then determined by gas–liquid chromatography of the corresponding methyl esters obtained by transesterification of the separated triglyceride and phosphatide fractions (Stoffel, Chu & Ahrens, 1959; Association of Official Analytical Chemists, 1970).

Sterols (cholesterol). The sterols were precipitated as digitonides from the hydrolysed sample, filtered, dried and weighed.

Ash. Samples of 5 g were ashed at 550°. The residue was treated with two 5 ml portions of diluted hydrochloric acid (1 + 1), evaporated to dryness after each addition and finally taken up in 5 ml dilute hydrochloric acid. Sodium and potassium were determined in the solution by flame photometry; calcium by oxalate precipitation and permanganate titration; iron by the method of the Association of Official Analytical Chemists (1970).

Vitamins. Thiamin was determined by the method of the Association of Official Analytical Chemists (1970), except that sodium hydroxide and potassium ferricyanide were added separately, riboflavin by microbiological assay with *Lactobacillus casei* as test organism (Barton-Wright, 1962), nicotinic acid by microbiological assay with

Lactobacillus plantarum as test organism (Barton-Wright, 1961) and pantothenic acid by microbiological assay with *Lactobacillus plantarum* as test organism (Bird, 1963). For folic acid, samples were homogenized with a 0·2 M-phosphate buffer solution, pH 6·1, containing 0·1 % ascorbic acid, according to the method of Eigen & Schockman (1963), and the non-conjugate folic acid was measured by microbiological assay using *Streptococcus faecalis* and *Lactobacillus casei* as test organisms. Vitamin B_{12} was determined by microbiological assay with *Lactobacillus leichmannii* as test organism (Skeggs, 1963). To measure tocopherols the samples were saponified and the unsaponifiable matter was extracted with diethyl ether; tocopherols were separated from retinol, carotenoids and cholesterol on an alumina column and then determined spectrophotometrically by the method of Tsen (1961). Retinol was separated from the unsaponifiable matter by partition chromatography on Sephadex LH 20 and then determined by ultraviolet spectrometry.

Statistical analysis

The design of the study made the statistical analysis complex because: (1) it was non-orthogonal, since not all systems of management were represented at each centre; (2) results were received from only three centres for the whole period; (3) for egg components which were determined monthly (i.e. moisture, fat, nitrogen, riboflavin, folic acid, vitamin B_{12}, tocopherols and cholesterol), corrections for missing values were made by interpolation, but it is impossible to determine what effect this has on bulked samples.

First, all observations were converted from a 'dry weight' to an 'egg as eaten' basis (excluding shell), using the appropriate moisture contents. Two sets of calculations were made: (1) for all centres for the first three quarters and (2) for centres A, S and Y for all five quarters, and the results of the two were combined. The general means and means for each system, each centre and each quarter were extracted by the method of least squares with an iterative procedure to estimate missing values (Davies, 1956). System and centre means were expressed on an 'annual' basis to remove any seasonal effects due to the use of results for five quarters. Non-orthogonal analysis of variance was used to test the significance of the various effects (Davies, 1956) and differences between systems (or between centres or quarters) were examined by the 'multiple comparison' method (Scheffe, 1953). As it is thought that significance levels may have been overstated, only differences that were significant at the 1 % level ($P < 0{\cdot}01$) are called 'significant' in the following presentation of the results. In particular, it was not possible to calculate the statistical significance of system-by-centre interactions, and those mentioned here are empirically large rather than formally significant.

RESULTS

Effects of management systems

The results for all nutrients examined, in eggs from each system of management, are presented in Table 4, except for fatty acids and amino acids; the number of samples analysed is shown in Table 5. It can be seen that for most nutrients no significant differences between systems were detected.

Table 4. *Mean values for nutrient (per kg egg, edible weight†) in eggs under different systems of management‡*

Nutrient	BA	DL	FR
Moisture (g)	747	751	746
Fat (g)	109	107	111
Nitrogen (g)	19·7	19·6	19·8
Protein (N × 6·25) (g)	123	122	124
Cholesterol (mg)	4350	4480	4690
Ash (g)	9·3	9·1	9·2
Sodium (mg)	1390	1390	1360
Potassium (mg)	1350	1340	1380
Calcium (mg)	550*	510	510
Iron (mg)	20·6	19·3*	20·8
Thiamin (mg)	0·91	0·88	0·90
Riboflavin (mg)	4·7	5·0	4·5
Nicotinic acid (mg)	0·68	0·65	0·70
Nicotinic acid equivalents (mg)	37·4	33·9	35·7
Pantothenic acid (mg)	17	18	18
Folic acid			
(*Streptococcus faecalis*) (μg)	60*	100	90
(*Lactobacillus casei*) (μg)	250*	320	390
Vitamin B_{12} (μg)	17*	26*	29*
Tocopherols (total) (mg)	15	18*	15
Retinol (μg)	1400	1380	1450

* Differences between this and other systems significant at the 1 % level ($P < 0{\cdot}01$).
† A 2 oz. egg 'as purchased' has an edible weight of approximately 50 g.
‡ BA, battery; DL, deep litter; FR, free range.

Table 5. *Number of samples of eggs examined for system of management* means*

Nutrient	BA	DL	FR
Moisture, fat, nitrogen, cholesterol, riboflavin, folic acid (*Streptococcus faecalis* and *Lactobacillus casei*), vitamin B_{12}, tocopherols, retinol	68	49	32
Ash, sodium, potassium, iron, calcium	36	25	17
Nicotinic acid, thiamin, pantothenic acid, fatty acids	25	18	12

* BA, battery; DL, deep litter; FR, free range.

For the mineral constituents, only small differences in calcium and iron content were observed. Larger differences between systems were found with respect to the contents of some vitamins. Thus free range eggs contained 50 % more folic acid (*Streptococcus faecalis* assay) and folic acid (*Lactobacillus casei* assay) than battery eggs. However, for folic acid (*Streptococcus faecalis* assay), very large system-by-quarter and system-by-centre interactions were evident and some of the difference may therefore be a reflection of seasonal variations and other factors. The greatest differences were observed in the vitamin B_{12} contents; the highest level of 29 μg/kg was found in free range eggs and the lowest of 17 μg/kg in battery eggs. The tocopherol content of deep litter eggs was

Table 6. *Quarterly mean values (per kg egg, edible weight) for nutrients which showed a significant seasonal* pattern*

Nutrient	Q1+Q5	Q2	Q3	Q4
Riboflavin (mg)	4·3	4·7	4·7	5·5
Folic acid (*Lactobacillus casei*) (μg)	300	250	300	400
Vitamin B_{12} (μg)	23	23	27	23

* Q1, Jan.–Mar. 1967; Q2, Apr.–June 1967; Q3, Jul.–Sept. 1967; Q4, Oct.–Dec. 1967; Q5, Jan.–Mar. 1968.

significantly greater than that in free range and battery eggs, which did not differ statistically, but again a large system-by-centre interaction was evident.

Small differences were found in the average retinol contents of eggs from each system of management, but they were not significant. It is known that the amounts of biologically active carotenoids in eggs are fairly small (Grimbleby & Black, 1952) and they were not estimated in this study. For cholesterol content there were no significant general effects but the differences between systems varied considerably from centre to centre.

Effects of season

Variations in the composition of eggs over the year were found in the contents of some vitamins. Differences were evident for riboflavin, folic acid (*Lactobacillus casei* assay) and vitamin B_{12}. The results for these nutrients are shown in Table 6, in which means for quarters that did not differ significantly from each other have been averaged. Differences appearing in this table are therefore statistically significant.

The general tendency is for the concentrations of these three vitamins to be greater in the second half of the year. The highest, 5·5 mg riboflavin/kg egg, was obtained in the last quarter of the year, with concentrations of 4·7 mg in the second and third quarters and 4·3 mg in the first quarter. For folic acid (*Lactobacillus casei* assay) and vitamin B_{12} the highest concentrations were found in the fourth and third quarters respectively. The results for retinol showed a significant difference between the first and fifth quarters (January–March 1967 and 1968).

Effects of source of supply

The variations in the composition of eggs supplied by different centres were greater than those caused by system of management or season. The number of nutrients showing significant differences between centres was greater than the number showing significant differences between quarters. Differences between centres were often greater than differences between systems. The results for those nutrients which showed some significant differences are given in Table 7, in which means for centres that did not differ significantly from each other have been averaged. Differences appearing in this table are, therefore, statistically significant.

The major differences, with the exception of iron, were found only in the vitamin contents. For iron the mean for centres H, L and A was 19 mg/kg, which was significantly lower than the 21 mg found for centres Y, S and T.

Table 7. *Centre* mean values (per kg egg, edible weight) for nutrients which showed significant variation between centre*

Nutrient	Content in eggs at centre: A	H	L	S	T	Y
Moisture (g)	744	752	744	752	744	752
Nitrogen (g)	20	19·5	20	19·5	20	19·5
Iron (mg)	19	19	19	21	21	21
Thiamin (mg)	0·8	1	0·8	1	1	0·8
Pantothenic acid (mg)	14	14	20	20	20	20
Folic acid						
(*Streptococcus faecalis*) (μg)	40	90	90	40	90	120
(*Lactobacillus casei*) (μg)	320	320	320	180	320	450
Vitamin B_{12} (μg)	16	23	23	29	23	29
Tocopherols (mg)	16	19	16	16	16	12
Retinol (μg)	1500	1300	1400	1300	1300	1500

* See p. 187.

The mean thiamin content of eggs from centres H, S and T was significantly greater than for centres Y, L and A, the respective means being 1 mg and 0·8 mg/kg. For pantothenic acid the eggs from centres H and A contained 14 mg/kg compared with 20 mg for the other centres. The concentrations of folic acid and vitamin B_{12} again showed the greatest variation. In terms of folic acid (*Streptococcus faecalis* assay), the concentration for centre Y was three times as great as that for centres A and S; the concentrations for H, L and T were more than twice those for the latter centres. A similar but less pronounced pattern was observed for folic acid (*Lactobacillus casei* assay): the concentration for centre Y was 450 μg/kg and for centre S 180 μg/kg; for the other centres it averaged 320 μg/kg. The concentration of vitamin B_{12} in eggs from centres Y and S was 29 μg/kg, which was significantly greater than that of 23 μg/kg for H, L and T; the lowest value of 16 μg/kg was obtained for centre A.

The tocopherol concentration was some 50 % greater for centre H (19·0 mg/kg) than for centre Y (12 mg/kg). Concentrations at the other centres were between these values, about 16 mg/kg. For retinol, means for centres H, S and T (1300 μg/kg) were significantly less than the means for centres Y and A (1500 μg/kg).

Fatty acid composition of egg lipids

There was no significant difference in the fat content of eggs produced by battery, deep litter and free range systems of management, the general mean being 109 g fat/kg egg. Similarly there were no significant differences between systems, quarters or centres of production in the proportions of total fatty acids present as triglycerides or phospholipids in whole egg after freeze-drying. Based on the analyses of fifty-five samples, the general mean proportions of total fatty acids present in egg were 69 % as triglycerides and 31 % as phospholipids. Small variations between systems were detected in the proportion of different fatty acids present in the triglyceride fraction. Thus the triglycerides from deep litter eggs were found to contain 1 % less octadecadienoic acid (18:2) and 1 % more octadecenoic acid (18:1) than deep litter or free

Table 8. *Fatty acid composition of egg lipids under different systems of management**

(See Table 5 for numbers of samples)

	As % total triglycerides			As % total phospholipids		
Fatty acid	BA	DL	FR	BA	DL	FR
16:0	26·4	26·5	26·5	33·9	34·3	31·2
16:1	5·3	5·4	5·2	1·5	1·5	1·4
18:0	6·7	6·4	6·3	14·4	15·4	16·4
18:1	50·0	49·2	49·0	28·6	27·7	28·7
18:2	10·3	11·1	11·4	11·7	10·5	12·9
20:4 | 20:5	< 1	< 1	< 1	4·1	4·3	4·1
22:6	< 1	< 1	< 1	4·2	4·5	3·4
Other	1·3†	1·4†	1·6†	1·6‡	1·8‡	1·9‡

* BA, battery; DL, deep litter; FR, free range.
† Included some or all of 14:0, 14:1, 18:3, 20:1, 20:3, 20:4, 22:5 and 22:6.
‡ Included some or all of 14:0, 14:1, 18:3, 20:1, 20:3 and 22:5.

Table 9. *Amino acid (AA) composition of eggs under different systems of management**

(Mean values of duplicate estimates of bulked samples)

	g AA/kg edible wt			mg AA/g N		
Amino acid	BA	DL	FR	BA	DL	FR
Alanine	6·9	6·6	6·7	350	340	340
Arginine	7·5	7·6	7·5	380	390	380
Aspartic acid	13·3	13·0	13·2	680	660	670
Cystine	2·2	2·4	2·2	110	120	110
Glutamic acid	15·2	14·3	14·8	770	730	750
Glycine	3·9	3·8	3·8	200	190	190
Histidine	3·1	3·0	3·0	160	150	150
Isoleucine	7·0	6·7	6·7	360	340	340
Leucine	10·3	10·4	10·3	520	530	520
Lysine	7·7	7·9	7·8	390	400	390
Methionine	4·1	4·0	4·0	210	200	200
Phenylalanine	6·5	6·5	6·2	330	330	310
Proline	4·9	4·6	4·5	250	240	230
Serine	9·6	—	—	490	—	—
Threonine	6·2	6·6	6·0	320	340	300
Tryptophan	2·2	2·0	2·1	110	100	110
Tyrosine	4·8	5·0	4·9	250	260	250
Valine	9·3	9·0	9·2	470	460	470

* BA, battery; DL, deep litter; FR, free range.

range eggs. Slightly greater variations were observed in the phospholipid fraction, the free range eggs containing about 3 % less hexadecanoic acid (16:0) than either battery or deep litter eggs, but more octadecanoic (18:0) and octadecadienoic (18:2) acids than eggs from the other systems and more octadecenoic acid (18:1) than the deep litter eggs. However, none of these differences was statistically significant ($P < 0{\cdot}01$) and there were no significant differences in the essential fatty acid content of the triglyceride and phospholipid fractions that could be attributed to the time of year or source of eggs. The proportions of different fatty acids in each fraction are shown in Table 8.

Amino acid composition of egg protein

The mean amino acid compositions of the bulked samples of eggs from each system of management are given in Table 9.

DISCUSSION

Systems of management

The main finding of this survey was that there was very little difference in the chemical composition of eggs obtained from free range, deep litter and battery hens. As shown in Table 4, major differences were found only with respect to folic acid and vitamin B_{12}, and small but statistically significant variations were found in calcium, iron and tocopherol concentrations. In the majority of the published reports on the composition of eggs from hens kept under different systems of management (Coppock, Daniels, Gresham & Howard, 1962; Chen, Common, Nicolaiczuk & Macrae, 1965) the birds were fed on experimental diets rather than 'normal' commercial rations, which makes comparisons with this survey difficult. Nevertheless, where the information is comparable it is generally in agreement with our findings.

Krieg (1963) reported that iron concentrations were significantly higher in battery eggs (9·2 g/kg) than in deep litter (8·1 g/kg) and free range eggs (7·6 g/kg), although the general levels for all systems were very much higher than in the present survey. The increased iron concentrations in battery eggs may possibly arise from the ingestion of iron from parts of cages, feed troughs and water troughs. There are no direct comparisons in the literature of the calcium content of eggs from different management systems.

The findings of higher concentrations of vitamin B_{12} in the free range and deep litter eggs may possibly have resulted from an increased amount of this vitamin having been available for absorption from two sources: microbial synthesis within the birds themselves and also from litter or, for the free range birds, from the herbage and soil. Popov & Ševčenko (1961) reported that the mean amount of vitamin B_{12} in the litter over a period of months was 425·0 μg/kg and the mean vitamin B_{12} concentrations in the livers of birds kept on litter was almost twice that of those in cages, although there was no difference in the amounts of vitamin B_{12} in the egg yolks. A similar explanation might apply to the differences found in the folic acid contents of eggs from the different management systems. There is no apparent reason for the slightly higher tocopherol concentrations in deep litter eggs.

Although the main effects of systems as a whole on the cholesterol content of eggs were not significantly different, there were some differences at individual centres. However, it is known that a number of factors may affect the cholesterol content of eggs, such as age of bird (Jones, 1969), dietary cholesterol and fat (Hulett, Davies & Couch, 1964) and breed of bird (Edwards, Driggers, Dean & Carmon, 1960), and therefore it is not inconceivable that differences would be found in this experiment because of the variety of breeds and ages of birds and feeds used. The mean cholesterol values found in this study are slightly lower than those selected by Watt & Merrill (1963).

The absence of significant differences in the fatty acid composition of the eggs is

supported by Coppock & Daniels (1962), who in two experiments could find no differences in the fatty acid composition of free range, battery or deep litter eggs. Some conflicting observations made by Sinclair (1961) can perhaps be attributed to the interpretation of the term 'free range' as synonymous with 'farmyard hen'.

The fatty acid composition of both triglycerides and phospholipids shown in Table 8 agrees closely with the results of Marion, Woodroof & Cook (1965) and other published results. It appears that the fatty acid composition of eggs is a fairly stable component which may only be altered by major changes in the unsaturated fatty acid content of the diet.

The amino acid composition of egg protein did not appear to be affected by the management system. The results agree reasonably well with other published values (Block & Weiss, 1956; Karapetjan & Mikaeljan, 1959; McCance & Widdowson, 1960; FAO, 1970).

Season of the year

There was a general upward trend over the year in egg riboflavin concentrations, which may have been related possibly to the age structure of the flocks. The trends in folate and vitamin B_{12} concentrations tended to be more erratic. It might be postulated that the intake of these vitamins over the year may vary because of the large number of factors involved. Thus microbial synthesis of these vitamins in the gut, litter, herbage and soil organic matter may be subject to a wide range of influences, all of which may effectively alter in an irregular manner the amount available for absorption. The absence of seasonal effects for many constituents must in large measure be due to the uniformity of modern laying rations, which provide a fairly steady intake of practically all the required nutrients to the laying hen over the year.

Location

The greatest amount of variation in egg composition was found to occur between centres. This finding is not surprising in view of the differences in breeds, feeds, age of bird, and management factors at different centres.

In terms of thiamin content of eggs, Howes & Hutt (1956) observed differences between breeds. Arroyave *et al.* (1957) reported breed differences in egg composition with respect to thiamin, retinol and iron. Environmental temperature has been observed by Smith, Wilson & Brown (1954) to affect the mineral composition of eggs, and there is a wealth of evidence to show that egg composition varies within certain limits with diet (Cruickshank, 1940–1; Coppock & Daniels, 1962; Pankey & Stadelman, 1969).

It is clear that it would be of little value to attempt to interpret the locational effects found in this survey in terms of the factors mentioned, but it may suffice to emphasize that such variation must be commonplace, and the effects of feeding, breed and environment at different farms are probably responsible for much of the variation in the composition of eggs available to the consumer. System of management and seasonal effects probably play a relatively insignificant part.

Table 10. *Comparison of published values for the composition of eggs (per kg edible weight), with the results for battery eggs*

Nutrient	Battery eggs	McCance & Widdowson (1960)
Moisture (g)	747	734
Fat (g)	109	123
Nitrogen (g)	20	19
Protein (g)	123	119
Sodium (mg)	1390	1350
Potassium (mg)	1350	1380
Calcium (mg)	550	560
Iron (mg)	21	25
Thiamin (mg)	0·9	1·0
Riboflavin (mg)	4·7	3·5
Nicotinic acid (mg)	0·7	0·7
Pantothenic acid (mg)	17	13
Folic acid (*Lactobacillus casei*) (μg)	250	80*
Vitamin B_{12} (μg)	17	7
Tocopherols (mg)	15	20
Retinol (μg)	1400	3000†

* A derived value based on assays using *Streptococcus faecalis* and *Lactobacillus casei* after enzyme treatment; because of methodological differences the two values are not comparable.

† Vitamin A potency.

Chemical composition of eggs

Although the detailed information from a survey of this nature may to some extent be of limited value because of the lack of 'control' over many of the variables involved, the survey as a whole is in another sense of greater value than a more precise experiment in that it provides information on the composition of eggs as purchased by the consumer. For instance, much of the information in food composition tables relating to the vitamin content of eggs has been collated from a variety of studies of which many were more concerned with egg composition in relation to nutrition, breed or environment of the laying hen than with the composition of eggs sold to the consumer. Furthermore, many of the values are based on information obtained some years ago. Since then egg production techniques have changed considerably, and new methods of analysis which have greater precision and reliability are now available.

The composition of eggs shown in *The Composition of Foods* (McCance & Widdowson, 1960) is based primarily on analytical determinations made before 1940; the main exceptions are vitamins, for which values were derived from literature sources up to 1956. These values have therefore been compared in Table 10 with the results for battery eggs obtained in the survey. Battery eggs were chosen for comparison because they now represent more than 80% of eggs purchased by the consumer in this country.

For most nutrients, the values compare well, with only a few outstanding differences. The most important of these are the differences in vitamin A, riboflavin, folic acid and vitamin B_{12}. Published values for the vitamin A content of eggs show a wide range owing to the influence of diet and to some extent the use of different methods of determination. Cruickshank, Kodicek & Wang (1945) give the range of observed values for the vitamin A content of fresh eggs as 1200–4800 μg/kg, and McCance & Widdowson

Table 11. *Percentage contribution of 50 g egg to daily nutrient requirements*†

Subject	System of management‡	Protein	Calcium*	Iron*	Thiamin	Riboflavin	Nicotinic acid equivalent	Retinol equivalent	Vitamin B_{12}*§	Toco-pherols*§	Folic acid*§ (*L. casei*)
Child 2–3 years	BA	17·6	5·5	14·7	7·7	33·6	23·4	23·3	34·0	7·5	6·2
	DL	17·4	5·1	13·8	7·3	35·7	21·2	23·0	52·0	9·0	8·0
	FR	17·7	5·1	14·9	7·5	32·1	22·3	24·2	58·0	7·5	9·8
Moderately active man 35–65 years	BA	8·4	5·5	10·3	3·8	13·8	10·4	9·3	17·0	2·5	3·1
	DL	8·4	5·1	9·6	3·7	14·7	9·4	9·2	26·0	3·0	4·0
	FR	8·5	5·1	10·4	3·8	13·2	9·9	9·7	29·0	2·5	4·9
Moderately active woman 18–55 years	BA	11·2	5·5	8·6	5·1	18·1	12·5	9·3	17·0	3·0	3·1
	DL	11·1	5·1	8·0	4·9	19·2	11·3	9·2	26·0	3·6	4·0
	FR	11·3	5·1	8·7	5·0	17·3	11·9	9·7	29·0	3·0	4·9
Man over 65 years	BA	10·4	5·5	10·3	5·1	13·8	10·4	9·3	14·2	2·5	3·0
	DL	10·3	5·1	9·6	4·9	14·7	9·4	9·2	21·7	3·0	4·0
	FR	10·5	5·1	10·4	5·0	13·2	9·9	9·7	24·2	2·5	4·9

* Nutrients which showed significant differences between management systems.
† Based on the recommendations of the Department of Health and Social Security (1969).
‡ BA, battery; DL, deep litter; FR, free range.
§ Based on Recommended Dietary Allowances: National Research Council: Food & Nutrition Board (1968).

(1960) quote a value of 3000 μg/kg for the vitamin A potency of whole raw eggs. In the present survey the retinol content of the eggs was determined, and the values obtained were found to be in reasonable agreement with some published values for the preformed vitamin A content of eggs produced in this country (Cruickshank *et al.* 1945; Grimbleby & Black, 1950, 1952).

The higher concentration of riboflavin in the battery (and deep litter and free range) eggs found in this study was probably due to the present practice of fortifying poultry rations with riboflavin, which was not done in the 1950s.

Another major difference is in the folate content. This has arisen from recent improvements in analytical techniques. Since many naturally occurring folates are extremely labile, large losses can occur during extraction and assay unless protected from oxidation by ascorbate (Hurdle, Barton & Searles, 1968). Early assays were made without ascorbate and therefore values tended to be low. A recent FAO/WHO (1970) report has indicated that the folate content of food should be assessed in terms of the 'free' folate present. 'Free' folate is defined as the folate content available to *Lactobacillus casei* with ascorbate and without pretreatment with conjugase. *Streptococcus faecalis* responds to a smaller number of naturally occurring folic acid derivatives than *Lactobacillus casei* and so gives lower values in folic acid assays than those obtained with *Lactobacillus casei*.

Nutritional significance of the results

We have attempted to interpret the nutritional significance of these results by examining the extent to which the differences in composition discussed in this paper might affect the nutrient contribution of an egg to the recommended daily intakes of nutrients for different types of person as set out by the Department of Health and Social Security (1969). This is illustrated in Table 11. Recommendations have not been made in this country for folic acid, tocopherols or vitamin B_{12}; comparison has therefore been made with the (US) National Research Council: Food and Nutrition Board (1968) recommendations for these nutrients.

Eggs are good sources of vitamin B_{12} and folic acid and it is of importance that these two vitamins showed the greatest variation between management systems. Vitamin B_{12} occurs only in foods of animal origin and is not therefore freely available to vegetarians, and folic acid is reported to be particularly well absorbed from egg yolk (Hurdle *et al.* 1968). Estimates of the average daily intake of vitamin B_{12} in the diet can only be tentative, but dietary deficiency of this vitamin is exceedingly rare in this country.

Differences in egg composition due to management systems are of little nutritional significance in the context of a good mixed diet in this country. It can, however, be seen that the differences would be measurable for some nutrients, particularly vitamin B_{12} and folic acid, in the diets of some individuals.

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REFERENCES

Arroyave, G., Scrimshaw, N. S. & Tandon, O. B. (1957). *Poult. Sci.* **36**, 469.

Association of Official Analytical Chemists (1970). *Official Methods of Analysis of the Association of Official Analytical Chemists* 11th ed. Washington, DC: Association of Official Analytical Chemists.

Barton-Wright, E. C. (1961). *Lab. Pract.* **10**, 633.

Barton-Wright, E. C. (1962). *Lab. Pract.* **11**, 28.

Bird, O. D. (1963). In *Analytical Microbiology* p. 497 [F. Kavanagh, editor]. New York and London: Academic Press.

Block, R. J. & Weiss, K. W. (1956). *Amino Acid Handbook*. Springfield, Ill.: C. C. Thomas.

Callender, S. T. (1971). *Geron. Clin.* **13**, 44.

Chen, P. H., Common, R. H., Nicolaiczuk, N. & Macrae, H. F. (1965). *J. Fd Sci.*, **30**, 838.

Coppock, J. B. M. & Daniels, N. W. R. (1962). *J. Sci. Fd Agric.* **13**, 459.

Coppock, J. B. M., Daniels, N. W. R., Gresham, G. A. & Howard, A. N. (1962). *J. Atherosclerosis Res.* **2**, 139.

Cravens, W. W., Sebesta, E. E., Halpin, J. G. & Hart, E. B. (1943). *Poult. Sci.* **22**, 94.

Cruickshank, E. M. (1940–1). *Nutr. Abstr. Rev.* **10**, 645.

Cruickshank, E. M., Kodicek, E. & Wang, Y. L. (1945). *J. Soc. chem. Ind.* **64**, 15.

Davies, O. L. (editor) (1956). In *Design and Analysis of Industrial Experiments* 2nd ed., p. 236. Edinburgh: Oliver and Boyd.

Department of Health and Social Security (1969). *Rep. publ. Hlth med. Subj.* no. 120.

Edwards, H. M. Jr, Driggers, J. C., Dean, R. & Carmon, J. L. (1960). *Poult. Sci.* **39**, 487.

Eigen, E. & Schockman, G. D. (1963). In *Analytical Microbiology* p. 431 [F. Kavanagh, editor]. New York and London: Academic Press.

Exton-Smith, A. N. & Stanton, B. R. (1965). *Report of an Investigation into the Dietary Requirements of Elderly Women Living Alone*. King Edward's Hospital Fund for London.

FAO (1970). *Amino Acid Content of Foods and Biological Data on Proteins*. Rome: Food and Agriculture Organization.

FAO/WHO (1970). *Tech. Rep. Ser. Wld Hlth Org.* no. 452.

Grimbleby, F. H. & Black, D. J. G. (1950). *Br. J. Nutr.* **4**, 323.

Grimbleby, F. H. & Black, D. J. G. (1952). *Br. J. Nutr.* **6**, 393.

Hanson, S. W. F. & Olley, J. (1963). *Biochem. J.* **89**, 102P.

Howes, C. E. & Hutt, F. B. (1956). *Poult. Sci.* **35**, 1223.

Hulett, B. J., Davies, R. E. & Couch, J. R. (1964). *Poult. Sci.* **43**, 1075.

Hurdle, A. D. F., Barton, D. & Searles, I. H. (1968). *Am. J. clin. Nutr.* **21**, 1202.

Jones, D. (1968). *Nature, Lond.* **220**, 921.

Jones, D. (1969). *Nature, Lond.* **221**, 780.

Karapetjan, S. K. & Mikaeljan, N. G. (1959). *Dokl. Akad. Nauk SSSR* **126**, 200.

Krieg, R. (1961). *Arch. Geflügelk.* **25**, 207.

Krieg, R. (1963). *Arch. Geflügelk.* **27**, 93.

McCance, R. A. & Widdowson, E. M. (1960). *Spec. Rep. Ser. med. Res. Coun.* no. 297.

Marion, J. E., Woodroof, J. G. & Cook, R. E. (1965). *Poult. Sci.* **44**, 529.

Marion, W. W., Nordskog, A. W., Tolman, H. S. & Forsythe, R. H. (1963). *Poult. Sci.* **43**, 255.

Miller, R. L. (1967). *J. Sci. Fd Agric.* **18**, 381.

Ministry of Agriculture, Fisheries and Food: National Food Survey Committee (1973). *Household Food Consumption and Expenditure*: 1970–71. London: HM Stationery Office.

Moore, S. (1963). *J. biol. Chem*, **238**, 235.

National Research Council: Food & Nutrition Board (1968). *Publs natn. Res. Coun., Wash.* no. 1694

Orton, C. R. (1971). *Br. Poult. Sci.* **12**, 15.

Pankey, R. D. & Stadelman, W. J. (1969). *J. Fd Sci.* **34**, 312.

Petersen, C. F., Lampman, C. E. & Stamberg, O. E. (1947). *Poult. Sci.* **26**, 180.

Popov, A. A. & Ševčenko, T. G. (1961). *Ptitsevodstvo* **12** 11.

Romanoff, A. L. & Romanoff, A. J. (1949). *The Avian Egg*. London: Chapman and Hall.

Scheffe, H. (1953). *Biometrika* **40**, 87.

Sinclair, H. (1961). *Lancet* i, 225.

Skeggs, H. R. (1963). In *Analytical Microbiology* p. 551 [F. Kavanagh, editor]. New York and London: Academic Press.

Smith, A. H., Wilson, W. O. & Brown, J. G. (1954). *Poult. Sci.* **33**, 898.

Stoffel, W., Chu, F. & Ahrens, E. H. Jr (1959). *Analyt. Chem.* **31**, 307.

Tsen, C. C. (1961). *Analyt. Chem.* **33**, 849.

Watt, B. C. & Merrill, A. L. (1963). *Composition of Foods: Agriculture Handbook* no. 8. Washington, DC: Agricultural Research Service, United States Department of Agriculture.

Printed in Great Britain