PLATE 2

1. Dorsal view of body in abdominal region. The relative positions of the proventriculus, gizzard and intestines are clearly outlined.
2. View of caecums injected with barium sulphate mash. The caecums were injected with barium sulphate mash via the rectum. Note the constriction at the junction of the caecums and rectum with the small intestine, and the constricted proximal portions and dilated distal portions of the caecums.

The Requirements of Poultry for Aneurin, Choline, Folic Acid, Nicotinic Acid, Pantothenic Acid and Riboflavin

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An assessment of the adequacy of vitamin supplies in rations for any class of stock requires information of two kinds: (1) the quantities of the different vitamins in feeds, and (2) the requirements of the animals of the class in question for these vitamins. Information on these two categories is given below.

The data for the vitamin content of common poultry feeding-stuffs have been collected from recent literature. These are given in Tables 1 and 2. Where individual values are not given, either data could not be found or the values reported were too inconsistent for an average value to be reliable.

Information about the vitamin needs of baby chicks is extensive. The requirements of growing and adult birds are less well known. The differences in requirements for producing hatching eggs, as compared with table eggs, have not been extensively studied. Few workers have extended their investigations beyond the question of hatchability to include studies of the effect of vitamin levels in the hen's diet upon viability and vigour of the chicks.

Standards of vitamin requirements of poultry were first put forward by a committee of the (U.S.A.) National Research Council (Committee on Animal Nutrition, 1944). A revision recently appeared (Bird, 1948). The recommended allowances are given in Table 3. The original values included a 20% margin of safety above estimated adequacy. This has been subtracted in compiling the present table. There were several omissions in the original table; some of these have been filled by values secured from the recent literature, a survey of which follows.

Recent work on vitamin requirements of poultry

Aneurin. There has been no recent report on the requirements of poultry for aneurin.

Choline. Only the chick seems to require a dietary source of choline; in older birds synthesis occurs. Hens given a semi-synthetic diet containing only 0·04% choline had an output of choline in eggs of four or five times the intake (Ringrose & Davis, 1946). When a natural diet, extracted with boiling neutral ethanol to reduce the choline content to 0·03%, was given, egg production and hatchability were only slightly less than in birds receiving the same diet supplemented with choline to raise the level to 0·21% (Lucas, Norris & Heuser, 1946).

Folic acid. Maximum growth at 4–6 weeks of age was obtained with diets containing 0·045 mg. folic acid/100 g. Haemoglobin formation was normal in 4-week-old chicks

Table 1. *Aneurin, choline and folic acid content of common poultry feeding-stuffs*

(mg./100 g.)

Feeding-stuff	Aneurin		Choline		Folic acid	
	Value	Reference*	Value	Reference*	Value	Reference*
Cereals						
Barley, whole and ground	0·40	36, 43	114	14, 18	0·06	35
Maize, white, whole and ground	—	—	—	—	—	—
Maize, yellow, whole and ground	0·54	22	45	14, 44	0·03	35
Oats, whole, crushed and ground	0·39	27, 43	98	14, 18, 44	0·02	35
Wheat, whole and ground	0·40	20, 26, 41, 43	80	14, 18	0·04	35
Cereal by-products						
Wheat bran	0·82	28, 29	124	14, 18	0·21	35
Wheat germ	2·26	6, 28	332	14, 18	0·09	35
Wheat middlings	1·79	28, 29	—	—	—	—
Wheat shorts	1·66	28, 29	149	14, 18	—	—
Wheat offals, coarse, U.K.	0·59	6, 31	—	—	—	—
Wheat offals, fine, U.K.	1·20	6, 31	—	—	—	—
Legumes						
Beans, mixed	0·72	11	—	—	—	—
Cowpeas	0·58	21	—	—	—	—
Peas, split and meal	0·97	21	160	44	—	—
Oilcake meals						
Coconut	—	—	—	—	—	—
Ground-nut	—	—	200	13, 14	—	—
Linseed	—	—	—	—	0·32	35
Sesame	—	—	—	—	—	—
Soya-bean	—	—	275	13, 14, 38, 44	0·77	35
Animal products						
Blood, dried	—	—	—	—	—	—
Buttermilk, dried	—	—	—	—	—	—
Fish meal	—	—	—	—	Nil	35
Fish meal, white	—	—	—	—	—	—
Herring meal	—	—	440	44	—	—
Meat meal	—	—	160	44	—	—
Meat-and-bone meal	—	—	229	38	0·16	35
Milk, skimmed, dried	—	—	—	—	0·06	35
Pilchard meal	—	—	380	44	—	—
Whey, dried	—	—	—	—	0·09	35
Miscellaneous						
Lucerne meal	0·25	15	100	44	1·13	35
Lucerne-leaf meal	—	—	125	14, 38	0·60	35
Potatoes, raw	0·15	45	—	—	0·05	42
Yeast, baker's, dried	—	—	—	—	—	—
Yeast, brewer's, dried	—	—	375	13	4·00	35

* The numbers refer to the References for composition of feeds on pp. 260–1.

on diets containing 0·045 mg., and 6-week-old chicks required only 0·035 mg./100 g. For normal feathering at least 0·044 mg./100 g. diet was needed (Robertson, Daniel, Farmer, Norris & Heuser, 1946). Lillie & Briggs (1947*a*) considered that 0·150 mg./

100 g. was necessary for normal growth and 0·200 mg./100 g. for normal feathering. Hutchings, Oleson & Stokstad (1946) found that between 0·050 and 0·100 mg./100 g.

Table 2. *Nicotinic acid, pantothenic acid and riboflavin content of common poultry feeding-stuffs*

(mg./100 g.)

Feeding-stuff	Nicotinic acid		Pantothenic acid		Riboflavin	
	Value	Reference*	Value	Reference*	Value	Reference*
Cereals						
Barley, whole and ground	7·0	23, 25, 34, 37	0·86	3, 32	0·13	1, 17, 33, 36
Maize, white, whole and ground	2·6	34	—	—	0·12	1, 5
Maize, yellow, whole and ground	2·3	23, 30, 34	0·79	3, 12, 32	0·11	1, 5, 17, 33
Oats, whole, crushed and ground	1·2	23, 34, 37, 46	0·97	3	0·13	1, 17, 33, 36
Wheat, whole and ground	6·1	23, 25, 34, 37	0·95	3, 12, 32	0·12	1, 17, 36
Cereal by-products						
Wheat bran	29·0	23, 34	2·48	3, 32	0·30	1, 5, 17, 33
Wheat germ	4·2	34	0·70	32	0·55	17
Wheat middlings	13·0	23, 34	1·28	3, 32	0·40	8
Wheat shorts	—	—	1·36	3	0·28	1, 33
Wheat offals, coarse, U.K.	29·4	2, 31	—	—	0·29	31
Wheat offals, fine, U.K.	16·3	2, 31	—	—	0·34	31
Legumes						
Beans, mixed	2·2	11	—	—	0·18	11, 33
Cowpeas	2·2	7, 19, 34	1·80	32	0·16	19
Peas, split and meal	3·3	19, 34	2·10	32	0·17	19, 33
Oilcake meals						
Coconut	—	—	<0·10	32	0·60	5
Ground-nut	—	—	5·30	32	0·30	5, 33
Linseed	5·1	23, 34, 47	<0·10	32	0·26	17, 33
Sesame	—	—	0·60	32	0·44	5, 33
Soya-bean	3·1	23, 34	1·40	3, 32	0·28	17, 33
Animal products						
Blood, dried	2·7	47	<0·12	32	0·05	17
Buttermilk, dried	1·7	23	4·20	3, 32	3·47	5, 9, 16, 33
Fish meal	—	—	0·93	3	0·51	5, 9, 17, 33
Fish meal, white	—	—	—	—	0·74	9, 17, 23
Herring meal	—	—	—	—	0·92	4
Meat meal	—	—	0·10	3	0·46	17
Meat-and-bone meal	6·6	23	—	—	—	—
Milk, skimmed, dried	1·8	23, 40	3·25	3, 32	2·30	1, 9, 10, 16, 33
Pilchard meal	—	—	—	—	—	—
Whey, dried	2·6	40	4·63	3, 32	2·00	9, 10, 16, 33
Miscellaneous						
Lucerne meal	3·4	34, 47	3·04	3, 32	1·21	24, 33, 34
Lucerne-leaf meal	5·3	23	—	—	1·62	9, 24, 33
Potatoes, raw	—	—	0·65	32	0·03	39
Yeast, baker's, dried	45·0	47	—	—	—	—
Yeast, brewer's, dried	50·0	7, 47	6·28	3	3·60	17

* The numbers refer to the References for composition of feeds on pp. 260–1.

diet was needed to give growth and haemoglobin formation comparable with those of chicks receiving a commercial ration fortified with dried whole liver, dried brewer's

yeast and cerophyl (dried powdered mixture of young leaves of wheat, oats and barley, manufactured by Cerophyl Laboratories, Kansas City, Missouri). Mills, Cottingham & Taylor (1947) found that the highest haemoglobin levels were obtained when the diet contained 0·050–0·100 mg./100 g., although they found only a slight improvement in growth when levels above 0·010 mg./100 g. were given. Cravens & Halpin (1949) considered that chick rations not favouring intestinal synthesis of folic acid, e.g., those rich in sugars, should contain between 0·050 and 0·100 mg./100 g.

Table 3. *Aneurin, choline, folic acid, nicotinic acid, pantothenic acid and riboflavin requirements of poultry at different stages of growth and laying*

(mg./100 g. feed)

	Young bird		Adult bird	
Vitamin	0–8 weeks	8–18 weeks	Laying	Breeding
Aneurin	0·17	—	—	—
Choline	128	—	(30–40)*	(30–40)*
Folic acid	(0·05–0·10)*	—	(0·012)*	(0·025)*
Nicotinic acid	1·47	—	—	—
Pantothenic acid	0·92	—	0·46	0·92
Riboflavin	0·29	0·17	0·17	0·24

* Values in parentheses added from the literature; remainder of values from Bird (1948).

Egg production was normal on rations containing 0·012 mg./100 g., although the requirement for normal hatchability appeared to be somewhat higher (Taylor, 1947). Cravens & Halpin (1949) suggested that not more than 0·025 mg./100 g. is necessary for normal hatching, and Schweigert, German, Pearson & Sherwood (1948) found that less than 0·042 mg./100 g. was enough.

An antagonism between folic acid and *p*-aminobenzoic acid was observed by Lillie & Briggs (1947*b*), who found that the advantages gained when folic acid was added to a synthetic ration were partly lost when *p*-aminobenzoic acid was also added.

Nicotinic acid. There has been no recent work on the requirements of poultry for nicotinic acid under feeding conditions approaching normal. Various workers have studied the increase in the nicotinic acid requirement of chicks receiving rations rich in maize or gelatine. In extreme cases the nicotinic acid requirement of the chick may be raised to at least 5 mg./100 g. diet, and bone ossein produces nicotinic acid deficiency in laying hens, with loss of weight, reduced egg production and low hatchability (Briggs, Groschke & Lillie, 1946).

Nicotinic acid deficiency was observed with a 'commercial ration' containing 55% maize and 34·5% soya-bean meal (Berry, Carrick, Roberts & Hauge, 1943).

Pantothenic acid. The requirement of hens for normal egg production was not over 0·15 mg./100 g. diet, but at least 0·800 mg./100 g. was required to sustain normal hatchability and to secure chicks of high viability with good growth rates (Gillis, Heuser & Norris, 1948).

Riboflavin. Bolton (1947) found that the amount of riboflavin required for good growth in chicks was 0·30–0·35 mg./100 g. diet, and that 0·36 mg./100 g. prevented

curled-toe paralysis. These values are slightly above those given in Table 3, perhaps because chicks depleted of riboflavin were used in the test.

Battery-kept yearling pullets showed rises in tissue levels of riboflavin as increasing amounts of the vitamin were given (Stamberg, Petersen & Lampman, 1947). There was little increase in tissue riboflavin at dietary levels above 0·51 mg./100 g. Artificially inseminated birds in batteries required 0·36 mg./100 g. diet for normal hatchability of eggs. Raising the intake to 0·51 mg./100 g. feed did not improve hatchability, but the quality of the chicks was better (Petersen, Lampman & Stamberg, 1947*b*). The highest percentage transfer of dietary riboflavin to eggs (39%) took place at an intake level of 0·36 mg./100 g. diet, and above 0·51 mg./100 g. the total transfer was but little greater (Petersen *et al.* 1947*a*).

Special factors conditioning vitamin provision for poultry

Storage losses in feeding-stuffs. Under normal conditions of storage, losses of water-soluble vitamins seem unlikely. Ground and unground samples of cereals, legumes, hays and lucerne-leaf meals were stored individually in the dark at 25° for 1 year without loss of aneurin, biotin, nicotinic acid or pantothenic acid (Lardinois, Elvehjem & Hart, 1944). There was no loss of choline from poultry mashes stored for 6 months (Cooley & Christiansen, 1948). Exposure of mashes to direct sunlight for 2 weeks caused only small losses of riboflavin (Stamberg & Petersen, 1946).

Environmental factors affecting requirement. Under experimental conditions simulating the insular tropics—temperatures of 90–91° F. and relative humidities of 60–70%—the aneurin requirement of chicks up to 5 weeks of age was raised from 0·10 to 0·30 mg./100 g. diet. The requirements for folic acid, nicotinic acid, pyridoxin and choline were not altered (Mills *et al.* 1947).

Genetic factors affecting requirement. White Leghorn chicks required less aneurin than Rhode Island Red chicks, whose needs were met by feeds containing 0·120 mg./100 g. (Lamoreux & Hutt, 1939).

Breed differences also exist in the amount of aneurin transmitted in the egg. Under comparable conditions White Leghorns laid eggs containing 0·105 mg./100 g. contents, whereas those laid by Rhode Island Reds and Barred Plymouth Rocks contained 0·064 and 0·066 mg./100 g. respectively (Scrimshaw, Hutt & Scrimshaw, 1945).

By means of selection over six generations Lamoreux & Hutt (1948) produced a strain of White Leghorns less susceptible to riboflavin deficiency. The resistant strain was poor by commercial standards.

Lillie & Briggs (1947*a*) obtained a poorer response from White Leghorn than from New Hampshire chicks in growth tests to determine the adequacy of a given level of folic acid.

Droppings as a source of vitamins. The riboflavin content of droppings increased by about 100% during 24 hr. at room temperature. The increase was about 300% in 1 week (Lamoreux & Schumacher, 1940). The organism responsible was isolated (Schumacher & Heuser, 1941). It seems possible that droppings may contribute small amounts of riboflavin to the hen's diet, so that moderate deficiencies in the ration may

be rectified. These findings probably explain the higher levels of riboflavin requirement as compared with the values in Table 3, found by Petersen and co-workers (cited above).

Vitamin adequacy of present-day poultry rations

Fifteen poultry rations—five each of starting, growing and laying mashes—were constructed to comply with the regulations of the Ministry of Food governing the composition and ingredients of poultry feeds [The Feeding Stuffs (Regulation of

Table 4. *Vitamin content of five National Baby Chick Food rations complying with Ministry of Food regulations*

(mg./100 g. feed)

Ration no.	Aneurin	Choline	Folic acid	Nicotinic acid	Pantothenic acid	Riboflavin
1	0·56	116	0·079	6·76	1·09	0·36
2	0·60	120	0·086	6·78	1·11	0·38
3*	0·59	127	0·180	7·65	1·14	0·38
4*	0·55	115	0·132	6·40	1·17	0·40
5*	0·57	124	0·159	7·79	1·18	0·41
Requirement†	0·17	128	(0·05–0·10)	1·47	0·92	0·29

* Containing dried brewer's yeast. † See Table 3.

Table 5. *Vitamin content of five National Poultry Food No. 2 (Growing Mash) rations complying with Ministry of Food regulations*

(mg./100 g. feed)

Ration no.	Aneurin	Choline	Folic acid	Nicotinic acid	Pantothenic acid	Riboflavin
1	0·66	128	0·102	8·87	0·98	0·24
2	0·62	114	0·088	7·01	0·92	0·23
3	0·66	115	0·112	8·30	0·93	0·25
4	0·68	113	0·095	7·86	1·19	0·23
5*	0·63	120	0·237	7·90	1·21	0·37
Requirement†	—	—	—	—	—	0·17

* Containing dried grass and dried brewer's yeast. † See Table 3.

Manufacture) Order, 1948 (Amendment Order 1948)]. The five rations constructed for each type of mash were such that at least one of the rations could have been made up during the last 2 years, according to the Cereal Coupon Split in force. The vitamin contents of the rations are given in Tables 4, 5 and 6, together with appropriate standards of requirements taken from Table 3.

The comparisons given below relate to birds fed exclusively on the appropriate mashes. Where stock has access to grass runs and can prey upon the lesser fauna the conclusions drawn may not be valid.

Starting mashes (Table 4). The margin of safety is greatest for aneurin and nicotinic acid; the supplies are three to five times the requirement. The supply of folic acid in the mashes is well above the lower limit—0·05 mg./100 g. diet. Rations containing dried brewer's yeast are above the upper limit. Both riboflavin and pantothenic acid

are present in amounts sufficient to provide margins of safety of about 20–40%. Choline alone is at the borderline level of requirement.

Growing mashes (Table 5). It is difficult to evaluate the adequacy of the vitamin provision of the rations in the absence of reliable standards of requirements for growing birds. The rations provide amounts of the different vitamins closely similar to those of the starting mashes, except for riboflavin of which the provision is about one-third less.

Table 6. *Vitamin content of five National Poultry Food No.* 1 (*Laying Mash*) *rations complying with Ministry of Food regulations*

(mg./100 g. feed)

Ration no.	Aneurin	Choline	Folic acid	Nicotinic acid	Pantothenic acid	Riboflavin
1	0·60	106	0·087	6·97	0·95	0·22
2	0·66	110	0·106	7·46	0·73	0·25
3	0·66	122	0·094	7·78	1·08	0·25
4*	0·60	132	0·299	9·04	1·28	0·42
5*	0·69	134	0·249	8·97	1·31	0·39
Requirement†						
Laying	—	(30–40)	(0·012)	—	0·46	0·17
Breeding	—	(30–40)	(0·025)	—	0·92	0·24

* Containing dried grass and dried brewer's yeast. † See Table 3.

Since adult birds laying eggs for eating purposes require less of the vitamins under consideration per 100 g. feed than chicks, it seems unlikely that the vitamin provision is inadequate. For riboflavin, where the requirement is known, a margin of safety of about 50% is provided.

Laying mashes (Table 6). Although no information is available about the requirements for aneurin and nicotinic acid, it is unlikely that risks of deficiency exist. The amount of nicotinic acid present is well above the lower limit of 5 mg./100 g. feed recommended for experimental chick rations prone to produce deficiency through their high content of maize and gelatine. Choline and folic acid are present in amounts well above requirements. Pantothenic acid is present with an ample margin of safety for birds laying eggs for eating; for breeding stock one ration is borderline and one is deficient. All rations are adequate in riboflavin for birds laying eating eggs. For breeding stock the provision of riboflavin is marginal, except in cases where dried grass and dried brewer's yeast are included in the ration.

SUMMARY

1. A compilation of data on the amounts of certain vitamins in some common poultry feeding-stuffs is given.

2. Information on vitamin requirements to supplement the (U.S.A.) National Research Council's standards is presented.

3. The adequacy of the vitamin content of typical poultry rations complying with Ministry of Food regulations has been assessed.

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The Fat-Soluble Vitamins in Poultry Nutrition

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Historical introduction

The importance of most of the fat-soluble vitamins in poultry nutrition has been recognized for a long time. A considerable amount of work has been done to establish the requirements of poultry for these vitamins under different conditions.

Vitamins A and D

Sugiura & Benedict (1923) carried out experiments with pigeons from which they concluded that 'fat-soluble vitamine is not essential in any stage of avian nutrition'. This unjustified statement was immediately challenged by Emmett & Peacock (1923), who showed that unless vitamin A was included in the diet of growing chicks they died, with lesions of the eye and renal deposits of urates, young chicks being more susceptible to the deficiency than older ones. This work was confirmed in a series of experiments by Hart, Steenbock, Lepkovsky & Halpin (1923, 1924).

In the same experiments the need of chicks for vitamin D also became apparent. Hart, Halpin & Steenbock (1920) produced 'leg weakness' in chicks by feeding a synthetic diet, and were unable to cure it with green vegetables. Two years later the same authors (Hart *et al.* 1922) concluded that factors present in cod-liver oil were needed to prevent rickets in the growing chick. The following year Hart, Steenbock, Lepkovsky & Halpin (1923) realized the importance of sunlight for birds deprived of the antirachitic vitamin, but it was not until some years later that the inefficient utilization of some forms of vitamin D by poultry was recognized (Mussehl & Ackerson, 1930).

Vitamin E

The first work on the role of vitamin E in poultry nutrition came from Card (1928), who studied it in hens in connexion with fertility and hatchability. As vitamin E is so