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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

widely distributed in cereal grains, he had difficulty in devising a diet deficient in it, until he actually destroyed the vitamin E of natural diets by treating them with ferric chloride (cf. Waddell & Steenbock, 1928). He was then able to demonstrate quite clearly that vitamin E (supplied as wheat-germ oil) was essential for egg production and hatching. Its importance for growing chicks was not recognized until nearly 10 years later, when Pappenheimer, Goettsch & Jungherr (1937) cured nutritional encephalomalacia or so-called 'crazy chick disease' by administration of wheat-germ oil.

Vitamin K

The history of vitamin K is more recent; the first reports of an antihaemorrhagic vitamin for chicks came about 15 years ago. Dam (1934), working on sterol metabolism, encountered in chicks receiving artificial diets a condition resembling scurvy which was not cured by administration of lemon juice, but was prevented by the feeding of cereals. He postulated that cereals contain an antihaemorrhagic factor, for which he coined the name vitamin K (*Koagulationsvitamin*). Its effect on the clotting time of chick blood formed the basis of methods of biological assay by which its identification and synthesis were followed (Almquist & Stokstad, 1935 *a*, *b*; Dam, Geiger, Glavind, Karrer, Karrer, Rothschild & Salomon, 1939; Almquist & Klose, 1939).

Requirements

It is well known that the requirement of an animal for any given vitamin, and the fat-soluble vitamins are no exception, may vary according to circumstances. This problem was considered at length at a previous meeting of The Nutrition Society, where Harris (1948–9), Meunier (1948–9) and Moore (1948–9) discussed requirements for the fat-soluble vitamins.

Rigid norms cannot be fixed for the requirements of poultry for vitamins A, D, E and K, but amounts covering their needs under most practical conditions and allowing a good margin of safety can be suggested. Such allowances have been recommended by the (U.S.A.) National Research Council (Committee on Animal Nutrition, 1944) and some of these figures are included in Tables 1 and 2.

Vitamin A

The symptoms of severe vitamin A deficiency are very characteristic. In young birds growth and feather production are poor, susceptibility to infection is increased and the mucous membranes become keratinized. Death occurs within a few weeks, and deposits of urates are usually found in the kidneys. In older birds the syndrome is similar, and in addition there is a mucous discharge from the mouth, eyes and nostrils, a condition known as 'nutritional roup'; the interior of the mouth may become studded with pustules. Hatchability and egg production are reduced.

Vitamin A can be utilized by poultry either as the vitamin itself or as its active provitamins. The relative efficiency of carotene and vitamin A in poultry feeds has been the subject of many experiments, and opinion on the matter is still divided. In evaluating such experiments, account must be taken of the relative instability of pre-

formed vitamin A in poultry mashes as compared with its precursors, especially as present in natural feeding-stuffs such as grass meal or maize. It is possible that the claims that chicks utilize carotene more satisfactorily than vitamin A are connected with this instability. Vitamin A is considerably more stable in poultry feeds if the diet also includes natural anti-oxidants such as are present in cereal grains; its stability is reduced in the presence of oxidizing agents, e.g. rancid fats.

Table 1 summarizes the recommended allowances of vitamin A (or carotene) for poultry and the approximate vitamin A content of various feeding-stuffs.

Table 1. *Vitamin A in the nutrition of poultry*

Requirements* (i.u./lb. food)		Sources: As carotene (μg./g.)		Sources: As vitamin A (i.u./g.)
Starting chicks	2000	Dried-grass meal or lucerne	200–400	Cod-liver oil 400 or 800
Growing chicks	2000	Carrots	100–150	(as at present available
Laying hens	3300	Maize†	7	in this country)
Breeding hens	3300			Herring meal‡ variable
Starting poults	4000			
Growing turkeys	4000			

* Committee on Animal Nutrition (1944). In stating these values, no distinction is made between vitamin A and its provitamins.

† Kuhn & Grundmann (1934).

‡ Based on values for fresh herrings given by Bacharach, Cruickshank, Henry, Kon, Lovern, Moore & Morton (1942).

Vitamin D

Deficiency of vitamin D in young chicks results in poor growth and rickets; the skeleton is not properly calcified, the bones become deformed and the beak is softened. In adult birds the deficiency is less obvious, but softening of the skeleton occurs, egg production is reduced, and soft-shelled eggs may be laid. Abnormal blackening of the feathers on diets low in vitamin D has been reported by Glazener, Mattingly & Briggs (1946) and confirmed by McGinnis, Kosin & Decker (1947). Glazener & Briggs (1948) suggest that this abnormal feather pigmentation is peculiar to certain breeds.

In the presence of sunlight, poultry, like other animals, can synthesize vitamin D, and acute deficiency is encountered only under intensive conditions. It is a striking fact that, unlike mammals, birds use vitamin D_2 very inefficiently, so that irradiated vegetable sterols are of little use in poultry feeding. It was the reported inefficiency of irradiated ergosterol in preventing leg weakness in chicks (Mussehl & Ackerson, 1930) that led Waddell to undertake a series of experiments which culminated in his discovery (Waddell, 1934) that the products of irradiation of cholesterol were different from those of ergosterol. It is more than likely that the recognition of vitamin D_3 would have been delayed for many years but for this difference in response to vitamin D_2 between birds and mammals.

An interesting suggestion made by Hou (1928, 1931) that the preen gland of chickens is essential for the utilization of vitamin D, and that a precursor of the vitamin present in the gland becomes activated by sunlight when rubbed over the body and feathers during preening, was not confirmed by the experiments of Knowles, Hart & Halpin

(1935). On the basis of work by Koch & Koch (1941), who found no provitamin D in the feathers or preen glands of pullets, but considerable amounts in the skin of the legs and feet, Ewing (1947) suggests that ultraviolet illumination from above is less efficient as an antirachitic agent than when directed at the legs and feet.

The requirements of poultry for vitamin D in the absence of sunlight vary with the Ca : P ratio of the diet, with the form of the phosphorus in the diet and with the source of the vitamin D. Dols (1936), Couch, Fraps & Sherwood (1937), and Nowotarski &

Table 2. *Vitamin D in the nutrition of poultry*

Requirements (A.O.A.C. units*/lb. food)		Sources	
Starting chicks	180†	Cod-liver oil	50–100 B.S.I. u./g.
Growing chicks	180†	(as available at present in this country)	
Laying hens	450†	Herring meal‖	Variable
Breeding hens	450†	White-fish meal	Variable
Starting poults	800†	Various commercial concentrates of vitamin D_3, usually containing about 1000 B.S.I. u./g.	
Growing turkeys	800†		
Breeding turkeys	800†		
Ducklings	150‡§		

* Association of Official Agricultural Chemists (1940).

† Committee on Animal Nutrition (1944). There is evidence (Bruce, Kon, Broom & Harmer, 1947) that the A.O.A.C. unit is smaller than the B.S.I. unit.

‡ Estimate based on work by Olsson (1942); Motzok, Graham, Branion & Slinger (1946); Black & Coates (1948).

§ B.S.I. units (British Standards Institution—Specification no. 911, 1940).

‖ Based on values for fresh herrings given by Bacharach *et al.* (1942).

Bird (1943) have all presented evidence that chicks can be raised to at least 12 weeks of age without vitamin D, provided the calcium and phosphorus content of the diet is high and the Ca : P ratio favourable. A reduced requirement of turkey poults for vitamin D has been reported (Mussehl & Ackerson, 1935; Evans & Brant, 1945), with high dietary levels of calcium and phosphorus. There have been reports by Bird (1944) and Boucher (1944) that irradiated animal sterols are more effective than cod-liver oil for promoting calcification in turkey poults when compared on an equal A.O.A.C. chick unit basis (Association of Official Agricultural Chemists, 1940). Although evidence is conflicting on the utilization of organically combined phosphorus by poultry, it is possible that some forms of vitamin D render organic phosphorus more readily available to the poult than does the vitamin D of cod-liver oil.

Preliminary experiments in this laboratory suggest that the inclusion of large quantities of yeast in the diet of chicks has a markedly rachitogenic effect similar to that reported for pigs by Braude, Kon & White (1943).

Vitamin D_3 is relatively stable when incorporated in poultry mashes. The recommended allowances of vitamin D, its sources and occurrence in feeds are given in Table 2.

Vitamin E

The widespread presence of vitamin E in cereal grains makes a deficiency of this vitamin very unlikely under practical conditions, unless some antagonist is included in the diet. Experiments have shown that, although a deficiency of vitamin E does not

affect egg production, the vitamin is essential for good hatchability, and embryos from vitamin E-deficient hens usually die within 2 or 3 days. Cocks have been kept for over a year on a diet deficient in vitamin E without losing fertility (Adamstone & Card, 1934), although histological examination revealed degenerative changes in the testes of some birds. In an extensive monograph on the subject, Pappenheimer *et al.* (1939) described the symptoms in young birds of a deficiency of vitamin E. There is a marked species difference. In chicks, lesions in the cerebellum result in nutritional encephalomalacia or 'crazy chick disease'. The birds are subject to ataxia and spasmodic convulsions followed by death. In ducklings the lesions are in the skeletal muscles, resulting in extreme weakness, the so-called 'nutritional myopathy'. In turkey poults the lesions are confined to the smooth muscle of the gizzard. Dam & Glavind (1938, 1939, 1940) and Bird & Culton (1940) report a generalized oedema, particularly of the heart and pericardium, as a result of vitamin E deficiency in chicks. However, Dam & Glavind (1942) and Bird (1943) found that this condition of 'exudative diathesis' could be influenced by dietary changes independent of vitamin E.

Vitamin E is relatively stable in mashes except in the presence of rancid fats. No definite requirements of poultry for vitamin E have been recorded in the literature, and there is ample evidence (Branion, Motzok, Slinger & Pettit, 1947) that addition of preparations of vitamin E to practical layers' or breeders' mashes is without beneficial effect on fertility, hatchability or onset of sexual maturity. In synthetic experimental diets for chicks, however, it is customary to include about 0·3 mg. α-tocopherol/100 g. diet. The inclusion of vitamin E in diets, particularly in diets containing lard, may assist the utilization of vitamin A (Patrick & Morgan, 1944). There is evidence that cod-liver oil may interfere with the proper utilization of vitamin E (Hammond, 1941) and reported outbreaks of nutritional encephalomalacia on poultry farms may have been due to an over-generous supply of cod-liver oil in the diets.

Vitamin K

A severe lack of vitamin K is also rarely encountered in practice owing to its presence in many common feeding-stuffs, particularly green feeds. Deficiency results in a clotting time of the blood much in excess of the normal, and very severe haemorrhage may follow quite minor injuries. In rare conditions, the absorption of vitamin K may be hindered or prevented by, for instance, biliary obstruction or damage to the intestinal mucosa. Almquist & Stokstad (1936*a*) found vitamin K in the droppings of chicks raised on a diet free from vitamin K. From this they concluded that it is synthesized by intestinal micro-organisms, but whether any becomes available to the bird without actual ingestion of the droppings is doubtful. Cravens, Randle, Elvehjem & Halpin (1941) reported that unless adequate vitamin K was present in the diet of breeding hens their chicks suffered from vitamin K deficiency. The inclusion of 1% dried cereal grass or 2% lucerne meal in the hens' diet enabled them to produce normal chicks.

The anti-gizzard-erosion factor

In his early work on vitamin K, Dam (1935) described gizzard ulcers in chicks as part of the syndrome of vitamin K deficiency. The following year, however, Almquist

& Stokstad (1936*b*) found that materials which protected chicks against haemorrhage did not all prevent the occurrence of gizzard lesions, and they postulated the existence of another fat-soluble vitamin necessary to prevent such lesions. Since then, very conflicting results have been obtained by several workers (Kline, Bird, Elvehjem & Hart, 1936; Almquist & Stokstad, 1937; Bird, Oleson, Elvehjem & Hart, 1938) and no clear-cut evidence for the existence of such a factor has so far been produced.

Conclusions

It is clear that under practical conditions the requirements of poultry for vitamins E and K will be adequately met by the inclusion of cereal grains and green feed. Birds kept extensively will synthesize most of the vitamin D required through the action of sunlight, and will have little need of an additional source; the normal vehicle for the addition of vitamin D is fish-liver oil, 0·5–1% of cod-liver oil being ample under intensive conditions. Although cod-liver oil also contributes sufficient vitamin A its stability in this respect is doubtful, and the carriers of carotenoids, such as maize and dried grass, are probably preferable as sources of vitamin A. Caution in the use of cod-liver oil is advisable, as a surplus may do more harm than good by destroying the vitamin E in the other components of the diet.

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The Incidence of Nutritional Diseases in Poultry

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It is not possible in a short space to cover the whole field of diseases of poultry associated with faulty diet; the subject may, however, be discussed briefly under three headings: (1) diseases associated with a specific deficiency; (2) diseases due to non-specific deficiency; (3) diseases possibly associated with faulty diet.

The importance of an adequate diet for the maintenance of poultry in normal health and for the efficient production, fertility and hatchability of eggs need not be stressed, as it is well recognized. Formerly, when fowls were reared extensively on grass, having access to worms, grubs and insects, coming into contact with their own droppings and being exposed to sunlight, there was little likelihood of diseases due to deficiency in the diet. With the increased use of the intensive system and more particularly of the battery system, fowls depend solely on the ingredients in their mash, and deficiency diseases have become more common.

Some conception of the prevalence of these diseases may be obtained from a survey of the results of post-mortem examinations of chicks and fowls from stations participating in the Accredited Poultry Schemes in Scotland and in the six northern counties of England during the period 1940–8. The results are given in Table 1. Comparable figures for the industry as a whole are higher, since the regulations of these schemes