In practice it never pays to treat individual birds; culling should be ruthless and continuous.

Summary

Poultry as laboratory animals are economical, easy to house, manage and feed. Other birds may be used for special purposes. Where space is an important consideration, Japanese quail may prove ideal once supplies of this species are available freely. Most diseases common to birds can be overcome by good management, but drugs and antibiotics can also be used for controlling many of their specific infections.

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Advances in nutritional knowledge through studies with birds

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It is not the intention to review in this paper the great body of work concerned directly with the nutrition of poultry, but instead to consider investigations of fundamental nutrition where birds have been peculiarly suited to a study of a particular problem.

As laboratory subjects, birds have several disadvantages compared with some of the other commonly used species. Because birds do not lend themselves to close inbreeding, they are genetically less uniform, so that a high variability between individuals may be expected. This variability is aggravated by the establishment of a social hierarchy in groups of birds kept together which results in differences in food consumption and uneven growth rates within experimental groups. They are not well adapted to digestibility studies since their feeding habits make accurate records of food intake difficult, and special techniques are necessary for the separate collection of urine and faeces. They are, however, relatively cheap and easy to produce in large numbers. Young chicks and turkey poults grow very rapidly and hence have high requirements for most of the known nutrients. They thrive on synthetic diets, and by simple omission of any desired nutrient an uncomplicated deficiency can readily be established and is usually characterized by easily recognizable signs. Further, birds do not practise coprophagy if kept on wire screens, so that dietary studies need not be complicated by ingestion of excreta.

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Vitamin studies

The characteristics mentioned above make birds particularly favourable for the study of vitamins, especially those that are synthesized in the alimentary tract. Among the classical advances in nutrition in which poultry have played a major part, the first to spring to mind is Eijkman's (1897) observation of polyneuritis in hens fed on polished rice. His work laid the foundations of the whole concept of vitamins and led ultimately to the isolation of thiamine. The discovery of vitamin K was based on Dam's (1934) report of a haemorrhagic disease in chicks which could be cured by extracts of liver and certain vegetables. That the disease was not easily demonstrable in mammals can now be explained since it is known that vitamin K is synthesized by bacterial action in the gut. The products of such synthesis are available to coprophagous animals such as rats and mice, whereas the chick requires an exogenous supply of the vitamin.

Among the more recent vitamin studies that have been furthered by work with poultry has been that of vitamin B_{12}. Before this vitamin was characterized, many workers had observed that the performance of growing and laying birds was not entirely satisfactory on diets containing proteins of only vegetable origin, and the existence was postulated of an 'animal protein factor'. Supplements of cow manure, as well as of animal proteins, improved the growth of chicks and the hatchability of eggs from hens given all-vegetable protein diets (Rubin, Groschke & Bird, 1947; Bird, Rubin & Groschke, 1948). When vitamin B_{12} was finally isolated (Rickes, Brink, Koniuszy, Wood & Folkers, 1948; Smith, 1948) it was found to have much the same effects as the so-called 'animal protein factor' and further was present in intestinal contents and faeces, particularly of ruminants, as the result of bacterial action.

As with vitamin K, it is not easy to demonstrate severe vitamin B_{12} deficiency in many laboratory animals since they are able to obtain supplies from the products of their own intestinal synthesis. Also, although vitamin B_{12} is essential for all growing animals it is only required in minute amounts and the offspring from normal parents usually carry substantial reserves in their tissues. Chicks have proved the most convenient subjects for work with vitamin B_{12}, for if hens are given diets devoid of animal protein and kept on screens out of reach of their own droppings, after a few weeks the eggs they produce contain very little vitamin B_{12}. Chicks hatched from these eggs grow very poorly on vegetable-protein diets unless they are given a source of vitamin B_{12}. This has been made the basis of a biological assay (Coates, Harrison & Kon, 1951) and although, like most biological assays, it is too cumbersome and expensive to be recommended for routine use, comparison of values obtained by the chick assay with those found microbiologically has led to interesting conclusions. For instance, results of chick assays of intestinal contents and faeces of ruminants were much lower than those obtained microbiologically with *Escherichia coli* or *Lactobacillus leichmannii* (Coates, Ford, Harrison, Kon, Porter, Cuthbertson & Pegler, 1951), indicating that these materials contained substances active as vitamin B_{12} for micro-organisms but not for higher animals. Chromatography of extracts of rumen contents revealed the presence of compounds

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similar to, but not identical with, cyanocobalamin; these compounds had vitamin B_{12} activity for micro-organisms (Ford, Kon & Porter, 1951). In due course other naturally occurring vitamin B_{12}-like compounds were isolated, many of them containing purines in place of the dimethylbenziminazole of vitamin B_{12}; other analogues of cyanocobalamin, containing substituted purines and benziminazoles, have been made by biosynthetic processes (see review by Porter, 1956). Measurements of their activity for chicks and micro-organisms have shown a distinct relation between chemical structure and biological activity, for, whereas most of the analogues have vitamin B_{12} activity for micro-organisms, the presence of a benziminazole structure in the molecule is essential for vitamin B_{12} activity in the chick. This requirement seems also true in man, for in clinical trials only those substances with activity for the chick were efficacious in human pernicious anaemia, and the purine-containing analogues, without effect in chicks, are similarly ineffective in man.

Metabolic studies

The science of nutrition cannot be confined solely to studies of the effects of variations in diet, but must also be concerned with the metabolic role and fate in the body of the different dietary components. Discoveries of this nature in poultry may not be universally applicable, since it is known that some of the biochemical processes in birds differ from those in mammals. A difference of this kind has been turned to advantage on at least one occasion, for it was the failure of irradiated ergosterol to prevent rickets in chicks that led Waddell (1934) to the recognition of the two forms of vitamin D, ergocalciferol (vitamin D_2) and cholecalciferol (vitamin D_3). Possibly a reappraisal of the difference between chicks and mammals in their ability to utilize ergocalciferol might throw some light on the biochemical function of vitamin D, of which we are still in ignorance.

In most studies of biochemical function it is desirable to use a tissue capable of rapid metabolism. Embryonic tissue fulfills this requirement, and because of its ready availability the developing chick embryo has frequently been chosen. Work with vitamin B_{12} again provides an example of this type of investigation.

Although deprivation of vitamin B_{12} is without obvious detriment to adult hens, the hatchability of their eggs is very seriously depressed. In the depleted eggs, development of the embryo appears to proceed more or less normally until about the 14th day, after which growth is arrested. Many embryos die on the 17th day with atrophy of the legs and multiple haemorrhages throughout the organs. The effects of the deficiency can be reversed by injections of cyanocobalamin into the egg during the course of incubation (cf. Davies, 1958). Chick embryos have been used by Moore & Doran (1961) to study the possible involvement of vitamin B_{12} in lipid metabolism. They demonstrated a severe derangement of the lipid components in embryos from hens deprived of vitamin B_{12}. Analysis of the livers of normal and deficient embryos showed little difference in total lipid or phospholipid content but a significant increase of triglyceride and decrease of cholesterol ester in the liver lipids of the deficient embryos. These findings are not peculiar to the chick embryo, but show a striking similarity to results published more than 20 years ago on the composition of plasma lipids in patients with pernicious anaemia (Williams, Erickson, Bernstein, Hummel & Macy, 1937).

The technique of tissue culture, whereby explants of organized tissue can be cultivated in vitro, provides a means for the detailed study of the biochemical role of vitamins and other nutrients. Since the tissue chosen is grown in isolation, away from the influence of other organs or of nervous or vascular control, the direct effect of chemical agents on that tissue can be observed. Material from the chick embryo is commonly used, and a series of experiments by Fell & Mellanby has thrown considerable light on the function of vitamin A. It has long been known that one result of hypervitaminosis A in the young animal is fragility of the long bones, but it was not clear whether it was a direct effect on skeletal tissue or an indirect action, possibly hormonal. Fell & Mellanby (1952) cultivated early bone rudiments from chick embryos in a medium containing normal fowl plasma, or the same plasma supplemented with high levels of vitamin A, or plasma from a bird suffering from hypervitaminosis A. The explants in normal plasma developed well, but those in the two plasmas high in vitamin A showed considerable distortion. After 2 days in plasma containing from 1550 to 3247 i.u. vitamin A/100 ml, growth began to decline so that the shaft of the bone became shorter and more slender than in the controls; the explants also changed in consistency, becoming soft and rubbery. Histological examination showed that, although the cartilage differentiated at the normal rate and ossification was not seriously reduced in the explant grown in high concentrations of vitamin A, the cartilage matrix was drastically affected; a shrinkage of the intercellular partitions and marked changes in staining reactions were observed.

In similar experiments the involvement of vitamin A in controlling keratinization of the epidermis was also studied (Fell & Mellanby, 1953). Explants of ectoderm from the trunk and limbs of chick embryos developed the expected squamous keratinizing epithelium when cultivated in a normal medium. If the explants were cultivated in a medium containing excess vitamin A they differentiated instead into a mucus-secreting ciliated epithelium more like that of the normal nasal mucosa. In further experiments this phenomenon and the effect on the cartilage matrix were both found to be accompanied by a modified sulphate metabolism. In developing ectoderm grown with $Na_2{}^{35}SO_4$, autoradiographs showed that little sulphate was taken up by the squamous epithelium whereas the mucus-secreting epithelium that developed in the high vitamin A medium utilized sulphate at a much greater rate (Fell, Mellanby & Pelc, 1954). By similar techniques the same workers (Fell, Mellanby & Pelc, 1956) showed that in long-bone rudiments from chick embryos uptake of sulphate was diminished and the $^{35}SO_4$ less well retained in cartilage of explants grown in presence of excess vitamin A. The changes in staining reactions observed in the earlier experiments accompanied an inability of the cells to bind sulphate. The authors postulate that vitamin A may influence the production by cartilage cells of an enzyme which results in the formation of a soluble sulphated mucopolysaccharide instead of chondroitin sulphate.

Studies on the alimentary microflora

One of the broader problems at present concerning nutritionists is the relation of the microbial population of the alimentary tract to the nutrition of the host. There is little information as to whether the observed events in the absorption and metabolism of nutrients are directly brought about by the host or whether they are mediated through the flora of the gut. For the investigation of such problems animals with a known, controlled gut flora are obviously necessary. This calls for the maintenance of an entirely sterile environment into which uncontaminated animals can be placed and reared on sterile food and water. By introduction of appropriate micro-organisms any desired flora can then be established and its effect on the animal can be observed. Modern developments in the technique of rearing germ-free animals have made such investigations practicable, and the methods have been discussed in a symposium at the (VIIth) International Congress for Microbiology, Stockholm (1958). The chief difficulty in the technique lies in obtaining animals in an uncontaminated condition, and mammals have in the first place to be delivered aseptically by Caesarian section and reared artificially. For nutritional experiments birds offer a convenient alternative, since fertile eggs from healthy stock are sterile inside the shell. The eggs can readily be disinfected externally before introduction into the germ-free apparatus, where they will hatch normally if given suitable conditions of temperature and humidity.

Germ-free chicks and turkey poults have so far largely been used to study the growth-promoting effects of antibiotics, but other nutritional problems are under investigation. Studies in rats, rabbits and man suggest that the intestinal flora is implicated in the metabolism of cholesterol, probably through an influence on the breakdown of bile acids. In chicks given cholesterol in the diet, Grant & Fahrenbach (1959) showed that the type of carbohydrate in the diet had a profound effect on serum cholesterol levels, which were almost doubled when sucrose replaced glucose as the source of carbohydrate. Addition of chlortetracycline to such diets did not affect the serum cholesterol levels of the chicks given sucrose but raised those of the group given glucose (Kritchevsky, Grant, Fahrenbach, Riccardi & McCandless, 1958). Findings with germ-free chicks were similar, in that absence of a flora resulted in increased serum cholesterol levels of birds given glucose or starch, but did not affect the already very high levels of those given sucrose (Kritchevsky, Kolman, Guttmacher & Forbes, 1959). These authors postulate a specific carbohydrate requirement of certain alimentary micro-organisms connected with cholesterol metabolism.

The experiments quoted above have been chosen as examples of nutritional research for which poultry have been particularly suitable tools. Clearly there are many problems still facing nutritionists for which birds can prove highly suitable not only in dietary studies but also for more detailed investigations of the metabolism of nutrients.

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Some basic mechanisms of hunger and satiety

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Introduction

Feeding and cessation of feeding are essential features in all living systems. 'All animals that have been studied, those without alimentary tracts as well as those which have, recognize food, spurn food when it is superabundant and put forth extra efforts to get it when it is rare. Hence, whatever be the machinery that may fix the pattern of priorities in rats, comparable patterns seem to be endowments of all animals whether or not they possess specialized neuromuscular or alimentary systems' (Adolph, 1947).

To survive, animals must not only eat but must eat a nutritionally adequate diet which they must select from the foods that are available in the external environment. Their choice of food is guided by the need for many nutrients that have been depleted in their bodies. The depletion of energy is expressed as hunger. 'Specific hungers' exist for many specific nutrients that have been depleted (Scott, 1948; Richter, 1942–3). Apparently deficits of many nutrients are not expressed as 'specific hunger' (Scott, 1948) and presumably their ingestion is left to chance.