

Concepts in practical diet formulation

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This paper attempts to show how the concepts and considerations involved in diet formulation have developed recently. Owing to space limitation only the main points of each are discussed.

Principles of formulation

Considerable advances have been made in the efficiency of poultry production, resulting partly from a better understanding of how diets should be formulated. Thus in 1966 the (US) National Research Council estimated that a broiler male required 5.1 kg food and 10.6 weeks to reach 2 kg live weight. Currently the respective values are probably just over 4 kg and about 50 d.

Formerly diets were based on standard formulas. The development of nutritional knowledge and the introduction of computers subsequently allowed compounders to vary the proportions of ingredients in the mix. Most commercial diets are now based on least-cost formulas derived by mathematical procedures such as linear programming. Those procedures most appropriate for the compounding industry also yield information on stock control and buying policy. However, the basic concept, namely that of producing at least cost per ton a feed mixture satisfying a certain set of criteria, has remained unaltered.

These procedures may or may not provide a true least-cost formula, depending on how the specifications were set. Thus if the energy level is specified as, say, 12.55 MJ (3000 kcal) metabolizable energy (ME)/kg in a broiler starter diet, the formulator has made the initial assumption that 12.55 MJ/kg is the most economic level of energy to adopt. This may or may not be true. A better approach is to produce a diet that is least-cost per unit of energy. This is done by specifying the nutrient levels not as discrete amounts but as levels relative to a convenient unit of energy. In this way the computer can select the most economical level of energy to adopt and automatically adjust the levels of nutrients to that level. This procedure involves setting an energy level, say 4.18 MJ (1000 kcal) and then allowing the weight of mix to vary between fixed limits known to result in acceptable energy levels in the diet.

It is therefore obvious that in economic formulation a knowledge is needed of the ranges in energy levels that can be tolerated in diets for various classes of poultry. Current requirement tables (e.g. (US) National Research Council, 1971) do not show this information, although it may perhaps be derived from the accompanying text.

It would be an advantage for least-cost formulation if future requirement tables could embody this information.

Fisher & Wilson (1974) have shown that as ME content of the diet increases within the range 10.00–15.06 MJ (2400–3600 kcal)/kg, broilers show linear responses in weight gain, food intake, food conversion efficiency and energy intake. Laying hens can probably tolerate a similar range in dietary ME content with no difference in egg output (Morris, 1968; Bolton & Blair, 1974), although the lower limit is probably 9.62 MJ (2300 kcal)/kg. Within these ranges, birds adjust to increased energy concentration in the diet by reducing consumption and the adjustment appears to be fairly exact for layers of light body-weight. Broilers and heavy layers show incomplete adjustment and overconsume as the energy concentration of the diet is increased. Morris (1968) found that perfect adjustment took place in the region of 1.13 MJ (270 kcal) intake/d but that in the region of 1.67 MJ (400 kcal) intake a 4–5% extra energy intake could be expected for a 10% increase in energy concentration.

The usual procedure in formulation is to maintain a constant energy:protein ratio as energy concentration alters. As the protein level alters it is also recommended (Scott, Nesheim & Young, 1969) that the relative proportions of amino acids remain the same. For many compounders these are safe procedures to adopt. It is now clear that, since the broiler and heavy layer are unable to adjust energy intake exactly as energy concentration alters, a constant energy:protein ratio for each class is open to question. Overconsumption of energy will result in overconsumption of protein and the other nutrients. However, this, although wasteful, is preferable to an imbalanced intake of nutrients, which would follow anything but an accurate re-adjustment of the nutrients.

Until recently it was assumed that maximal performance should be sought. This is now questionable and the most economical performance is desired. The nature of the response to nutrient inputs is therefore important. In this context the word 'requirement' loses some of its meaning. The laying hen may 'require' 160 g protein/kg diet, but egg production may be most economical with 150 or 170 g/kg. Models have been derived for some nutrients to yield input-output information, such as that described by Fisher, Morris & Jennings (1973). The accuracy of the model is very important because its functions are to give a good prediction of output at specified inputs of the nutrient in question and to allow the marginal response to be derived.

Information derived by modelling can be used to formulate diets and this is probably the most accurate approach. Instead of thinking in terms of levels of nutrients in the diet, the formulator can formulate in such a way that the bird receives specified intakes of nutrients per d or per unit live weight. Some commercial diets are already being formulated on this basis. This is a radical approach that has much to commend it, but modelling is still in the developmental stage and is a technique that only large compounders with the necessary expertise can hope to adopt. Most compounders would need to know a great deal more about the level and availability of nutrients in raw materials and about the likely responses in stock under varying practical conditions before they were convinced that its adoption was desirable.

Rearing broilers sex-separated

A concept emerging in broiler production is that it can be more efficient to rear the sexes separately than mixed. Broiler males and females have different growth patterns so that their weights at marketing are different, males being heavier. Rearing the sexes separately has the advantage that different diets can be formulated to suit their specific growth needs. Growth rate and food conversion efficiency appear to be comparable in both sexes up to 2 weeks of age. Thereafter the female grows more slowly and, according to several reports, requires more food to do so, which has been attributed to a possible higher maintenance requirement (Moran, 1974). Canadian results (Moran, 1974) and recent results obtained by Blair, Lee & Wilson (unpublished results) indicate that the response to increased dietary protein is less in females than in males. Thus expensive protein can be saved by finishing the females on 170 g protein/kg diet while males are finished on 200 g protein/kg diet.

Criteria in formulation

Whatever approach is taken to formulation, certain criteria have to be adopted. Among these are the following.

Margins of safety

The object in formulating diets for any class of livestock is to match the nutrients in the food to the needs of the animal. Two sets of basic data are therefore required: the nutrient requirements of the animal and the composition of the feeding-stuffs available.

The most recent estimates of the nutrient requirements of poultry were published by the (US) National Research Council (1971). Requirement estimates published by the (UK) Agricultural Research Council (1963) are currently being revised. Detailed tables of the composition of feeding-stuffs have been published by Scott, Nesheim & Young (1969) and by Bolton & Blair (1974).

One of the concepts embodied in requirement tables is that the estimates are minimum requirements and not recommended practical allowances. For practical formulation we have therefore to consider whether to increase the appropriate requirement values by some margin of safety to derive suitable levels for inclusion in the diet. A common approach is to add a margin of safety to certain of the micro-nutrients but not to the major nutrients such as protein and amino acids.

The aim in allowing a margin of safety is to ensure that the required levels are present in the food, even after storage. The effects of food compounding and storage on vitamin potency have therefore to be taken into account. This has become more important now that it is a legal requirement for the total levels of vitamins A, D and E to be guaranteed when they have been added to practical diets.

The current legislation, which came into force in January 1974, is controlled by The Fertiliser and Feeding Stuffs Regulations, 1973 (Great Britain: Parliament, 1973) and the Medicines Act, 1968 (Great Britain: Parliament, 1968). Under the new regulations the statutory declaration has been extended to include the total amounts

of copper if over 50 mg/kg, magnesium if over 5 g/kg, vitamins A, D and E, molybdenum, selenium and the presence of any permitted antioxidant or colourant. The Regulations allow a 30% downward tolerance for vitamins A and E and ± 30 –50% in the instance of vitamin D. The declaration of vitamin contents must be accompanied by an indication of the period during which the declared amount will be present. There are maximal limits on the levels of certain nutrients permitted in complete diets. The maximum vitamin D in layer diets is 75 $\mu\text{g}/\text{kg}$ and for other classes of poultry it is 50 $\mu\text{g}/\text{kg}$.

The vitamins normally added to poultry diets are A, D, E and K, riboflavin and pantothenic acid. Choline, pteroylmonoglutamic acid, biotin and cyanocobalamin are often added to diets for breeders and young birds. According to Putnam (1973) stability trials indicate that 25–30% of vitamin A is lost during manufacture and storage for 3 months. Vitamin losses are increased by pelleting and by the inclusion of hygroscopic materials such as choline chloride or common salt in the diet. To allow for these losses the trade associations have recommended an excess of 30% for vitamins A and D beyond declaration in complete feeds, together with a declaration of the amount of vitamin E as added. A common approach in the industry is to add 4 times the required levels of vitamins A and D to cover losses, 1.2 times the required levels of vitamins E and K and up to 1.25 times the required levels of the water-soluble vitamins.

The trace minerals added to poultry diets are usually zinc, Cu, Mg, manganese, iron, iodine and perhaps Se. A common approach in formulation is to supplement the diet with some or all of these minerals at levels supplying the requirement plus a small safety margin. Under the current legislation Fe is limited to 1250, I to 40, cobalt to 10, Mn to 250, Zn to 250, Mo to 2.5 and Se to 0.5 mg/kg.

Dietary constraints

It is usual in formulating diets to set constraints on the levels of some feeding-stuffs. These constraints may specify lower, exact or upper limits, and normal inclusion rates for a wide range of feeding-stuffs have been outlined by Bolton & Blair (1974).

Enough is known about the common ingredients for acceptable inclusion rates to be put forward with reasonable confidence, but problems connected with the unconventional feeding-stuffs suggest that in the present state of knowledge conservative levels should be adopted. For instance, until recently it was thought that the main problem associated with rapeseed meal (RSM) was thyrotoxicity due to hydrolysis of the glucosinolates to isothiocyanates and oxazolidinethiones by the action of thioglucosidase (*EC* 3.2.3.1). Clandinin, Robblee & Slinger (1973) suggested that 50–100 g RSM/kg could be included in layer rations and it seemed probable that the introduction of varieties low in glucosinolates would allow higher levels to be used. However, it is now apparent that even 50 g RSM/kg is too high in layer rations, since this causes tainted eggs in at least some strains of hens (Blair, Robblee, Dewar, Bolton & Overfield, 1975). Our present recommendation is to exclude this feeding-stuff from layer diets.

One constraint that has an important influence on dietary composition is related to pigment. Consumer preference in the UK is for egg yolks that are moderately pigmented (scoring 8–10 on the Roche Yolk Colour Fan (F. Hoffmann-La Roche & Co. Ltd, Basel, Switzerland)) and it is therefore common for layer rations to contain 25–50 g grass meal or 500 g maize/kg. Alternatively a synthetic pigment can be used. In broiler production a white carcass is desired in the UK and, as a result, only low levels of yellow maize can be employed in finisher diets. This is an unfortunate constraint because maize is often an economic feeding-stuff and grass meal may be, but there is evidence that perhaps 20% of the public would be willing to accept yellow or creamy carcasses (Cumberland, 1973).

Protein and amino acid constraints

In formulating practical diets one can logically ask the question 'If we know enough about amino acid requirements ought both protein and amino acid specifications be set?'. If both are set in a linear programme the solution differs from that obtained by specifying only the amino acids, and a saving of protein can sometimes be achieved by omitting the protein specification. Even greater savings of protein could probably be achieved by a greater use of synthetic lysine but the relative price of this amino acid is still too high. We have compared the growth of broilers given diets formulated in the two ways. Our results suggest that growth performance is unaffected by removal of the protein specification from the formulation constraints (Blair, Lee & Wilson, unpublished results).

Linoleic acid and egg size

One concept that has repercussions on dietary formulation is that egg size can be increased by raising the linoleic acid content of the diet. To meet this constraint, various fats and oils or feeding-stuffs such as maize, unextracted soya beans or distillery or brewery by-products may have to be used. The level of linoleic acid that satisfies the essential fatty acid requirement is between 8 and 10 g/kg (Menge, 1968; Balnave & Brown, 1968; Balnave, 1971), but it has been suggested that the level for maximal egg size may be as high as 25 g/kg (Shutze, Jensen & McGinnis, 1959; Menge, 1968). The latter level can be reached by including 50 g maize oil/kg in the diet but is obviously an expensive constraint in formulation. Recent results from the Agricultural Research Council's Poultry Research Centre (Shannon & Whitehead, 1974) suggest that linoleic acid is not specifically required for maximal egg size and that a dietary level of 8 g/kg is adequate. Couch & Coon (1973) have reported that light hybrid hens lay and breed satisfactorily with only 2.5 g linoleic acid/kg diet providing they have been reared normally. Therefore a safe level to adopt in practical layer diets is 10 g/kg, which can be achieved fairly readily with common ingredients.

Yield promoters

The concept of fortifying practical diets with yield promoters is well-founded but practices have changed over the last few years and probably will do so again when

the UK becomes a full member of the European Economic Community (EEC). Following the recommendations of the Swan Committee, the Therapeutics Act, 1969 (Great Britain: Parliament, 1969) classified antibiotics into two groups: (1) those with application in human and animal medicine, which are prohibited as yield promoters, and (2) those permitted as food antibiotics.

At present the antibiotics and antibiotic-like substances permitted for food use are bacitracin, moenomycin, virginiamycin, nitrovin, nifursol, sulphaquinoxaline and sulphanitran. Other permitted yield promoters are Cu, arsenicals and dimetridazole. The present EEC legislation is different. Penicillin and tylosin are on its permitted list, while arsenicals are not allowed. By the end of 1977 there will have to be harmonization of legislation in the enlarged EEC.

Among current trends in the use of yield promoters in poultry diets is the use of higher levels than hitherto, which are reportedly economic because the prices of many of these additives have fallen greatly over the last 20 years. Another is the use of yield promoters in layer diets, and those permitted in the UK are moenomycin, bacitracin and the arsenicals. Another likely development is the use of synergistic mixtures.

Food processing and feeding regimens

Crumbing and pelleting have beneficial effects on food intake but have detrimental effects on vitamin stability. According to Pickford (1968), the most important factors are temperature and moisture content. Excess moisture is harmful to vitamin stability, whereas a dry meal leads to excess frictional heat during pelleting, creating conditions conducive to vitamin destruction. The optimal moisture content appears to be 110–120 g/kg. The safety margin suggested for vitamin A and D supplementation should cover normal processing losses, but a margin of 40% is recommended by Pickford (1968) when the formulation contains problem ingredients such as high levels of minerals, milk by-products and sugar, and when the die size is 5 mm or less.

It is customary for growing stock and for broiler breeder stock to be given regulated amounts of food. Currently there is interest in regulating the food of commercial layers in an attempt to reduce production costs. Data derived from mathematical models can be useful in this connexion, for with laying stock it may be desirable to restrict only the energy intake. A less exact way in which the compounder can achieve this aim is to increase the concentration of nutrients by 10% when a 10% level of restriction is imposed.

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