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The importance of protein quality in animal feeding

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The importance of protein quality for practical rations becomes evident as soon as an attempt is made to economize and to establish for such rations the lowest level of protein that will give efficient production. Woodman & Evans (1951) demonstrated this point with pigs fed on a simplified barley–fine-bran ration. Supplementation with fish meal at the rate of 4·2% protein gave efficient production that could be attained with groundnut meal only when included at the rate of 9·9% protein. In laying experiments, the difference between fish meal and groundnut meal was reflected in egg production only when the total protein content of the ration was reduced to 11% (Carpenter, Duckworth & Ellinger, 1954*a*). The same proportions of fish meal and groundnut meal in a 14% crude-protein ration gave equal egg production. Consequently, economies that are permissible with a high-quality protein may not be so with a concentrate of a poorer quality.

The principal aim of animal production is the economic and efficient conversion of feeding-stuffs. Financially, the real economies depend mainly on market conditions. Economy in terms of protein—also important to us as importers of a large proportion of concentrates—can be achieved by the correct allocation of available feeding-stuffs and by the conservation of quality during their production. The formulation of economic rations depends on knowledge, on the one hand, of the function of the rations in terms of the animals' requirements and, on the other hand, of the way to use available feeding-stuffs to fulfil these requirements. The poorer-quality concentrates may then be included in successful rations, provided their limitations are recognized and corrected.

Here, the feeding of non-ruminants will be considered and that only under intensive systems of management where requirements must be satisfied entirely by the rations. The utilization of protein by ruminants is, to a large extent, governed by the metabolism of the rumen micro-organisms. Criteria that determine protein quality under those conditions have been discussed by Chalmers & Synge (1954). Should the early weaning of calves become an established practice, many considerations given here may find application in calf rations used during the period before rumen activity becomes fully developed.

Practical rations are generally compounded to contain protein at levels higher than the requirement determined under experimental conditions. This excess is regarded as a margin of safety which compensates for fluctuations in the quantity and

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quality of the protein in available feeding-stuffs. On the farm, the excess of protein is frequently modified or altogether cancelled, when rations compounded for straight feeding are given together with home-grown cereals. The success of such a dilution is, at the best, a matter of trial and error where production is recorded. Without regular records dilution may lead to the wastage associated with imbalanced rations.

To understand what determines quality in a concentrate and to evaluate this quality in a significant manner, the function of concentrates in practical rations must be considered. Two principal sources supply the protein component of pig and poultry rations. The first are the cereals, primarily the source of energy in the ration, containing only low percentages of protein. Yet they represent such a high proportion of the ration that their contribution of nitrogen nevertheless assumes importance. The use of cereal by-products such as miller's offals enhances that importance. The second are the concentrates added as supplements to the cereals to create a ration of the required protein content and an overall balanced amino-acid composition.

Cereals

In some current practical rations for different classes of poultry (National Institute of Poultry Husbandry, 1957) the protein contributions from cereal origin are as follows:

Type of ration	Protein in the ration (%)	Protein of cereal origin (as percentage of total protein)
Chick starter	18·0	45
Broilers'	18·5	40
Growers'	13·5	65
Layers'	16·0	50

These estimates of contribution of cereal protein would be yet higher had the present high price of miller's offals not excluded their use. Rations for weanling pigs up to the weight of 100 lb. may derive between 50 and 70% of the total protein from cereals according to the proportion of miller's offals and bran that are included.

In the circumstances, contributions of the essential amino-acids from cereals become important. The cereals contributing 50% of a ration's total protein, if completely balanced, contribute 50% of the requirement. The chick's requirements for the essential amino-acids have been summarized by the (U.S.A.) National Research Council: Committee on Animal Nutrition (1954). Hence the capacity of the commonly used cereals to fulfil requirements in proportion to their protein contribution may be calculated. On this basis wheat, barley, oats and maize are all deficient in lysine and, with the exception of maize, do not contain enough cystine and methionine. The contributions of glycine and arginine are borderline except in oats, and in maize alone the tryptophan content is low.

Similarly the cereal proteins fail to reach the required level of lysine and are borderline for cystine together with methionine for weanling pigs ((U.S.A.) National Research Council: Committee on Animal Nutrition, 1953).

Less is known about the hen's requirements for amino-acids for egg production ((U.S.A.) National Research Council: Committee on Animal Nutrition, 1954). In general, for this purpose the content of lysine and the sulphur amino-acids is less critical in cereals than for the feeding of chicks and pigs.

As contributors of protein, the cereals and some of their by-products have an advantage in that they do not undergo processing of the type that might damage quality. By-products of the milling industry will change in composition according to the current extraction rate; but it is of interest that one of the products of milling, wheaten flour, contains all its lysine in the 'available' form (Clegg, 1957).

Cereals vary in protein content and composition according to variety and fertilizer treatment (Duckworth, 1952). Associated changes in feeding quality of maize, often the sole cereal in practical rations in the United States, have been examined in some detail. Nitrogen-balance studies with pigs conducted with maize samples containing 10·6 and 14·9% protein demonstrated the superiority of the low-protein maize, the difference being corrected by additions of lysine and tryptophan to the high-protein maize (Eggert, Brinegar & Anderson, 1953). Differences in the quality and composition of maize protein were explained by increases in the proportion of zein in varieties that had been bred for a high protein content. Recent amino-acid analyses of some East African varieties of maize have indicated that composition can differ appreciably, independently of total protein content and of zein in particular (Wolfe & Fowden, 1957). These authors selected samples to cover only a narrow range of protein contents (8·3–10·2%) and nevertheless obtained a wide range of concentrations, especially for the basic amino-acids. Avoidance of high-protein maize is therefore no guarantee against low protein quality.

In the United Kingdom rations generally contain a mixture of cereals, and fluctuations in amino-acid composition are likely to be of less consequence.

Concentrates

Concentrates that are offered as feeding-stuffs are derived from a wide variety of raw materials and their amino-acid compositions may be much more varied than those of the cereals. Further, a common feature of the concentrates is that almost all undergo some form of processing, often as by-products. In particular, they are nearly all subjected to the conditions of high temperature and moisture that cause damage to the less stable amino-acids ((U.S.A.) National Research Council: Food and Nutrition Board, 1950). Damage to protein quality of fish meals has been associated with the formation of amino-acid–sugar complexes (Miller, 1956). The proteins in feeding-stuffs in general are vulnerable to this type of damage. Lysine and the sulphur amino-acids are not only readily damaged in the concentrates but, being the limiting amino-acids in the cereal proteins, their concentration largely determines the supplementary value of the concentrates.

When considering the evaluation of protein quality of animal feeding-stuffs against this background, a number of conditions must be observed.

(1) Tests must be carried out with the class of stock for which the feeding-stuff is intended. Protein requirements for the production of meat and feathers in the

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young chick are known to differ both qualitatively and quantitatively from those for egg production by the hen.

(2) The test concentrate should be given as supplement to a cereal basal ration similar to the type employed under practical conditions. For instance, the cereal basal ration may consist of maize alone according to general American practice or of a mixture of cereals as it would be used in the United Kingdom.

(3) To assure an evaluation strictly confined to protein quality rations should be balanced for all other essential nutrients.

(4) A lack in the protein quality of a concentrate may often be compensated by giving that concentrate in greater quantity. In a practical-type ration, with an acknowledged margin of safety, a reduction in protein quality may therefore only reduce that margin of safety by an unknown amount, without reflecting the difference in production. Hence it is important that the concentration of protein in the test rations should be critical. In assessing the comparisons quoted in the literature the levels of protein should be examined. Frequently, the verdict of 'no difference' rests on tests in which protein was given at levels above requirement.

What constitutes a critical level of protein for a given class of stock may vary according to the energy content of the ration. The chick consumes rations in the amounts that are needed to satisfy its energy requirements (Hill & Dansky, 1954), high-energy rations being consumed in smaller amounts, and consequently the intake of protein and amino-acid is reduced. On this basis, Carpenter (1954) estimated that a relatively low-energy ration based on mixed cereals supplies, at a protein content of 11%, the same intake of protein as a 14% protein, high-energy ration based on maize alone and consumed in smaller amounts. Williams & Grau (1956) found that as the energy content of a lysine-deficient ration was reduced, the resulting increased food intake progressively raised protein intake and thus corrected the lysine deficiency.

Application of tests for protein quality. The highest critical level of protein, at which additions of concentrate bring no improvement in food-conversion efficiency and reductions are accompanied by a fall in production, is in itself a measure of

Table 1. *Values of protein concentrates in terms of protein contributions required for standard production of growing pigs*

Supplement	Supplementary protein in ration (%)	Supplementary protein as percentage of total	Reference
White-fish meal	4·4	30	Woodman & Evans (1951)
Groundnut meal	9·9	54	
White-fish meal	4·6	28	Evans (1952*a*)
Dried yeast	4·5	29	
White-fish meal	4·1	27	Evans (1952*b*)
Soya-bean meal	6·3	39	
White-fish meal	4·3	29	Evans (1954)
Condensed fish solubles	6·0*	37*	

*This contribution of condensed fish solubles gave a weight gain only 91% of that for the white-fish meal control.

quality for any given concentrate. It is the criterion by which Woodman & Evans (1951) and Evans (1952*a*,*b*, 1954) assessed the value of concentrates for rearing pigs. The results of their growth trials are summarized in Table 1. The levels of supplementary protein giving equivalent performance are shown for a number of concentrates together with their relative protein contribution. Accordingly, concentrates are graded in the following order: white-fish meal $\equiv$ dried yeast $>$ soya-bean meal $>$ groundnut meal. Condensed fish solubles had an adverse effect on palatability and therefore could not be given at a level that was entirely equivalent to the standard ration.

Working with growing pigs, Becker, Lassiter, Terrill & Norton (1954) found that whereas a maize–soya-bean meal ration attained the highest critical level at 14% protein, the corresponding maize–menhaden fish-meal ration had to contain 16% protein. There was no difference in efficiency of production when both supplements were given in 18% protein rations.

For the measurement of gross protein value (G.P.V.) for chicks casein is the standard supplement of low-protein test rations. The quality of concentrates, contributing protein at the same rate as casein, is compared by the performance of chicks (Heiman, Carver & Cook, 1939). Here, the standardized allocation of control groups allows comparison of results from one experiment to another. Results covering the G.P.V. over a wide range of feeding-stuffs have already been summarized by Duckworth (1955).

The low levels of protein employed in the determination of G.P.V. emphasize differences in quality that might otherwise not attain statistical significance. This emphasis is useful where uniformity amongst experimental animals is difficult to attain and the differences in quality may be expected to be small. The G.P.V. is therefore valuable for examining the effects of processing on protein quality. Flame driers, steam heaters and batch vacuum driers used in the manufacture of white-fish meal were compared according to the quality of their products (Carpenter, Ellinger & Shrimpton, 1954). The concentrates prepared from different green crops were compared and the success of modifications to the extraction process was judged by G.P.V. determination (Carpenter, Duckworth & Ellinger, 1954*b*; Cowlishaw, Eyles, Raymond & Tilley, 1956*a*,*b*). The G.P.V. of distiller's solubles could be doubled when at the second stage of drying, the rollers used in the industry were substituted by an experimental vacuum dryer in which the temperature did not rise above 50° (Duckworth, Ellinger & Shrimpton, 1955).

Conversely, the experimental heating of a vacuum-dried cod-flesh meal reduced the G.P.V. by 28% (Carpenter, Ellinger, Munro & Rolfe, 1957). As for the other fish products examined in this series, the G.P.V's of the cod-flesh meals were correlated with their 'available lysine' content. Supplementation with free lysine improved the G.P.V. of the heated meal but without restoring it fully to the value of the unheated control. Amino-acid analysis of acid hydrolysates indicated the loss of 12% of the total lysine and 67% of the cystine, but the methionine content remained unchanged (Ellinger & Mitchell, 1957).

The evaluation of concentrates for laying hens was developed along similar lines (Carpenter *et al.* 1954*a*). In a U.K. type ration it was found necessary to reduce total protein to 11% of the ration before supplements of white-fish meal and groundnut meal, each contributing 3% protein, gave significantly different egg production. At these low levels of protein the method of housing appeared to affect both egg production and food-conversion efficiency.

When a concentrate is given to contribute a particular amino-acid, quality may be most effectively assessed in terms of the availability of that amino-acid. Kratzer & Green (1957) added blood meals, valued as a source of lysine, and free lysine as supplements to a lysine-deficient basal ration and compared the growth response of chicks. This response gave a measure of the amount of lysine available to chicks, which was expressed as a percentage of the total lysine, determined microbiologically on acid hydrolysates of the blood meals. Accordingly, spray-dried blood meals were superior to vat-dried blood meals. However, quality differed considerably amongst the spray-dried meals, one sample falling within the range for the vat-dried product.

It must be stressed that values attributed to concentrates in the above tests are comparative. They do not specify the levels at which concentrates must be given in economic practical rations. The highest critical protein level might be a useful guide for the use of a good concentrate. A poor concentrate would need to be fed at a higher level to obtain normal production. Increase in protein intake is known to be accompanied by an increased requirement for lysine and methionine (Grau & Kamei, 1950; Brinegar, Williams, Ferris, Loosli & Maynard, 1950). Thus a diet that would increase the requirement for these acids cannot be recommended, since economy not only of protein but also of the supply of limiting amino-acids must be considered. Hence correction of protein quality is generally achieved more economically by supplementation with another concentrate rather than by increasing the level of protein intake. G.P.V's are also principally a means of grading protein quality. The experimental diets in this test not only contain much less protein than practical rations; the ratio of cereal to concentrate protein is also very much greater. Under these circumstances, the lysine deficiency of the cereal proteins for chicks emphasizes the importance of supplementary concentrates as sources of this acid. Such emphasis is no disadvantage, if the fate of lysine is taken to represent that of the more labile amino-acids in a heated concentrate. G.P.V's may then be regarded also as giving a measure of the damage sustained by the sulphur amino-acids.

Conclusion

Means are available for grading protein concentrates according to quality; so far they have mainly been applied to discriminate between products of different origin, which could be expected to differ judging by their amino-acid composition. But, given a discriminating test, even products derived from the same type of raw material are known to vary in quality. It is to allow for such variations, amongst others, that rations are at present compounded to contain protein at levels appreciably above the known requirements. As a guide, the above tests may help to obtain better and more uniform products for a given raw material and, without risk, allow some economies to be introduced in the allocation of protein concentrates for practical animal feeding.

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The quantity and quality of protein for human nutrition

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Some of the earliest work on the chemistry and physiology of proteins is associated with the names of Magendie, Mulder, Liebig and Boussingault (Beach, 1948); these men were working and writing in the first half of the nineteenth century. It is exactly 100 years ago since Karl Voit, called by Cathcart (1921) 'the master and