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## Preface

Heuser (1941) wrote: '*the requirement is for the various amino acids... In practice it is necessary to meet the requirements of as many of the individuals as we can* ***economically****... The actual need is probably on the basis of certain amounts of amino acids per unit weight of maintenance plus definite additional quantities for productive increases such as units of growth and quantity of eggs. Meeting these minimum needs will be materially influenced by* ***food consumption***.

## Introduction

The objective of this paper is to demonstrate that the opportunity cost of using fixed tables of nutrient requirements when formulating feeds for broilers can be considerable, and that nutritionists should consider a more dynamic approach to defining the lower bounds of amino acids in particular, in line with the objective of the business, which is to maximise profit. In order to do this, it is necessary to consider the potential growth rate of the broiler, the cost of feed and amount of feed consumed, and the income generated from the sale of product.

In the past 50 years there has been virtually no change in the amino acid recommendations for broilers by breeding companies and learned institutions. The assumption is that food intake will increase to meet the increased requirements of the bird. But, as demonstrated by Morris and Njuru (1990) (Table 1), this is not the case. The maximum gain in weight and in protein content in the slow-growing cockerels in that trial was achieved on diets with considerably lower protein contents than was needed to maximise the gain in the broilers, whilst the broilers continued to benefit from the additional dietary protein provided. A similar result was published by Havenstein et al. (2003) in which modern broilers were given feeds similar to those used in 1957 vs. 2001 feeds. Liveweight at 84 d was 4480 g on the 1957 feed, with a feed: gain of 3.39 vs. a body weight of 5520 and conversion of 2.72 on the 2001 feed. Feed intake in fast-growing chickens cannot keep pace with their amino acid requirements when dietary protein content is low, resulting in reduced body protein growth and worsening feed conversion efficiency. As the potential growth rate of broilers increases through selection, if these birds are to perform close to their potential the protein content of feeds needs to be increased, especially in the early growing period when gut capacity is limited but amino acid requirements are high.

**Table 1.** Liveweight, food intake, feed conversion efficiency (FCE) and protein content of broiler and layer-type chickens at 21 d of age (from Morris and Njuru, 1990)

| CP in feed g/kg | Live-weight g | Food intake g/chick | FCE g gain/ kg food | Protein content g/chick |
|---|---|---|---|---|
| *Layer chickens* | | | | |
| 167 | 235 | 683 | 293 | 35 |
| 188 | 290 | 702 | 362 | 45 |
| 209 | 295 | 711 | 366 | 46 |
| 230 | 291 | 650 | 394 | 46 |
| 251 | 299 | 689 | 384 | 47 |
| *Broiler chickens* | | | | |
| 167 | 414 | 938 | 400 | 53 |
| 188 | 618 | 1193 | 486 | 85 |
| 209 | 706 | 1183 | 564 | 100 |
| 230 | 786 | 1230 | 607 | 114 |
| 251 | 836 | 1320 | 603 | 123 |

Knowledge of the potential growth rate of broilers is of paramount importance in predicting voluntary feed intake throughout the life of the bird (Emmans, 1981; 1987), and much more emphasis should be placed on this genetic characteristic by broiler breeding companies than has been the case in the past. With such knowledge, the optimum economic level of all the essential amino acids may be determined under different economic and environmental circumstances, thereby leading to a more dynamic approach to feed formulation, as described below.

***Defining the potential body protein growth of each genotype***

The way in which genetic progress in broiler growth has been measured in the past is by comparing the number of days required to reach a given body weight. Using this approach, genetic progress has been considerable over the past 70 years, as indicated in Table 2 below. This progress, although impressive, is of no value when attempting to determine how to feed the birds to achieve their potential, nor how to feed them to maximise profit for the enterprise. For this, a more specialised procedure is required. Birds representative of the genotype must be grown to about 15 weeks of age in near-perfect (non-limiting) nutritional and environmental conditions, and this growth must be described by a Gompertz equation which may then be used to determine the daily requirement of each essential nutrient for maintenance and growth. Such evaluations have been conducted over the past 35 years (Hancock et al., 1985; Vargas et al.,

2020) which show the changes in mature body weight, rate of maturing and lipid-to-protein ratio, three of the most important changes addressed by poultry geneticists. More recently, Tyson's and Cobb have used the above procedure to evaluate the Cobb 700 and 500 strains, and their results are compared with the earlier evaluations, in Table 3.

**Table 2.** Progress in broiler growth over the past 70 years as measured by the number of days, and the amount of feed used, to reach a body weight of 1.8 kg.

| Period | Days to 1.8 kg | Food per unit gain |
|---|---|---|
| 1950 | 84 | 3.25 |
| 1960 | 70 | 2.50 |
| 1970 | 59 | 2.20 |
| 1980 | 51 | 2.10 |
| 1990 | 42 | 1.93 |
| 2000 | 36 | 1.55 |
| 2010 | 33 | 1.50 |
| 2020 | 28 | 1.46 |

**Table 3.** Changes measured in mature body protein weight (Pm, g), rate of maturing (B, /d) and lipid-to-protein ratio (LPRm) in Ross and Cobb broilers since 1985

| Strain | Date | Males | | | Females | | |
|---|---|---|---|---|---|---|---|
| | | Pm | B | LPRm | Pm | B | LPRm |
| Ross 788[1] | 1985 | 928 | 0.0340 | 1.00 | 730 | 0.0343 | 1.20 |
| Cobb 500[2] | 2018 | 1557 | 0.0310 | 0.59 | 1024 | 0.0351 | 1.28 |
| Ross 308[2] | 2018 | 1551 | 0.0322 | 0.57 | 1033 | 0.0345 | 1.17 |
| Cobb 700[3] | 2022 | 1632 | 0.0404 | 0.75 | 1204 | 0.0414 | 1.28 |

[1] Hancock et al. (1995)
[2] Vargas et al. (2020)
[3] Unpublished

Describing a genotype in terms of its Gompertz growth parameters, including the growth of body and feather protein as well as body lipid content, enables the calculation of the amount of each essential nutrient required by the bird on each day of the growing period. Comparing this requirement with the content of each nutrient supplied in the feed enables the calculation of the amount of feed the bird would need to consume in order to grow at its potential. Whether the bird is capable of consuming the desired amount of feed depends on whether it can lose sufficient heat to the environment and whether gut capacity is adequate.

Accounting for these constraints to desired feed intake is the key to predicting successfully the actual feed intake by the bird each day, and is the basis of the method devised by Emmans (1981; 1987) for predicting voluntary feed intake in farm animals. Few models can achieve this: in most models, feed intake is an input rather than an output, which prevents such models from being able to optimise feeds or feeding programs. The main benefit of a model that accurately predicts feed intake is that it may be used dynamically to optimise the feed composition that will maximise profit for the enterprise.

The above discussion is about defining the potential growth characteristics of a genotype, but this does not imply that a broiler producer should attempt to achieve this potential when feeding the flock of broilers. Knowing the potential enables the feed intake of the flock to be predicted, but the objective when feeding the flock should be to maximise profit from the enterprise, and this is likely always to be achieved at a lower growth rate than the potential.

***Determining the optimum economic feeding values***

The primary objective of most businesses is to make a profit. When using tables of nutrient requirements, or nutrient contents that maximise growth rate or feed efficiency, to define the lower bounds for nutrients in a feed formulation, the cost of feeding and revenue are ignored. Given the wide diversity globally in raw material costs, husbandry conditions, the form in which broilers are sold (live; dressed, with or without head, legs, giblets and fat pad; or further processed as portions with or without skin, or mechanically deboned meat) and markets for broiler meat, it is impossible to expect a fixed set of nutrient requirements to result in maximum profit in all situations. The lower bounds need to be dynamically chosen to reflect these differences, and to take account of changes in input costs and revenue. Possibly, the main reason for using fixed requirement values is that the nutritionist feels safe when justifying the levels used, as these are usually from reputable sources. Moving away from these fixed levels involves risk, the responsibility for which might be beyond the remit of the nutritionist. Yet, if management were made aware of the opportunity cost of using fixed nutrient requirements, they would surely approve of a more dynamic approach to defining the minimum bounds to be used.

The application of systems thinking and modelling to the problem of feed formulation leads to the replacement of the conventional approach with one in which nutritional decisions are made entirely in terms of the objectives of the business. Nutrient specifications are chosen that will maximise a desired objective function such as margin over feed cost, margin/$m^2$ per annum or number of hatching eggs per flock. Feeding animals to achieve some company objective is not the same as feeding them to meet a 'requirement'. Genetic potential as well as economic circumstances will change over time and different nutritional strategies will be needed to maximise margins. Also, nutritional decisions will depend on the stage in the production process at which margin is to be assessed. These are real differences, each requiring specific nutritional decisions.

Two approaches may be used to determine the optimum balanced protein levels to feed a flock under different economic circumstances. A protein response experiment, as described below, will provide information that can be used for this purpose; alternatively, simulation modelling may be used to provide the required information almost instantaneously at a fraction of the cost of a protein response trial. These approaches are described below.

***Defining the optimum using response experiments***

Assuming that the amino acid balance for each phase of broiler growth, published by breeding companies or Institutions (e.g., Rostagno *et al.,* 2017; Cobb, 2018; Aviagen, 2019) is correct, this balance could be used to formulate a range of balanced protein levels from, for example, 0.8 to 1.2 times the level recommended. By retaining the relative levels of amino acids in each phase of the feeding program, growth rate, feed intake and body composition could be measured over the range of balanced protein levels chosen. The resultant data may be used to calculate feeding costs and returns under different scenarios, and would remain relevant as long as the potential growth rate of the genotype remains constant. An example of the use of this approach is given in Table 4 (from Azevedo *et al*., 2022).

Because the amino acid recommendations of the three references in Table 4 differ, the maximum margin over feed cost occurs in some cases when balanced protein is below the recommendation and in others, above, within a sale category. But in all cases the optimum balanced protein level is highest for the more expensive product, thereby illustrating the folly of not taking account of the form in which the bird is sold when deciding on the lower bounds for dietary amino acid levels when formulating the feeds to be used.

In Table 5 the effect of changes in the cost of protein-containing ingredients on the optimum balanced protein level to use in broiler feeds is presented. Once again, the value of using a higher balanced protein content when selling further-processed birds is evident, but it is also apparent that when the cost of protein-containing ingredients change, so does the balanced protein content that maximises margin over feed cost. The opportunity cost, of using fixed amino acid lower bounds instead of reacting to changes in raw material costs and the form in which broilers are marketed, is substantial in many cases. Opportunities arising from changes in input costs or product value need to be seized immediately if maximum benefit is to be gained, and this is only possible if performance can be predicted, rather than measured in the field. Predicting nutritional responses so that the process of optimization may be speeded up may be achieved with the use of nutritional modelling.

**Table 4.** Estimated margin over feeding cost[a] of male and female broilers offered a range of balanced protein (BP) levels when sold live, dressed or further processed[b] on days 42 or 56

| Balanced Protein[c] | | | Day 42 | | Day 56 | |
|---|---|---|---|---|---|---|
| Rostagno | Cobb | Aviagen | Male | Female | Male | Female |
| | | | Margin from sale of live bird (US$/bird) | | | |
| 0.60 | 0.66 | 0.64 | 0.245 | 0.243 | 0.347 | 0.320 |
| 0.70 | 0.77 | 0.74 | 0.390 | 0.327 | 0.523 | **0.424** |
| 0.85 | 0.94 | 0.90 | **0.474** | **0.363** | **0.553** | 0.416 |
| 1.00 | 1.10 | 1.06 | 0.456 | 0.334 | 0.493 | 0.349 |
| | | | Margin from sale of dressed bird (US$/bird) | | | |
| 0.60 | 0.66 | 0.64 | 0.387 | 0.373 | 0.647 | 0.586 |
| 0.70 | 0.77 | 0.74 | 0.629 | 0.523 | 0.934 | 0.779 |
| 0.85 | 0.94 | 0.90 | 0.781 | **0.606** | 1.135 | **0.884** |
| 1.00 | 1.10 | 1.06 | **0.790** | 0.595 | **1.142** | 0.852 |
| | | | Margin from sale of further processed bird (US$/bird) | | | |
| 0.60 | 0.66 | 0.64 | 0.748 | 0.690 | 1.183 | 1.049 |
| 0.70 | 0.77 | 0.74 | 1.123 | 0.955 | 1.706 | 1.434 |
| 0.85 | 0.94 | 0.90 | 1.432 | 1.159 | 2.096 | 1.695 |
| 1.00 | 1.10 | 1.06 | **1.531** | **1.212** | **2.201** | **1.736** |

[a] Margin calculated using base prices for protein-containing ingredients and product sold.
[b] Breast, legs (thighs plus drums), wings and remainder.
[c] Proportion of balanced protein levels recommended by Rostagno *et al*. (2017), Cobb (2018) and Aviagen (2019) based on lysine recommendation in first two phases.

***Defining the optimum using simulation models***

The most important criterion when evaluating a simulation model to be used to optimise the feeding of broiler chickens is that it must be able to predict feed intake. Margin over feed cost is an appropriate objective function when maximising profit, so the cost of feeding is critical in determining the profitability of the enterprise, and feed intake changes with the dietary protein supply: contrary to the conventional wisdom that birds eat to satisfy their energy requirements. Determining the value of the output, or revenue, might appear to be straightforward, being the product of the weight of the bird and the price per unit weight, but broilers are sold in many different forms in different markets, and the optimum amino acid level will differ depending on whether the bird is sold live, dressed or further processed, as demonstrated above. The weights of different physical parts of broilers and turkeys at different ages or body weights can now be accurately predicted on the basis of the actual amount of a given feed that is consumed each day (Danisman & Gous, 2011; 2013; Gous et al., 2019) and hence revenue may be accurately predicted under different circumstances.

**Table 5.** Effect of increases or decreases of 25 % in the cost of protein-containing ingredients on the proportion of recommended [a] balanced dietary protein level that maximises margin over feed cost for broilers sold live, dressed or further processed [b] at 42 and 56 d of age (from Azevedo *et al*., 2022)

| Sales categories | Day 42 | | Day 56 | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| | Base price[c] | | | |
| Live bird | 0.92 | 0.88 | 0.88 | 0.82 |
| Dressed bird | 0.97 | 0.94 | 0.95 | 0.91 |
| Further processed | 1.04 | 1.01 | 1.02 | 0.99 |
| | Protein-ingredient prices -25 % | | | |
| Live bird | 1.00 | 0.96 | 0.98 | 0.93 |
| Dressed bird | 1.03 | 1.00 | 1.01 | 0.98 |
| Further processed | 1.08 | 1.06 | 1.07 | 1.04 |
| | Protein-ingredient prices +25 % | | | |
| Live bird | 0.85 | 0.80 | 0.77 | 0.71 |
| Dressed bird | 0.92 | 0.87 | 0.89 | 0.85 |
| Further processed | 1.00 | 0.97 | 0.98 | 0.95 |

[a] Balanced protein levels recommended by Rostagno *et al*. (2017).
[b] Breast, legs (thigh plus drum), wings and remainder.
[c] Ingredient prices used in the exercise presented in Table 4.

### *Choosing the objective function*

When optimising the way in which broilers should be fed, an objective function needs to be chosen. This may be defined in terms of any output from a broiler growth model, and is either maximised or minimised. Some producers are intent on minimising feed conversion ratio (FCR), whilst others may be required to minimise N or P excretion. Realistically, if the objective of the business is to make a profit, the objective function would be an economic indicator of some sort, such as margin over feed cost or margin per $m^2$/year.

To illustrate the effect of choosing to maximise margin over feed cost or to minimise FCR or N excretion as the objective function, an exercise was conducted using the EFG Broiler Growth Model (EFG Software, 2015). The Aviagen (2019) balanced amino acid recommendations were used as the basis of these comparisons, with lysine being used as the reference amino acid (Table 6). It is clear that considerable differences in performance and profitability may be achieved by changing the amino acid supply to achieve different objectives.

**Table 6.** Consequences on lower bound for lysine and on performance variables of maximising margin over feed cost or minimising feed conversion ratio (FCR) or N excretion

| | Base[1] | Maximise margin over feed cost | Minimise FCR | Minimise N excretion |
|---|---|---|---|---|
| Feed | | Lysine content, g/kg | | |
| Starter | 12.8 | 13.2 | 14.0 | 11.0 |
| Grower | 11.8 | 11.5 | 12.8 | 9.0 |
| Finisher | 10.0 | 8.0 | 12.0 | 8.0 |
| Performance variable | | | | |
| Live weight at 35 d (g) | 2020 | 2102 | 2007 | 1969 |
| Feed intake to 35 d (g) | 3507 | 3725 | 3417 | 3823 |
| FCR | 1.58 | 1.61 | **1.55** | 1.76 |
| N excretion (g/bird) | 96.0 | 94.0 | 102 | **83.3** |
| Cost of feeding (c/bird) | 1622 | 1620 | 1620 | 1556 |
| Revenue (c/bird) | 2224 | 2331 | 2208 | 2183 |
| Margin over feed cost (c/bird) | 602 | **711** | 588 | 627 |
| Cost of production (c/kg) | 1094 | 1043 | 1101 | 1070 |

Now that tools are available for predicting feed intake and the weights of different saleable parts of a broiler, it seems sensible to choose the levels of dietary amino acids to be used in a formulation program based on the objectives of the business (maximise profit) rather than to use fixed table values, no matter how these are derived.

## Summary

Simulation models that account for the changes in broiler genotypes brought about by genetic selection may be usefully employed to predict the potential growth of such genotypes in the future. In addition, if such models can accurately predict feed intake and hence growth rate and carcass composition, then broiler producers have a valuable tool with which to predict the nutrient requirements that would maximise profit for the broiler enterprise.

The optimization process that maximizes margin over feed cost, or any other suitable objective function, involves predicting the feed intake and hence cost of feeding, and revenue, based on the price and weight of the product sold, both of which can accurately be achieved with some of the simulation models available today. Making appropriate changes to the balanced protein content of the feeds offered whenever this is deemed necessary is a dynamic approach to feed formulation that will ensure greater profit for the enterprise than if the nutrient contents remained static, as is generally the case currently.

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