Modelling Broiler Populations for Purposes of Optimisation

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General Introduction

With the narrow margin of profit in the broiler enterprise, how can producers increase profit potential? It is not an easy task to answer this question since the net financial return depends on many factors; some are related to the animal, some to the feed, some to the environment and others are outside the production system, like availability and cost of labour and capital. Many researchers have attempted to improve the efficiency of the system using alternative management strategies and to develop a unified theory that could simultaneously evaluate all the relevant factors and the interactions between them. Simulation models are seen as the most promising means of moving this subject forward.

Geneticists are continually improving the potential growth rate of broilers, yet there has been little change in feed specifications for these birds over the past few decades. Only recently has it been possible to make use of simulation models to optimise the feeds and feeding programs of modern broiler strains at a commercial level, but little testing of these programs has been carried out. What is needed is a thorough investigation of these models, which at present are based on an individual, as opposed to a population response. Modelling plays an increasingly important part in animal science and research as a way of organizing and evaluating the large body of existing knowledge. With the use of an accurate description of the potential growth rates of broiler genotypes, it is possible to make more efficient use of growth models which are becoming more abundant in the industry and which, in turn, enable the nutritionist or producer to predict the performance of animals when subjected to a given feed or feeding programme.

The predictions made by most of the growth models now available are based on individual animals, and the results obtained may be inadequate in optimising the nutrient requirements of a broiler population because of the variation that exists in these populations. Variation in performance traits in broilers may be the result of variation in the genotype, in the environmental conditions within the house, and in the composition of the feed offered to the birds, and these sources of variation cannot all be accommodated in a model that simulates the food intake and growth of just one bird. But if variation is to be incorporated into growth models, it is necessary to ascertain the effects of variation in the various genetic parameters on the mean response of the population. A sensitivity analysis

is useful in accomplishing this objective. Similarly, it is important to know what the optimum size of a simulated population should be, that takes account both of the accuracy of the simulation and the time taken to complete the exercise. This is especially important when optimisation routines are followed, as such calculations are time consuming.

As a means of addressing these issues, simulation exercises were conducted using EFG Broiler Growth Model version 6 and EFG Broiler Optimiser Model version 1 (EFG Software, 2006) to determine:

(a) whether it is worth generating a population when optimising feeds and feeding programs for broilers, rather than using the average individual,

(b) the size of the population required to obtain an accurate estimate of the population response when optimising the feeding program for different objective functions,

(c) the effect of changing the value of genetic parameters such as mature protein weight, rate of maturing, feathering rate and the maximum lipid:protein ratio in the gain on the optimum amino acid contents and nutrient densities of broiler feeds, and

(d) the effect of variation in nutrient composition of different batches of feed, which have the same nutrient profile but different qualities of the main protein source, on broiler performance.

A review of sources of variation in the nutrient content of poultry feed was conducted, and simulation exercises were carried out to determine to what extent broiler performance is affected by the segregation or breakage of pellets into small pieces at the time of delivery and along the feed conveyor within the broiler house, by the change in nutrient quality that might occur along the conveyor, and by the microclimates that develop in a longitudinally ventilated broiler house.

The tendency in broiler marketing in most parts of the world is to sell broilers cut up, as portions or deboned after evisceration, rather than selling whole birds. Estimation of the growth rates of carcass parts is therefore of considerable importance if simulation models are to be useful in optimising the feeds and feeding programmes of broilers under different conditions. Allometric equations are used in the EFG broiler growth model to predict the weights of these carcass parts from the weight of body protein at the time. These equations are based on data collected many years ago, and it would be useful to determine whether they are still relevant in the face of announcements by the major broiler breeding

companies that tremendous strides have been made in improving breast meat yield, for example, by judicious selection. For the purpose of this investigation it was important to determine to what extent the weights of the physical parts varied at the same body protein weight, thereby enabling a more accurate estimation of the variation that could be expected in these weights when developing a population response model. Towards this end, experiments were conducted to determine the effect of dietary protein content on the performance of Cobb and Ross broilers, including mortality and uniformity, and on the allometric relationships between the physical and chemical components of the body and body protein.

The overall objective of these exercises was to address issues relating to the use of simulation models in predicting food intake and growth of broilers, in optimising the amino acid contents and nutrient densities of feeds for broilers, and in representing a population of broilers when the performance of only one bird is simulated at a time.

Chapter 1

Modelling and optimising feeding programs of broilers

1.1 Introduction

Maximization of profit is the main objective of modern broiler production. The net financial return depends on many factors; some are related to the animal, some to the feed, some to the environment and others are outside the production system, like availability and cost of labour and capital. Since feed is the largest item of production cost, the determination of the most profitable feeding programme in relation to broiler characteristics becomes the essential components driving production efficiency.

The problem faced by nutritionists and broiler producers in formulating a feeding system for growing broilers include making decisions about the minimum bounds of each of the essential nutrients in each of these feeds, deciding when each feed should be replaced by the next in the series, whether males and females should be fed similar feeds and for the same length of time, how to account for strain differences in potential growth rate, and whether the feeding programme should remain the same irrespective of the price of ingredients. These and many other questions based on biology and on economics just cannot be solved with the knowledge of experimental results. The solutions can only be found with the use of simulation models (Gous, 1998, 2002). This can be of considerable help to nutritionists and broiler producers in improving the basis on which nutritional decisions are made, thereby improving the profitability of a broiler enterprise.

Models can be developed for different production priorities. However, if the overall goal of a model is to optimise the operation, many of the above factors will need to be incorporated into the model if it is to be of use: genetic potential, sex differences, lean tissue deposition, intake patterns, feedstuff digestibility, environmental conditions, bird variation, parts yield, and other factors (e.g. disease) (Firman, 1994; Gous, 2002).

Variation in the performance of traits in broilers may be the result of variation in a number of factors that influence the trait. There are at least three sources of variation in any broiler house: variation in individual genotypes, variation in environmental conditions within the

house, and variation in the composition of the feed brought about by ingredients used and by separation of feed in the feed trucks during transportation, and along conveyors within the house. However, several models have been developed at a single bird level, for instance genotype-specific models that consider an individual animal as being representative of a population of broilers. This model is considered a fixed effect model because there is no random effect associated with mature weight and as a result, it is not satisfactory to optimise the feeding program of a population of boilers. Population models should be developed in order to predict both the expected value and the overall probability distribution of the parameter.

For models that are too complex for investigation of their properties by formal mathematics, simulation is an important tool verifying that model performs as intended (Brown and Rothery, 1994). Simulation may be used for both deterministic and stochastic models. According to Brown and Rothery (1994), the difference between the two types of models: one simulation is adequate for a deterministic model, whereas many simulations (each one corresponding to an independently selected random choice for the stochastic elements) are usually necessary for a stochastic model.

This review will focus on information gathered for the development of a population optimisation model; it will investigate the important parameters for proper optimisation procedures and discuss the theories and principles of bioeconomic growth models.

1.2 Types of models

Models can be defined broadly as static or dynamic, deterministic or stochastic and as either empirical or mechanistic (Black, 1995a). Dynamic models describe time explicitly as opposed to static models that represent the state of a system for only one instant in time. Computer simulation models are by their nature dynamic. The state of the system is continually predicted over time.

Deterministic models produce only outcomes from a calculation whereas with stochastic models there is a range of possible outcomes representing natural variability. The majority of animal simulation models that are currently available are deterministic. That is, they predict the outcome for one animal that is assumed to represent the mean of a group of

similar animals. A stochastic model considers probability distributions, such as those that relate to variation and covariation (Knap, 1995). The Reading model used for predicting nutrient responses (Fisher *et al*., 1973); the EFG Broiler Growth Model for predicting broiler performance and economic analysis (Emmans *et al*., 2003); to predict nutrient requirement or to economically optimise swine production system (Pomar *et al*., 2003) are examples of such models.

Empirical models are based on equations that describe correlations and associations between two or more variables and which imply nothing about the underlying mechanisms controlling operations within the system (Zoons *et al*., 1991; Black, 1995a). Mechanistic models describe relationships between dependent and independent variables by a pathway representing the biological process. Emmans (1981a and b) concluded that the Gompertz function is frequently chosen as a means of describing the potential growth rate of an individual in mechanistic models for its mathematical properties, biological meaning of parameters and its reasonable fit. The limitation of empirical models is that the model describes only a mathematical relationship between a dependent variable and an independent variable without further explanation of the biological processes involved (Zoons *et al*., 1991; Black, 1995a). As a result, when these relationships are incorporated into computer simulation models, predictions are frequently inaccurate.

In addition to the above broad classification, models differ from one other in the problems that they recognise and in the solutions that they give to these problems (Emmans, 1995).

1.3 Evolution of models

The first animal growth models were static models (Whittemore, 1980; Black, 1995a). Gompertz (1825) as cited by Parks (1982) published some of the first work in animal growth and nutritional requirement. The calculations of nutrient requirements of animals at specific body weights were based on factorial representations. Later research was mostly limited to developing prediction equations and standard growth curves for various animals that reflected responses to management, genetic selection and dietary treatment (Fisher *et al*., 1973; Macleod, 2000). Emmans (1981b, 1987) and Emmans and Fisher (1986) utilised Gompertz growth curves of the maximum genetic potential for broilers and later on commercialised for personal computers as the FORTEL^{TM} model, with improvements in

the theoretical aspects. Hurwitz and his colleagues at Hebrew University developed another model (Hurwitz *et al.,* 1978; Talpaz *et al*., 1986; Talpaz *et al*., 1991). This model is available under the name of CHICKOPT™ (Oviedo-Rondon and Waldroup, 2002).

Subsequently, broiler growth models were prepared by several groups, including Pesti *et al*. (1986); Ivey Growth model (IGM®) (Harlow and Ivey, 1994); Bromely Park Hatcheries Limited growth model (BPHL) (King, 2001); Liebert and coworkers (2000) as cited by Oviedo-Rondon and Waldroup (2002), have been working on a model to evaluate the utilisation of limiting amino acids and derivation of requirements. Each of these models contained various combinations of empirical and mechanistic equations and all were designed to be practical use for solving whole animal problems. EFG Software (2006) of Kwazulu-Natal, South Africa has developed a model to estimate the optimum concentration of amino acids and energy to determine the economical feeding program for broilers and other species (Fisher and Gous, 2000; Gous, 2001). This program makes use of the theoretical concepts developed by Emmans (1981a and b); Emmans and Fisher (1986); Emmans (1987a and b). The details of the new version of this model will be discussed further in the thesis.

Generally, with the help of modern computer data processors, growth models are improved from time to time with minimum prediction error. However, they have had limited utilisation by nutritionist. This is partly due to the incomplete description of the animal, the environmental conditions and other factors (e.g. the effect of marginal deficiencies of amino acids on the performance of different strains, down-grading, etc.), which affect the optimisation program.

1.4 Modelling process

The word ‘model’ implies a mechanism for the simulation of real animal responses: it requires inputs, a means of processing them, and delivers outputs (Whittemore, 1980). The major steps in the process of modeling a whole animal are outlined in Figure 1.

The animal is a physiological system with measurable features (physiological data) and biological process (physiological pathways). The first step in modeling is to collect the relevant basic data that explain the whole system. The physiological processes and the

control of the system are then developed from this information. The concepts and data are transformed into mathematical equations by algorithms that can be solved rapidly by computer programs in a quantitative and dynamic approach.

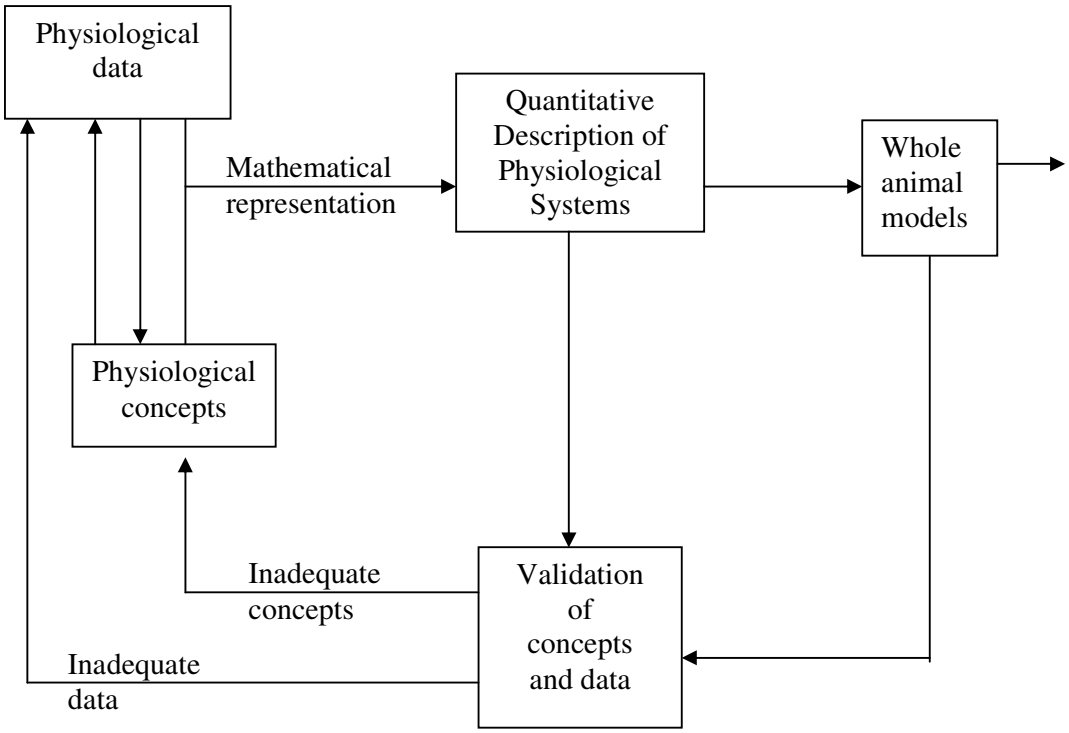

Figure 1.1: An outline of the major steps in the modelling process (adapted from Black *et al*., 1993).

The next step is to check the validity of the model with regard to pathways and information, by comparing simulations outputs with the experimental results. The process of validation continues until the model outputs and actual observations agree over a wide range of different situation. Otherwise, the modeling process begins again whenever there is a considerable difference between the predictions and the actual results.

1.5 Testing and evaluation of models

Testing and evaluation of models is a long and on-going process (Stilborn *et al*., 1994; Black, 1995b). Model evaluation is concerned with establishing the appropriateness and accuracy of predictions over a wide range of simulated conditions. The first step in evaluating a model is to know how the model will be used (Harlow and Ivey, 1994). Most of the evaluation processes include examining the general behaviour of the model, identifying the variables and equation parameters to which the model outputs are highly sensitive (Black, 1995b; Berhe, 2004), determination of accuracy, its precision and its bias (Harlow and Ivey, 1994).

The existence of accurate results from experiments and complete description of experimental conditions to which the model is sensitive determine the evaluation results. Some of the available growth models evaluated by different researchers: Chickopt™ model was evaluated for broilers (Hurwitz *et al*., 1980); growing turkeys (Hurwitz *et al*., 1983a; Hurwitz *et al*., 1983b); Ivey Growth Model (IGM®) and EFG nutrition optimiser has been tested for accuracy by Harlow and Ivey (1994) and Gous (2001; 2002) respectively.

A model may be accurate and precise but for various reasons may not predict the response of broilers to changes in a feeding program, e.g. because the growth curves, efficiency of feed utilisation and resistance to stress differ between strains (Harlow and Ivey, 1994). However, it is important to understand the strengths and weaknesses of any model in order to obtain the maximum commercial benefit from that model.

1.6 Applications and limitations of models

Models help to identify those aspects of the animal that are covered by assumptions and which need experimentation. The use of models has been discussed in depth by Harlow and Ivey (1994), Hruby *et al*. (1994), Ferguson (1996), Schinckel *et al*. (2003), Hermesch *et al*. (2003) and Moughan (2003). Furthermore, models can be useful in preventing time and money being wasted on further experimentation that will produce information that is already known, and to identify areas of future research (Black, 1995a). Results of

experiments allow an individual or producer to make decisions by considering the risks associated with biological production system (Gous, 2002).

A major limiting factor in the application of animal growth models is lack of an adequate description of the conditions within commercial enterprises (Black, 1995b). A description of the potential growth rate of different genotypes is a first step in using simulation models, either to predict requirements or to predict the effects of different feeding programs and environmental conditions, on the performance of broiler (Stilborn *et al*., 1994; Hancock *et al*., 1995; Gous *et al*., 1999). Some of the available models are based exclusively on empirical observations, such as direct relationships between daily lysine and energy intake, and average daily gain in growing animals, established using multiple regression (Birkett and de Lange, 2001). However, considering the major objective of any animal production enterprise, which is maximizing the margin over feed cost, there is no better way to obtain the optimum economic feeding strategy than by the use of simulation models (Gous, 1998, 2002).

1.7 Modelling broiler growth

The general problem in animal production is that of predicting growth rate, body composition and feed intake (Emmans and Fisher, 1986; Emmans and Oldham, 1988; Ferguson and Gous, 1993). It is widely believed that the composition of the body will change systematically, in both chemical and physical terms, when potential growth is attained (Emmans, 1995) and a sufficient description of potential performance must deal with such changes (Gous *et al*., 1999). Zoons *et al*. (1991) described growth as a complex phenomenon determined by both genetic and environment factors. The problem of predicting growth rate, which is crucial in nutrition (Emmans and Fisher, 1986), can be approached in one of three ways:

- The prediction of the growth of the empty body as a whole;
- The separate prediction of the growth of the four chemical components and
- The prediction of one component with the remaining three considered in relation to this component.

Emmans (1981b) mentioned that growth is made up of two components: normal growth (protein, ash, water and some minimum amount of lipid) and fat growth. Armsby and

Moulton (1925) as cited by Emmans and Fisher (1986) suggested that the body of an animal can be considered as gut fill and the empty body weight

1.7.1 The empty body weight and its components

The empty body weight can be defined as the plucked body weight minus the gut fill. The body tissue can be considered as the sum of the weight of protein, ash, water and lipid with small amount of carbohydrate being ignored. Most of the available model (Emmans, 1981b; Emmans and Fisher, 1986; Emmans *et al*., 2002) use the third approach, protein as a base component from which the remaining three components are calculated. The lipid-free dry matter can be considered as a homogenous component (Emmans and Oldham, 1988). Protein in the body can be described by means of a growth function, and strict relationships between weights of the body components in the potential growth (Emmans and Fisher, 1986; Emmans and Oldham, 1988; Emmans, 1989) can be used to determine the growth of water, ash and lipid. Therefore, body protein is the driving variable in most of the models, with moisture and ash contents, and rates of growth, determined by their allometric relationships that exist with protein (Emmans, 1981b; 1987a; 1989; Emmans and Fisher, 1986; Hancock *et al*., 1995; Gous *et al*., 1999 and Emmans *et al*., 2002). If two components of the body have the same value for the rate parameter B then an allometric relationship is expected (Emmans, 1988). However, Hancock *et al.* (1995) and Gous *et al.* (1999) reported that there was a problem in estimating the mature lipid weight after 56d of growth in females using a simple allometric relationship, due to rapid increases in lipid deposition after 56d of age. Imbalanced feed, the digestibility of the feed, feed restriction and sex can alter the rate of lipid deposition in relation to protein deposition, so the allometric relationship that exists between these components can be applied only when the animal is growing at its potential in a thermoneutral environment (Emmans and Oldham, 1988). Gous *et al*., 1990 and Gous (1998) suggested that a free-choice feeding systems should be applied when evaluating the growth parameters and allometric relationships of broiler strains, to obtain a more accurate estimate of the mature lipid to protein content of the strains.

On the other hand, some researchers had a different suggestion about the relationship between the empty body components. Eits *et al*. (2002) suggested that the constant

relationship between water or ash and protein will only exist if the animals are growing according to their potential growth curve under the conditions of *ad libitum* consumption of balanced diets. According to these authors, the ash to protein ratio was strongly affected by nutrition, at extreme protein ratios. Kyriazakis and Emmans (1992) assumed that, in case of limited growth, deposition rates of water and protein are assumed to decrease in line with their inherent allometric relationship. However this assumption was not supported by Eits *et al*. (2002) findings at certain protein weights. Therefore, the theory of Kyriazakis and Emmans (1992) may not be generally valid across all genotypes or degrees of maturity (Eits *et al*., 2002).

There are different methods of estimating lipid and protein during model development. Emmans (1981b) predicted lipid retention as a function of the current state of the animal rather than as a function of the energy surplus consumed by the animal. This is because lipid content of the growth of birds can be dramatically affected by the composition and bulkiness of feed, environmental condition and the ability of the bird to lose heat (Emmans, 1981b; 1987a, b). Kyriazakis and Emmans (1991) have demonstrated conclusively that animals and birds will make use of lipid reserves as an energy source when the dietary protein supply is sufficiently abundant, and when the lipid content of the animal is in excess of the genetically determined lipid to protein ratio in the body, brought about by feeding excessive amounts of energy. A more sensible approach to modeling growth would be to describe the potential growth rate of the animal before considering the effects of nutrition (Emmans and Fisher, 1986). As a result, food intake can then be predicted without any feedback effect.

The first requirement for modelling is breed description, characterized by mature body weight, mature fat content, and rate of maturing for body and feather protein (Stilborn *et al*., 1994). From this information, it is possible to derive the genetic parameters (for instance, mature protein, lipid to protein ratio, etc.). For instance, the genetic parameters required for the Edinburgh growth model (Emmans 1981a) were mature protein weight, rate of maturity, the time at which body weight gain was maximal (t^*), the minimum lipid to protein ratio at maturity. Subsequently, as in the case of the EFG broiler growth model (Emmans *et al*., 2002) initial body weight, feathering rate and maximum lipid in the gain were added to the above parameters. These parameters had a significant effect on the performance of broilers and the effect varied depending on the feed composition (Berhe,

2004; Berhe and Gous, 2004). Because of the difficulty in obtaining the values of the parameters used to describe the potential growth rate of broilers, the EFG model allows the user to describe a minimum number of variables, from which the parameters of the Gompertz growth curve are derived for both males and females. Once the genotype is described, the feed composition and the environmental variables should be incorporated to make the prediction output more realistic.

1.7.2 Physical body composition of the growing broiler

Gut fill (GF) represents the difference between the empty and the live body weight. It is clear that GF can be affected by feeding level, feed characteristics and time of feeding. In order to determine the feather-free body weight gains from the growth rate of the empty body, the amount of gut fill must be predicted or known. In most poultry growth models, gut fill is either regarded as a constant proportion of live weight or is ignored, and this could be considered as a weakness in growth model development. Emmans (1989) described in detail the growth of the physical body of turkey. He considered the meat, skin, giblets, abdominal fat, evisceration losses, blood and feather and total carcass bone. It is difficult to construct a mathematical relationship between these parameter since there is considerable variation due to differences within and between eviscerators when separating these parts from the carcasses, in addition to the genetic differences that exist. According to Emmans (1989), carcass bone weight may be taken as the physical measure of size as that of body protein weight is used as the chemical measure of size. According to his report, the relationship between these two measures of size were consistent, with both carcass bone and body protein weight following a Gompertz function.

Breast meat represents the largest portion of carcass weight. Gous *et al*. (1999) found that the value of the rate parameter for *pectoralis major* and *minor*, and for their sum, was the same as for the empty feather-free body for all the genotypes tested. That is, the assumption of a simple allometry between the two tissues is justified (Emmans, 1988). Therefore, it is possible to estimate breast meat from the empty feather-free body weight.

The growth of feathers

Considerable attention has been given to predicting feather growth from either body protein or empty feather-free body weight (Emmans, 1989; Hruby *et al*., 1994; Stillborn *et al*., 1994; Hruby *et al*., 1995) because of the difficulties in describing the growth of feather. Hancock *et al*. (1995) and Gous *et al*. (1999) found that the rate parameter, B, for feathers was greater than that for either body protein or that for the total feather-free body. Therefore, there was no justification for using an allometric analysis (Emmans, 1988). Moreover, some description of mature feathering is needed, in addition to the rate parameter for feathers (Gous *et al*., 1999).

Rate of feather growth is a useful measure when comparing genotypes (Emmans *et al*, 2002; Berhe, 2004; Berhe and Gous, 2004). It should be included in any broiler growth model since the difference in the rate of feather development during different stages of growth, as well as between sexes, would contribute to a change in the response to amino acid supply.

In general, the relationships between nutrient intake and chemical and physical body composition are affected by a range of factors associated with nutrition, genotype, environment, and stage of maturity (Hruby *et al*., 1994; Gous, 1998; de Lange *et al*., 2003). In order to identify practical means of manipulating production efficiency, an understanding of these relationships is required. Simulation of body weight gain or chemical body composition solely based on protein deposition might be accurate in case of animals with *ad libitum* consumption of balanced diets but can induce systematic errors in the simulations in case of low food intakes or extreme protein to energy ratios. This is because the values of other variables in models, such as maintenance, heat loss, *ad libitum* food intake and physical body weight, may have a significant impact on the accuracy of predictions by such models (Emmans and Kyriazakis, 1995).

1.7.3 Predicting food intake

Accurate predictions of food intake are important for production systems due to the low profit margins inherent in such systems. In order to predict the amount of food that the

animal will consume under *ad libitum* conditions, it is necessary first to be able to predict the rate of intake in a non-limiting environment and on a balanced feed (Gous, 2002). According to Emmans and Fisher (1986) this rate of intake is termed the 'desired food intake' and is that which will allow the potential growth rate to be attained, since the animal is assumed to eat to satisfy its requirement for the first limiting feed resource. This theory of food intake is discussed by Emmans and Fisher (1986).

The idea of 'eating to requirement' has been remarkably successful in predicting the voluntary food intake of growing animals (Emmans, 1997). This requirement model assumes that an animal consumes feed in order to meet its genetic potential, subject to constraints such as gut volume, where genetic potential is defined as an animal's growth rate given that its environment has never been a limiting factor (Emmans, 1981b; Gous, 1998, 1999; Yearsley *et al*., 2001). An animal's total food intake requirement is therefore determined by the sum of its maintenance and its growth requirements. A detailed description of the requirements model is presented by Emmans and Kyriazakis (2001). In the case where food intake is constrained, the accuracy of the model's prediction is determined by the accuracy with which the constraints can be specified (Yearsley *et al*., 2001).

Once food intake is known, it is possible to predict many variables, e.g. body protein growth rate, all chemical and physical component, income and cost of feeding.

1.8 Optimising the feeding program for broilers

Broiler production is a highly competitive enterprise, characterized by small margins. The optimum feeding program for broilers is that which results in the highest profit for the enterprise. In this context, maximizing economic efficiency is crucial because feed is the largest production cost in the enterprise. Determining the optimum nutrient density, the optimum concentrations of amino acids relative to energy in each feed, and the optimum length of time that each feed should be fed, is therefore both a nutritional and an economical decision (Gous, 1998, 2002). Furthermore, various studies (De Lange and Schreurs, 1995; Moughan *et al*., 1995) have shown that maximizing technical criteria does not always yield the highest net return.

Optimising the feeding of commercial broilers during their growing period is not an easy mission. The traditional approach to predicting performance has been to carry out experiments in which different nutrient contents are fed and the outcome is resolved, or using experience as an accurate means of predicting the consequences of different courses of action, but these approaches are not sustainable (Gous, 2002). For instance, the dietary amino acid content producing the maximum growth response is often regarded as being the requirement for that amino acid. However, Fisher *et al*. (1973) have shown that requirements of animals are not fixed but are variable. According to Gous (2002; 2004) it is important to understand the interaction between the bird, the environment and feed and feeding programme used before the optimum economic feeding schedule can be determined. This needs extremely complex experiments to test all combinations of these factors; and then because of the changes that take place in the genotypes themselves these experiments would have to be repeated at regular intervals. Therefore, experiments should be used to measure the numbers that will make a theory work, or to test the theory, or to allow the nutritionists and/or the producers to choose between two theories (Gous, 2002; 2004). He recommended that it is only through the development of a plausible theory, and the advent of computers, that it has been possible to integrate all of these factors into a workable form.

Considerable attention has been given to the development of mathematical models representing the growth of broilers to evaluate the response of any change in the production strategies and to improve profitability. There is no defensible way of estimating the nutrient requirements of growing animals or of optimising the feeding of broilers, other than by the use of simulation models (Gous, 2002; 2004).

1.8.1 Parameters need to be considered for simulation of optimisation models

As modelling becomes a more important tool for optimising the feeding program of animals, it is crucial to identify and quantify the information required for optimisation. However, different models use different approaches although they have similar basic principles. These include the most significant factors, such as genotype, feeding program or diet composition, and environmental aspects (Bailleul *et al*., 2000; Gous, 2001). According to Gous (2002; 2004), the information required for optimisation consists of feed

costs at different levels of amino acid provision, a description of all the relevant details of revenue for slaughter house variables (eviscerated yield, rejects, etc.), carcass composition and further processing. He explained that the feed costs for any nutritional specification are readily calculated by linear programming. This will take account of feed ingredient availability, to which transportation and processing costs may be added. Then, the problem of optimisation will be in the definition of animal response (Gous, 2004). In order to fill the gap which is missed in the optimisation procedures, Gous (2002; 2004) suggested that the following information would be necessary to determine the potential protein growth rate of the genotype; differences between individuals at a time and within individuals over time; the effect of nutrient content and energy-to- protein ratio on food intake, carcass composition and protein gain; the effect of genotype on the amount of excess energy that may be stored as body lipid, and the maximum rate at which this can take place; the effects of high or low environmental temperatures on all of the above; and the constraints placed on the animal by the environment and by the feed, which prevent the birds from consuming the necessary amount of a feed to grow at their potential. Considering the above information, it will be easy to apply both nutritional and economical decisions in any broiler production. However, again, this will be achievable only with the use of an accurate simulation model (Gous, 1998; 2002; 2004).

Some of the available poultry optimisation models include the 'Reading' model, which determines the optimum amino acid intake of a flock of laying hens to maximize profit, based on the relationship between the marginal cost of the amino acid and the marginal revenue for eggs, as well as the standard deviations of egg output and body weight in the flock (Curnow, 1973; Fisher *et al*., 1973); the Chickopt™ program, which consists of an optimizer tied to a compartmental growth model based upon a Gompertz growth curve (Harlow and Ivey, 1994); the OmniPro® ll model in which amino acid estimations are based on a sum of maintenance and weight gain for body tissues and feathers, divided by the efficiency of absorption (Oviedo-Rondón *et al*., 2003), a theoretical idea proposed by Hurwitz *et al*. (1978); and the Pesti *et al*. (1986) model, which is based on the quadratic response of the birds to feed, where feed cost is determined as a variable of the profit maximization model. This implies that the complexity or the type of information required would depend on the level of organization at which the optimisation is to be made.

1.8.1.1 Approach used in the EFG Broiler nutrition optimiser

EFG Broiler nutrition optimiser has recently been developed by EFG Software[1]. It can be defined as a dynamic, deterministic and mechanistic optimisation model. The integrated optimisation system comprises:

1. a feed formulation program, WinFeed 2
2. a broiler growth model
3. an optimisation routine

The flow of information is presented in Figure 2. The optimiser defines nutritional constraints for practical broiler feeds. These are passed to the feed formulation program where the least-cost feed that meets these constraints is determined. The characteristics of this formulated feed are then passed, as input, to the broiler growth model. The performance expected from this feed when given to a defined flock of broilers in a given environment is predicted by the model, and this predicted performance is then passed to the optimiser to complete the cycle.

The next cycle starts by the optimiser modifying the feed specifications according to some inherent rules, to an optimum. The objective function to be optimised can be defined in terms of any output from the broiler growth model, but realistically would be an economic index of some sort.

The broiler growth model calculates revenues from any mixture of whole-bird sales or processing. Typical economic variables are included although these are readily customised to fit with individual enterprises. The key to this approach clearly lies in the ability of the broiler growth model to reflect accurately the performance expected under commercial conditions.

[1] EFG Software (KwaZulu-Natal), 25 Fairfield Ave., Pietermaritzburg 3201, South Africa, Tel: +27 33 260 6805, Fax: +27 33 260 6806, e-mail: gous@ukzn.ac.za

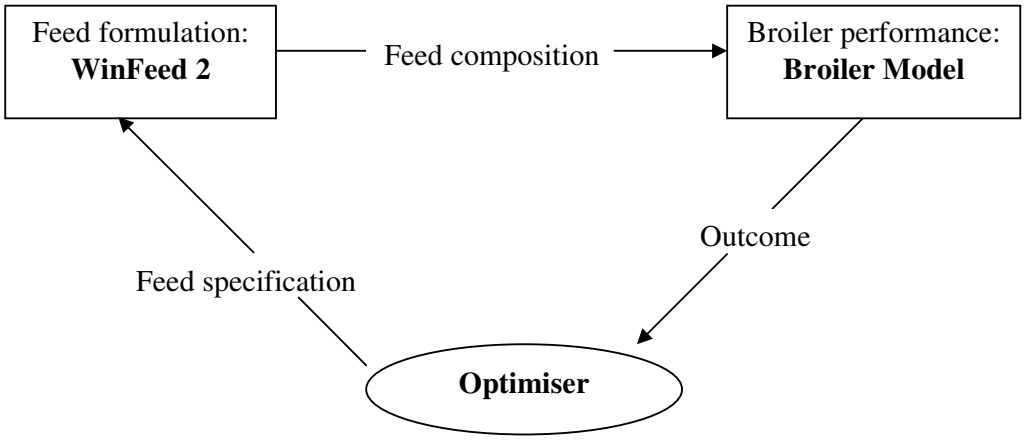

Figure 1.2: Flow of information in optimising the feeding program of a broiler chicken (adapted from Gous, 2002).

The feed formulator, WinFeed2, takes account of all the basic information (including feed prices, feed and nutrient constraints etc.) and passes the necessary information (digestible amino acid content, ME, digestible protein and lipid content) to the broiler growth model.

Currently, the EFG Broiler nutrition optimiser optimises, independently, three aspects of a commercial broiler feeding programme:

- it optimises amino acid contents in each feed, given a feeding schedule;
- it optimise the nutrient density of each feed in the feeding schedule, and
- given feeds of a fixed composition, the optimum feeding schedule is determined.

The optimum feeding schedule would differ depending on the amino acid content and the nutrient density in each of the feeds in the feeding schedule, so ideally, all of these variables should be optimised simultaneously. The complete approach of this optimiser with examples was described in Gous (2001; 2002).

1.9 Dealing with populations rather than with individual broilers

Almost all broiler and pig growth models (referenced above) have been developed at the level of one animal, yet commercially it is populations that are being managed and fed. Individual models assume that all broilers have equal growth potentials and are at the same stage of growth. Therefore it is not entirely satisfactory when optimising the feeding of a population of broilers using such models. However, in order to predict nutrient requirements of a population over time, it is important to understand first how an individual within the population will respond, at a time, to increasing dietary concentrations of the nutrient (Emmans and Fisher, 1986). The efficiency of an animal production system results from the efficiency of individual animals (Knap, 1995). For instance, the Reading model (Fisher *et al*., 1973) is based on the assumption of a simple linear-plateau relationship between amino acid intake and the output characteristics for an individual. The response of a group of birds is then derived as the average of the individual responses.

Emmans (1995) and Ferguson *et al*. (1997) suggested that the problem of predicting the growth of a population of birds was best approached by considering firstly the growth of an individual and then the variation between the individuals that comprise the population (Figure 3). The approach is discussed in Emmans and Fisher (1986).

Knap (1995) outlined the reasons for considering variation between animals in growth models when simulating different systems:

- The profitability of the systems may be affected to a large extent by the amount of variation in the production traits;
- The change from one system to another may have small effects on average levels but large effects on variation;
- Differences between systems can be discovered more readily when variation is made visible; and
- In order to study the relationships between traits, covariance should be created, which requires variation (Emmans and Fisher, 1986).

According to Gous (2002) differences between treatment means are generally meaningless when the difference cannot be compared to the amount of variation within treatments.

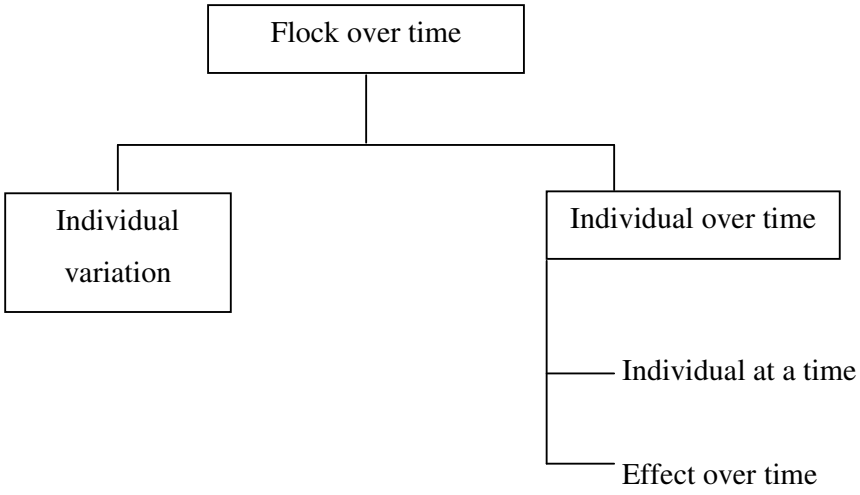

Figure 1.3: Analysis of the problem of predicting the performance of a flock (adapted from Emmans, 1995).

There are also models that predict the performance of a population taking into account the different maintenance requirements and maximum production potential, e.g. The Reading Model (Fisher *et al*., 1973), EFG Broiler Growth Model (Emmans *et al*., 2003), Pig Model (Pomar *et al*., 2003). The Reading model has shown how the response of individuals (laying hens) is very different when these responses are combined into a population response. Whereas the response of an individual hen to an increasing supply of an amino acid is linear up to a point and then a plateau is reached where no further increase in response can be measured, the population response is a continuous curve with no abrupt threshold. This is the result of combining the responses of a range of individuals at a time. In growing animals there are differences in the same animal over time as well as between animals at a time, making the need for a population model of broiler growth even more important (or critical) than in the case of laying hens, which are in a relatively steady state.

Pomar *et al*. (2003) and Berhe and Gous (2004) simulated a population of pigs and broilers respectively, using a similar technique and reported that maximum protein deposition occurred when there was no variation in the populations of pigs or broilers and that the degree of curvature of the transition zone increased with the population variability. They illustrated that less protein was deposited and there was a greater degree of curvature in the response in more variable populations.

Most nutrition-growth models use amino acids as a stochastic parameter in the simulation exercise considering the cost and important role in the feed formulation and animal performance. However, the relationship between protein retention and supply has been represented in many ways; such as constant efficiency (Zhang *et al*., 1984), as two phase linear (Taylor *et al*., 1979), as curvilinear (Fuller and Garthwaite, 1993), or by linear plateau (Campbell *et al*., 1984). The linear plateau model is most commonly used in growth response models. However, most researchers suggest that efficiency of protein is not constant but decreases gradually as protein increases or energy intake decreases (ARC, 1981). The adequacy of the linear plateau model is not supported by experimental results and some concerns have been raised in relation to its suitability when representing a population of pigs or broilers (Moughan, 1999). According to Curnow (1973), Fisher *et al*. (1973) and Fuller and Garthwaitte (1993), a curvilinear response of protein deposition to protein intake, at the level of the population, might result from variation in individual animal responses. The simulation results of Pomar *et al*. (2003) and Berhe (2004) indicate that the linear plateau model for individual animal is compatible with observations made in experiments, which result in a curvilinear response in protein gain to increases in protein intake within a population.

1.10 Discussion

Over the last decades many models have attempted to integrate theories and observations into a sound framework that can be useful for both conceptual and computational purposes. Currently, the few optimisation models available to researchers and producers vary in the amount of information considered as inputs to the model, with stochasticity being totally neglected in most models.

In a situation where the population is infinite, it is impossible to sample the whole population. It is very difficult to decide upon an efficient method of generating a population considering the extent of variation between the parameters and time taken to simulate the performance of each individual. The generated individuals should be as representative as possible of the population. Gous (1998) and Berhe (2004) used 500 and 100 males and females separately to represent the population, respectively. Both authors reported that the response of the average individual differed from that of the mean of the population but the difference between the two responses was greater in the simulation

results of Gous (1998). In pigs, 465, 500 and 2,500 individuals or replicates were used by Ferguson *et al*., 1997; Knap (2000) and Pomar *et al*. (2003), respectively, to account for individual variations in their simulation exercises. There is no consensus in the literature of the optimum number of individuals that will adequately represent the population when optimising the feeds and feeding programme of broilers. Considering that the time taken to simulate a population increases with the number of individuals it is worthwhile determining the optimum number of individuals to use when simulating a population response.

Poor uniformity reduces revenue and increases waste, and therefore optimisation programs should account for the most important factors that may influence uniformity. A marginally deficient feed is one of many factors that affect the uniformity of the flock. This is due to the capability of some birds to consume more than others; these birds benefit from the extra feed and grow faster than those whose intake is constrained by gut capacity or the inability to lose sufficient heat to the environment. Some strains have been observed to exhibit increased mortality on marginally deficient feeds, the cause of which is not yet known. This has important implications when optimising the feeds and feeding programme of broilers.

This review indicates that there are crucial knowledge gaps with regard to development of comprehensive population growth models. This project is concerned with simulating the consequence of different degrees of genetic and feed variation with a view to optimising the feeding of broiler at the population level.

Chapter 2

Effects of feed protein content on the performance, uniformity and mortality of Cobb and Ross broilers in the period to 21d of age

Abstract

An experiment was conducted to determine the response of two broiler strains available in South Africa to different dietary protein levels on performance including uniformity and mortality percentage. 480 Cobb and 480 Ross day-old sexed broiler chickens were housed in cages. Ninety-six cages were used with 10 chickens per pen and with males and females being reared separately. Two basal feeds, one high (H) and the other low (L) in protein were formulated to contain equal contents of ME and major minerals, using a well balanced amino acid mixture. These two feeds were blended (20H:80L, 40H:60L, 60H:40L, 80H:20L) to produce four additional levels of protein. Food intake and body weight of individual birds in each pen was measured at weekly intervals up to 21d.The highest body weight gain and feed conversion efficiency (FCE, g gain/ kg food), were recorded in the Cobb strain, with a correspondingly higher food intake. Dietary protein content had a quadratic effect ($P<0.001$) on all measures of performance, but not in the slopes of the response between the two strains. The body weight gain of the Cobb strain was 1.7g/d greater than the Ross strain and the FCE was 34.5g gain/kg feed consumed greater than the Ross strain. There were no interactions between the treatments in any of the parameters measured. In general, a variation of individual body weights was similar between the two strains. There was a higher mortality in the Cobb strain relative to Ross, especially at low protein contents, but the trend was not consistent across the feed protein contents. In conclusion, the two strains used in this trial, to 21d, exhibited similar responses to changes in dietary protein content, although the Cobb strain consumed more food and hence grew faster at all protein contents than did the Ross strain.

2.1 Introduction

Considerable attention has been focussed on determining the responses to dietary protein in broilers using the common measures of performance such as body weight gain, food consumption and conversion, and even carcass composition (Cahaner *et al*., 1987; Cabel

and Waldroup, 1991; Smith and Pesti, 1998; Swatson *et al*., 2000; Rezaei *et al*., 2004). These variables are often used as a means of evaluating bird performance and strain differences. However, little attention has been given to the assessment of mortality and flock uniformity when strains are given marginally deficient feeds, yet these measures of performance are important when optimising the protein content in feeds for broilers.

Poor uniformity reduces revenue and increases waste, and optimisation programs therefore need to take account of any factors that may influence uniformity. It is well known that individuals in a flock of broilers exhibit different tendencies to overconsume feed when faced with a marginally deficient feed. Emmans and Fisher (1986) reported that the performance of a broiler population depends largely on the inherited genotype of an individual in the population and the extent to which the genotype varies between individuals. It is likely therefore that marginally deficient feeds will affect uniformity, as some birds will eat more than others, and benefit from the extra feed. Another factor that may be influenced by protein supply is mortality, although evidence of this is somewhat equivocal, but nevertheless mortality is also an important criterion when determining profitability, and if the feed quality has an effect on mortality then this should also be accounted for in an optimisation routine.

This study is directed towards determining whether mortality and the amount of variation within and between strains of broilers are influenced by the amount of dietary protein in feeds given to these birds.

2.2 Materials and methods

2.2.1 Animal and Housing

480 Cobb and 480 Ross day-old sexed broiler chickens were housed in the brooder room at University of KwaZulu-Natal, Ukulinga research farm. Ninety-six cages were used with 10 chickens per pen and with males and females being reared separately. Two nipple drinkers were available in each cage. Birds were supplied with heat through a gas blower. Body weight of individual birds in each pen was measured at weekly intervals up to 21d.

2.2.2 Feeds and feeding procedure

Two basal feeds, one high (H) and the other low (L) in protein were formulated to contain equal contents of metabolisable energy (ME) and major minerals, using a well balanced amino acid mixture (Tables 2.1 and 2.2). These two feeds were blended (20H:80L, 40H:60L, 60H:40L, 80H:20L) to produce four additional levels of protein. Troughs were placed inside the brooder cages for the first 10 days of the experimental period and, thereafter, outside the cage. The two basal feeds were sampled after mixing and these samples were analysed for apparent metabolisable energy (AME), crude protein (CP) and amino acid contents (Table 2.2). Feed and water were offered ad libitum throughout the trial. Food intake was measured once a week by subtracting food left over from that offered.

Table 2.1: Composition (g/kg) of the two basal feeds used in the trial

Ingrdient	High protein content	Low protein content
Yellow maize	400	702
Soyabean full fat	300	129
Soyabean 44	197	
Fish meal 65	28.3	
L-lysine HCl	3.7	2.2
DL-methionine	1.1	0.3
L-threonine	0.1	
Vit + min premix	1.5	1.5
Filler		72.0
Limestone	14.5	18.4
Salt	2.1	2.9
Monocalcium phosphate	14.2	17.2
Sodium bicarbonate	4.5	4.6
Oil-sunflower	33.1	50.0

Table 2.2: Calculated nutrient composition (g/kg) of high protein (H) and low protein (L) diets

Nutrient	Calculated (H)	Analysed (H)	Calculated (L)	Analysed (L)
AME (MJ/kg)	12.90	13.22	12.90	12.57
TME (MJ/kg)		13.63		12.98
Protein (g/kg)	253	268	110	124
Dry matter	887	910	872	895
amino acids*				
Lysine	1.60	1.54	0.60	0.46
Threonine	0.84	1.90	0.35	0.29
Valine	1.07	1.33	0.55	0.47
Isoleucine	1.02	1.31	0.39	0.42
Leucine	1.88	2.31	1.08	0.99
Histidine	0.60	0.69	0.28	0.30
Arginine	1.58	0.65	0.59	0.56
Calcium	1.0		1.0	
Avail. Phosphorus	0.5		0.5	
Sodium	0.25		0.25	
Chloride	0.25		0.25	

*Digestible amino acids; AME = Apparent metabolisable energy; TME = True metabolisable energy

2.2.3 Experimental design and statistical analysis

The factorial experimental consisted of six dietary protein levels, two breeds and two sexes (6x2x2). Each treatment was replicated four times. Data were subjected to statistical analysis using Analysis of Variance and regression procedures of Genstat (2005) in order to compare the treatment effects and to determine the response in the measures of performance to protein content. Food intake and body weight were recorded weekly and mortality was recorded whenever this occurred. Food intake values reported were adjusted

to mortality. Mortality percentage was transformed in order to normalise the variability over the treatments.

2.3 Results

Food intake (g/d), feed conversion efficiency (FCE, g gain/ kg food), average daily gain (g/d), coefficient of variation (CV) of body weight (%) and mortality (%) over the period from 0 to 21d are given in Tables 2.3, 2.4 and 2.5; Figures 2.1, 2.2, 2.3 and 2.4. Linear and quadratic regression coefficients are presented in Tables 2.6 and 2.7. There was a difference ($P<0.001$) between the Cobb and Ross strains in all measures of performance. The highest body weight gain and FCE were recorded in the Cobb strain, with a correspondingly higher food intake (Table 2.3). There was no significant effect of dietary protein content on mortality in either strain (Table 2.5). Dietary protein content had a quadratic effect ($P<0.001$) on all measures of performance, there being the difference ($P<0.001$) was in the constant terms but not in the slopes of the response between the two strains. The body weight gain of the Cobb strain was 1.7g/d greater than the Ross strain and the FCE was 34.5g gain/kg feed consumed greater than the Ross strain (Table 2.6). There were no interactions between the treatments in any of the parameters measured. In general, the CV of individual body weights was similar between the two strains (Table 2.4 and Figure 2.4). There was a higher mortality in the Cobb strain relative to Ross, especially at low protein contents, but the trend was not consistent across the feed protein contents.

Table 2.3: Mean food intake, feed conversion efficiency (FCE) and average daily gain from 0 to 21 d old Cobb and Ross broilers

	Food intake (g/d)						FCE (g gain/kg feed)						Average daily gain (g/d)					
	Cobb			Ross			Cobb			Ross			Cobb			Ross		
Protein	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F
1 (low)	36.1	35.3	35.7	35.8	33.8	34.8	427	410	419	406	407	407	15.4	14.5	14.9	14.5	13.7	14.1
2	40.7	41.8	41.2	39.1	38.7	38.9	518	501	510	472	467	470	21.1	20.9	21.0	18.5	18.1	18.3
3	42.5	40.8	41.7	41.2	39.2	40.2	559	534	546	522	522	522	23.7	24.2	23.9	22.8	20.7	21.7
4	40.7	41.8	41.2	38.9	38.6	38.7	582	578	580	586	538	562	23.8	21.8	22.8	21.5	20.5	21.0
5	40.6	38.9	39.7	39.9	39.1	39.5	610	614	612	592	549	571	24.8	23.9	24.3	23.6	21.5	22.5
6 (high)	37.7	38.1	37.9	39.1	36.9	38.0	707	645	676	604	605	605	26.6	24.6	25.6	23.6	22.3	23.0

	LSD	SEM	P-value	LSD	SEM	P-value	LSD	SEM	P-value
Protein	1.19	0.60	< 0.001	20.02	14.20	< 0.001	0.94	0.47	< 0.001
Strain	0.69	0.34	< 0.001	11.56	8.20	< 0.001	0.54	0.27	< 0.001
Sex	0.69	0.34	0.027	11.56	8.20	0.003	0.54	0.27	< 0.001

Table 2.4: The coefficient of variation of Cobb and Ross broilers, as a measure of uniformity, at increasing dietary protein contents for each week (W) and throughout the experimental period

	Coefficient of variation (%)									
	Cobb					Ross				
Protein*	W0	W1	W2	W3	W0-3	W0	W1	W2	W3	W0-3
1 (low)	6.7	9.3	11.3	10.5	13.6	6.9	7.8	10.8	8.8	14.8
2	8.0	10.9	13.5	11.9	15.0	6.6	10.3	14.6	15.8	14.7
3	7.8	11.5	19.2	17.3	16.1	6.4	11.1	16.6	15.9	16.5
4	7.4	12.0	18.3	18.0	16.0	6.8	13.0	19.7	16.9	14.6
5	8.3	11.1	17.3	16.7	12.1	6.7	11.1	17.8	15.1	13.6
6 (high)	8.2	13.2	12.0	15.5	10.4	7.2	10.5	16.7	17.1	9.1

*Protein content of the diet.

Table 2.5: Effect of feed protein content on mortality (%) in Cobb and Ross broilers from 0 to 21d of age

	Mortality (%)	
Protein*	Cobb	Ross
1 (low)	10.18	4.53
2	7.87	0.01
3	4.53	6.42
4	4.53	0.01
5	0.01	4.53
6 (high)	4.53	7.87

*Protein content of the diet.

Table 2.6: Regression coefficients of food intake and feed conversion efficiency (FCE) on feed protein content from 0 to 21d, with strain as a group

	Food intake			FCE		
Source	Coefficient	S.E	P value	Coefficient	S.E	P value
Constant	12.71	2.95	< 0.001	131.7	50.4	0.01
Protein	0.306	0.034	< 0.001	3.338	0.581	< 0.001
Protein x Protein	-0.0008	0.0001	< 0.001	-0.005	0.0016	0.002
Strain Ross[1]	-1.237	0.381	0.002	-34.51	6.51	< 0.001

[1] Constant term for Ross strain differs significantly from that of Cobb strain.

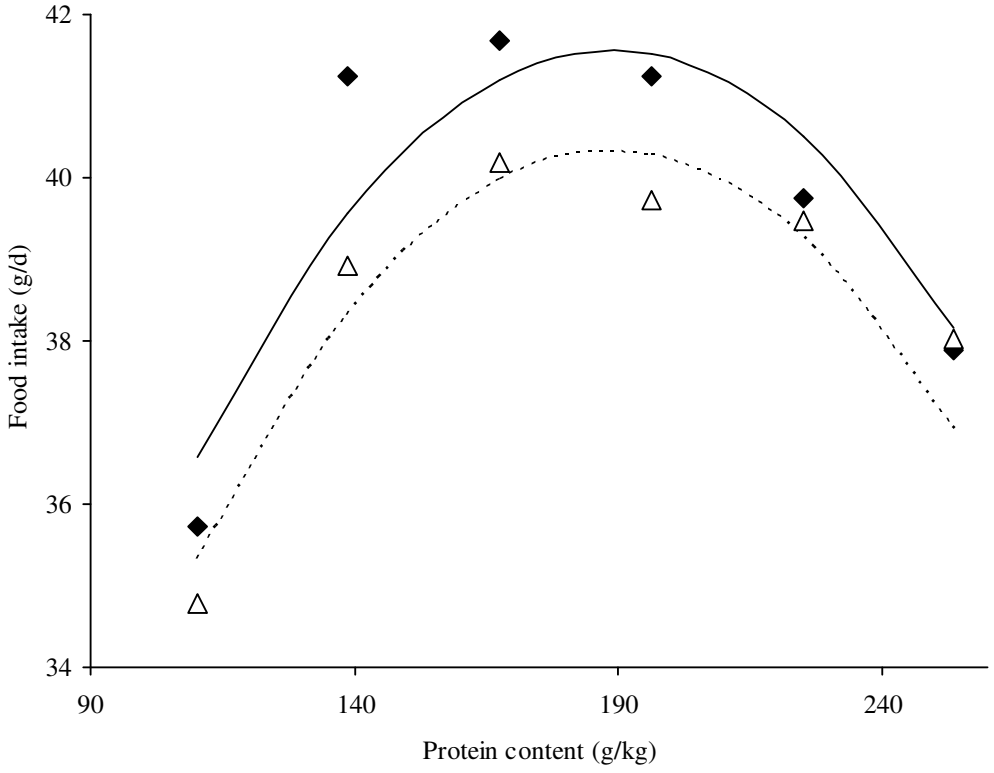

Figure 2.1: Food intake as influenced by dietary protein content in Cobb (◆, regression line─) and Ross (△, regression line ----) broilers from 0 to 21d, with fitted curves

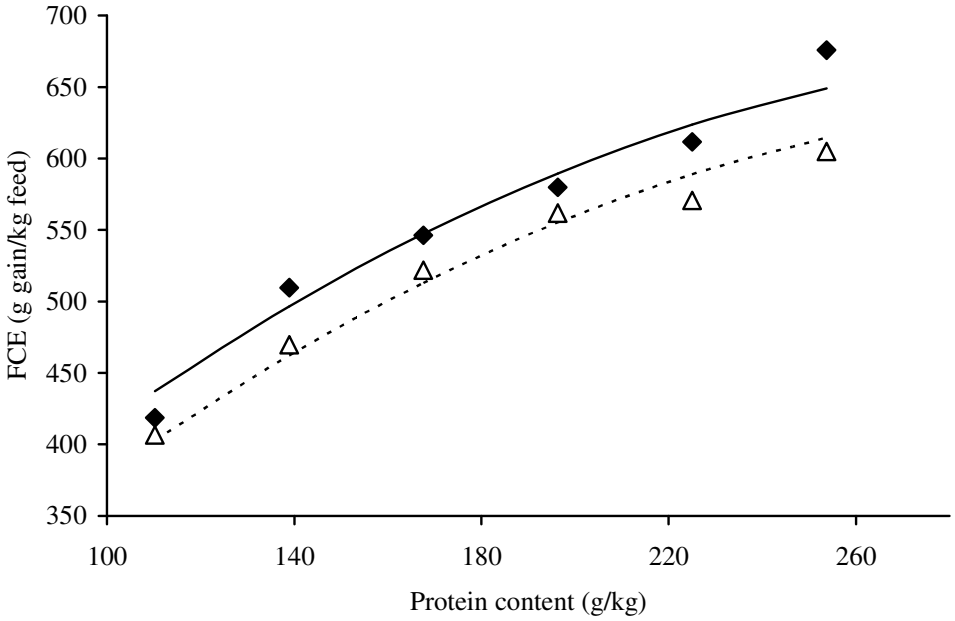

Figure 2.2: Feed conversion efficiency (FCE) of Cobb (◆, regression line─) and Ross (△, regression line ----) broilers over the period 0 to 21d, with fitted curves, as influenced by dietary protein content

Table 2.7: Regression coefficients of gain in weight (g/d) on protein intake (g/d) over the Period 0 to 21d, with strain as a group

	Gain in weight		
Source	Coefficient	S.E	P value
Constant	0.44	1.68	0.794
Protein in (P_{in})	4.817	0.517	< 0.001
P_{in} x P_{in}	-0.234	0.0376	< 0.001
Strain Ross[1]	-1.661	0.267	< 0.001

[1] Constant term for Ross strain differs significantly from that of Cobb strain.

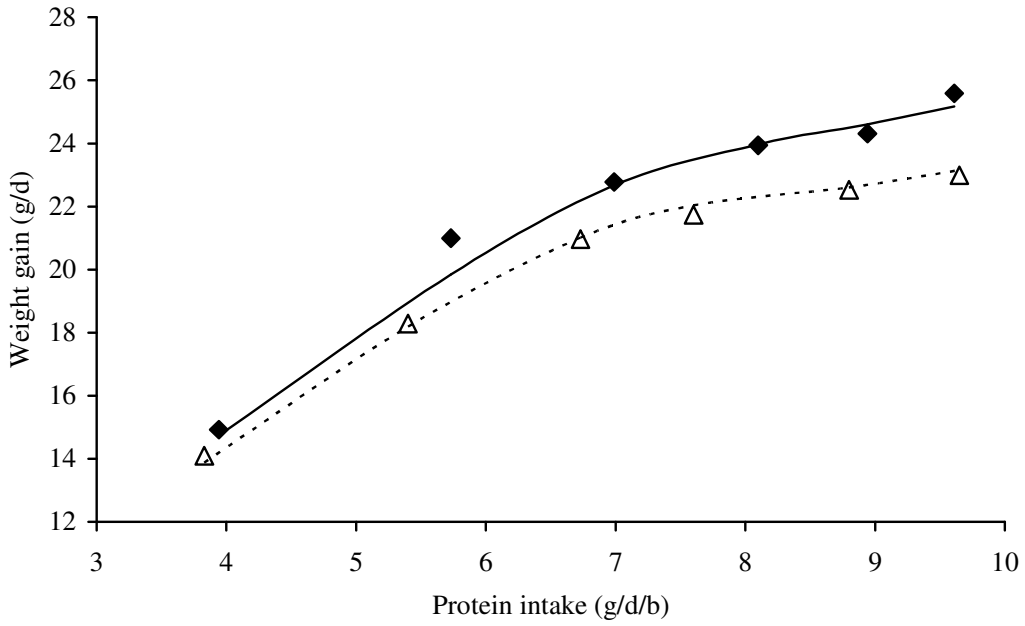

Figure 2.3: Effect of protein intake on weight gain of Cobb (◆, regression line—) and Ross (△, regression line ----) broilers over the period 0 to 21d, with fitted curve.

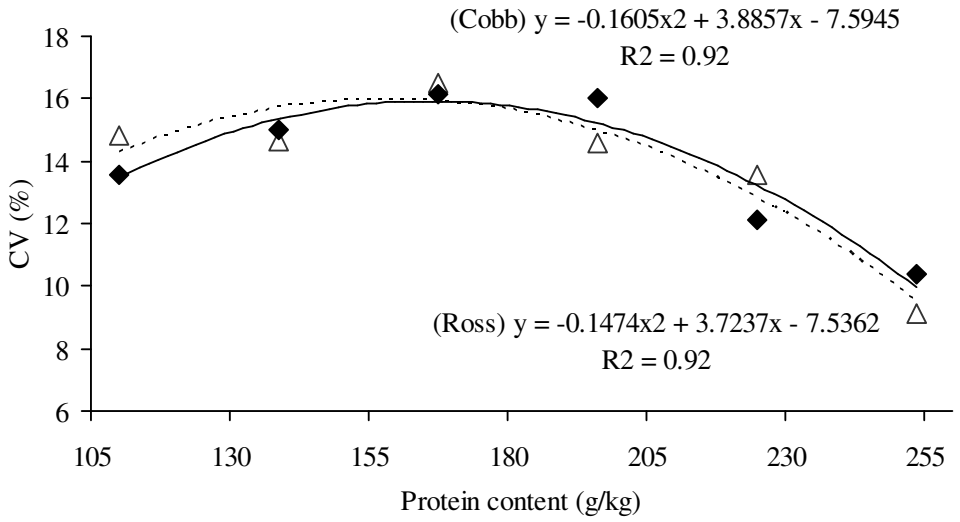

Figure 2.4: Effect of feed protein content on flock uniformity of Cobb (◆, regression line—) and Ross (△, regression line----) broilers from 0 to 21d of age

2.4 Discussion

It is well recognized that feed protein content can affect significantly the growth rate and food intake of broilers (Cabel and Waldroup, 1991; Smith and Pesti, 1998; Smith *et al*., 1998; Swatson *et al*., 2000; Rezaei *et al*., 2004). These authors reported that body weight gain and FCE were significantly increased when the dietary protein contents of the feed were increased, and the results of this experiment have confirmed these earlier reports. However, very little information is available in the literature concerning the extent of these effects on uniformity and mortality especially for different strains of broilers. Thus, this study focused on the response of the two most common strains of broilers in South Africa, namely, Cobb and Ross, to feeds varying in protein content, specifically in relation to the effects on uniformity and mortality.

Results from this experiment showed that Cobb broilers performed better than the Ross strain over the range of protein levels included in the experimental feeds. This was due either to the higher potential growth rate or to the apparently greater capacity of the Cobb strain to consume greater quantities of feed at all protein contents, resulting in higher intakes and hence greater weight gains and FCE's than with the Ross strain on all these feeds. Strains differ in their ability to deposit protein or lipid as a result body weight and the maximum amount of food intake to maximize the growth rate varied (Orr *et al*., 1984; Smith and Pesti, 1998; Smith *et al*., 1998; Dozier and Moran 2001). This justified the variation observed between strains as illustrated in Table 2.3. Of interest was the similarity in the shape of these responses, these being almost identical in both strains. Although mortality (Table 2.5) was not significantly different ($P>0.05$) among the treatments groups or between strains, there was a tendency for the Cobb strain to exhibit higher mortality on the low protein feeds, which may be due to the fast growth rate relative to the Ross strain, but could also be a result in some way of the high intake of a low quality food. Classen (2000) suggested that rapid growth has produced problems not seen in slower growing birds. He mentioned skeletal and cardiovascular disease (sudden death syndrome, ascites) as examples of growth-related problems. Therefore, further research is justified to investigate the real effect of feed protein content on mortality in the two strains of broilers. It was noted that mortality was, in many cases, not related to treatment effect (for instance, there were cases of deaths due to legs being trapped in the cage floor overnight). Similar results were reported by Rezaei *et al*. (2004).

Variation in body weight within a population is an important criterion when optimising the feed and feeding programme of a population of broilers as it relates to the spread of product yield from the processing plant. Uniformity is directly related to quality: the more uniform the product, the greater the value, as this implies a reduction in downgrades and hence an increase in profitability. The type of feed and the environmental conditions to which broilers are exposed both affect uniformity. According to the results of this experiment, uniformity was greatest in both strains when they were given feeds of the highest protein content. As the protein content declined uniformity deteriorated but increased slightly on the lowest protein feeds, the response being significantly quadratic. This type of experiment needs to be repeated a number of times to corroborate the results obtained here. Once an accurate estimate of the effects of protein content on uniformity and mortality within each of the two strains are known, such information would be usefully included in models designed to optimise the feeds and feeding programmes of broilers.

2.5 Conclusions

The two strains used in this trial, to 21d, exhibited similar responses to changes in dietary protein content, although the Cobb strain consumed more food and hence grew faster at all protein contents than did the Ross strain. Accounting for increased mortality and decreased uniformity in a simulation model would necessarily need to be empirical until the reasons for these changes with dietary protein content and strain are understood, after which a mechanistic approach to these changes could be used.

Chapter 3

Effect of dietary protein content on the allometric relationships between carcass portions and body protein in Cobb and Ross broilers

Abstract

This study was designed to examine the effect of dietary protein content on the performance and the allometric relationships between physical and chemical components of the body with body protein. Broilers were fed starter feed for three weeks and finisher feed thereafter to six weeks. Six levels of protein were used in both feeding programs. 1680 Cobb and 1680 Ross day old sexed broilers were used, with 70 chicks being placed in each of 48 pens. Three birds per pen were randomly selected at 14, 28, 35 and 42 d for carcass analysis. In the slaughtering process, the feathers were removed; breast meat, drum, thigh and wing were weighed and the feather-free body minced. The water, protein and energy contents of each carcass were measured. Food intake, body weight, feed conversion efficiency, uniformity and mortality served as criteria for performance evaluation.

Cobb broilers performed better than Ross on all feeds and feeding programmes, and in addition exhibited increases in food intake as dietary protein content decreased, whereas food intake in the Ross bird declined, implying that the optimum dietary protein content for these two strains would differ. The highest uniformity was observed at the highest dietary protein content in both strains. There was no nutritional effect on mortality, but the Cobb strain had a higher mortality ($P<0.01$) over all feeds than the Ross strain. Small but significant deviations from the mean allometric relationships between the physical components and body protein occurred with drum weight (influenced by feed protein content) and breast meat yield (influenced by strain and sex), these possibly resulting from differential amounts of body lipid being deposited in these tissues in the different genotypes. The ability of genotypes to deposit lipid in different parts of the body needs to be researched in more detail.

It can be concluded that although variation exists in the growth rate of broilers differing in strain and sex, and when offered feeds differing in protein content, nevertheless the

allometric relationships between the carcass components (other than feathers and body lipid) and body protein are not influenced by any of these factors. Consequently, when predicting the growth rate of any of the physical parts of the body, the same allometric relationship may be used in all cases.

3.1 Introduction

Allometric relationships between the weights of the chemical components and body protein may be used to describe potential growth (Emmans and Fisher, 1986; Emmans, 1988, 1989). Whereas the relationship between water and protein in the body of broilers at maturity has been regarded as being the same between genotypes (Emmans 1988; Wang *et al*., 1999), Eits *et al*. (2002) reported that low or high levels of ideal protein-to-protein-free energy ratios had a considerable effect on the weight of water at a given protein weight compared with feeds having an average nutrient composition. Because of this disagreement in the literature, more evidence of the effect of feed protein content on the allometric relationships between carcass components is needed. Furthermore, the relationships between carcass portions (such as breast meat, drum meat, thigh, etc.) and body protein have not been extensively investigated, especially when feeds differing in protein content have been fed.

Traditionally, the major criteria for assessing the performance of broiler strains have been growth rate and feed conversion efficiency, and less frequently, carcass composition, but there is circumstantial evidence that some strains show higher mortalities and a greater variability in final body weight than others when high or low-protein feeds are fed. Such information is crucial when optimising the feeds for different strains. In this study, therefore, flock uniformity and mortality rate were added to the performance variables studied.

The objectives of this study were therefore to determine the effect of dietary protein on the allometric relationships between the carcass components and body protein, and on the performance, including mortality and uniformity, of two strains of broilers available in South Africa.

3.2 Materials and methods

3.2.1 Birds and Housing

The experiment was conducted at Ukulinga Research farm using 1680 Cobb and 1680 Ross sexed day-old broiler chickens. 48 floor pens (1.5mx2m) were used with 70 chickens being placed per pen, and with males and females being reared separately. The experiment was terminated when the broilers were six weeks old. The temperature in the tunnel-ventilated broiler house was maintained at close to predetermined levels, starting at 31^{O}C and reducing to 21^{O}C by 21d, then maintaining that temperature to 42d.

3.2.2 Feeds and feeding procedure

Chicks were fed a crumbled starter feed for the first three weeks, and a pelleted grower feed for the remaining three weeks. Two basal starter feeds, one high (H) and the other low (L) in protein were formulated (Table 3.1) containing equal contents of AME and major minerals, using a well balanced amino acid mixture (WinFeed 2[2]). All the essential amino acids were supplied at their requirements, relative to lysine. The two basal feeds were fed alone and as blends (20H:80L, 40H:60L, 60H:40L, 80H:20L) thereby producing six levels of protein in total. Feed and water were supplied *ad libitum* throughout the trial.

3.2.3 Measurements

All surviving birds were group weighed by pen at weekly interval with food consumption being determined at the same time. Twenty broilers were randomly selected from each pen and weighed individually on days 1, 21 and 42 to measure variation. Three birds per pen were randomly selected at 14, 28, 35 and 42 d for carcass analysis. In the slaughtering process, the feathers were removed from the birds by dry plucking and the carcasses were reweighed to obtain a feather-free weight. The skin from the breast, thighs and drum were removed before these parts (meat and bone) were weighed. All parts were then returned to

[2] EFG Software (Natal) 25 Fairfield Ave, Pietermaritzburg 3201 South Africa Tel: +27 33 260 5477 Fax: +27 33 260 5067 e-mail: gous@ukzn.ac.za

the carcass, which was then minced and mixed thoroughly before taking 300 g samples for laboratory analysis. The water content of each carcass was determined by freeze-drying a known weight of minced carcass. The freeze-dried sample was then milled for further analysis. The milled samples were freeze-dried again, after this procedure, to remove any moisture that may have accumulated during this process. The crude protein content of each carcass was calculated as nitrogen x 6.25, where nitrogen content of the dry matter was determined on a LECO nitrogen analyzer (LECO Africa (Pty) Limited, P.O. Box 1439, Kempton Park, South Africa). The lipid content of the samples was determined using the equation L (%) dry basis = -.08756 + 0.04754 GE (Gous, unpublished), where L (%) as is = (L (%) dry basis x (100-Moist %)) / 100.

3.2.4 Statistical analysis

All the measures of performance data were subjected to analysis of variance and regression procedure using SAS Version 8 (SAS Institute, 2000). Treatment means were compared and regression analysis using GLM was conducted to evaluate linear and quadratic effect of protein content and protein intake on animal performance. The effects of strain and protein content on carcass portions and chemistry were also analysed using the GLM procedure and SAS version 8 (SAS Institute, 2000) to compare statistically the response of the birds on each treatment on the allometric relationships between the chemical and physical body characteristics and body protein content. Carcass protein weight was calculated by multiplying protein content in the carcass by the carcass weight.

The lipid to protein ratio was calculated from the natural logarithms of total body protein and total body lipid weights. Angular transformation was used to normalise mortality percentage. Lines were fitted using a power function (allometric model) which describes the log-log linear relationship of two body components (ln (Br) = ln a + b x ln (P)), in which: ln = natural logarithm, Br = breast meat weight (g), a = scale parameter, b = allometric slope, P = body protein weight (g).

Table 3.1: Ingredient composition (g/kg) of the basal feeds used in the starter and finisher feed trial.

	Starter		Finisher	
Ingredient	LP	HP	LP	HP
Yellow maize	400	400	600	494
Wheat bran	160		62.2	
Soybean full fat	282	300	196	350
Soybean 44		119		
Sunflower 37		50.0	33.5	72.4
Fish meal 65	100	100	40.0	40
L-lysine HCL		1.4		
DL methionine				0.5
Vit+min premix	1.5	1.5	1.5	1.5
Limestone	11.5	9.6	15.5	14.0
Salt	0.2	0.1	1.9	1.9
Monocalcium phosphate	5.0	7.9	12.0	12.9
Sodium bicarbonate	2.9	3.2	3.4	1.0
Oil - sunflower	36.9	7.3	34.4	11.5
Nutrient composition*				
AME (MJ/kg)	12.6	12.6	13.0	13.0
Crude protein	197	248	149	199
Lysine	11.9	16.0	7.9	11.0
M + C	6.6	7.9	5.4	7.0
Threonine	7.5	9.4	5.6	7.4
Tryptophan	2.1	2.7	1.5	2.2
Calcium	1.0	1.0	1.0	1.0
Avail. Phosphorous	0.5	0.5	0.5	0.5

*Digestible amino acids; M+C= Methionine + Cystine, Avail = Available

3.3 Results

Growth performance

The effect of dietary protein content on food intake (g/d), feed conversion efficiency (g gain/kg feed) and weight gain (g/d) is presented in Tables 3.2 and 3.3; Figures 3.1 and 3.2. Cobb broilers consumed significant more food ($P<0.001$) and grew significantly faster ($P<0.001$) than Ross broilers in the starter period (Table 3.2) but the response in food intake to dietary protein content was similar in both strains, with food intake remaining relatively constant on all except at the lowest protein feed (Figure 3.1). As a result, FCE was similar in both strains. In the finisher period the Ross birds consumed significantly more than the Cobb broilers (Table 3.3) but in this case there was no difference in growth rate between the two strains, resulting in a significantly poorer FCE for the Ross strain (487 *vs*. 522 g gain/kg feed; $P<0.001$). The pattern of food intake in the finisher period also differed between the two strains (Figure 3.1): the Cobb birds increased their food intake as the dietary protein content was decreased, but food intake decreased with protein content in the Ross strain. Regression coefficients of feed intake (g/d) and FCE (g gain/kg feed) on protein content (g/kg) and average daily gain (g/d) on protein intake (g/bird, d) are presented in Tables 3.4, 3.5 and 3.6. These coefficients are for a linear effect except where a quadratic effect was significant ($P<0.05$), in which case the linear and quadratic coefficients are included in the Tables. The effect of dietary protein in the starter period had a quadratic response for all the measures of performance but a linear response in the finisher feeds. There was an interaction between protein level and strain on food intake in the finisher period and also on average daily gain in the starter feeding program. Furthermore, there was an interaction between sex and strain on the above responses and feeding programs (Table 3.5 and 3.6). The effect of increasing protein content of feed was more sensitive in the starter feeding period, i.e. higher regression coefficients. Variation in live weight within a treatment decreased in both strains as the feed protein content increased (Table 3.7), and whilst there was no nutritional effect on mortality (Table 3.7), mean overall mortality was twice as high in the Cobb strain (0.78 *vs*. 0.38%), this difference being statistically significant ($P<0.01$).

Carcass analysis

Effect of dietary protein content on the carcass components at 42 d of age is given in Tables 3.8 and 3.9. There was no significant effect of dietary treatment on the carcass portions except on breast meat ($P<0.001$) and wing ($P<0.05$). There was no significant difference between the two strains in most of the carcass portion except breast ($P<0.001$) and thigh meat weight ($P=0.01$). However, the weight of all carcasses was increased with increasing protein content of the feed. Parameter estimates for the allometric relationships for carcass portion and body component with body protein weight are presented in Tables 3.10a and b and Figures 3.3, 3.4, 3.5 and 3.6. There was no treatment effect on the allometric relationship between carcass portions and body protein content except on lipid, lipid to protein ratio and drum when body protein was as a continuous variable in the independent variables. Strains and sex had significantly ($P<0.01$) affected the allometric equations between the total breast meat and the body protein weight. All the relationships with body protein weight were linear. The allometric relationship gave accurate descriptions based on the coefficient of determination (R^2) (Tables 3.10a and b).

Table 3.2: Mean food intake (g/d), average daily gain (g/d) and feed conversion efficiency, FCE (g gain/ kg feed consumed) of broilers from 0 to 21d (n = 48).

	Food intake (g/d)						Average daily gain (g/d)						FCE (g gain/kg feed)					
	Cobb			Ross			Cobb			Ross			Cobb			Ross		
Protein[1]	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F
219.5	45.5	45.4	45.4	39.4	40.5	40.0	34.6	32.6	33.6	29.3	29.2	29.3	760	721	740	743	722	732
220.4	46.4	48.6	47.5	43.7	43.6	43.7	36.3	38.2	37.2	33.4	34.3	33.9	782	785	783	765	788	776
221.4	46.7	48.5	47.6	45.5	42.5	44.0	36.7	37.9	37.3	34.9	33.4	34.2	788	781	784	771	786	778
222.3	46.3	47.9	47.1	43.3	43.5	43.4	37.2	37.8	37.5	33.0	34.2	33.6	805	788	797	770	778	774
223.3	47.0	47.6	47.3	43.6	42.8	43.2	38.0	36.9	37.4	33.7	33.3	33.5	796	785	791	774	778	776
224.2	47.2	48.4	47.8	44.3	43.4	43.9	37.8	37.2	37.5	34.0	33.9	34.0	801	770	785	775	791	783
Mean	**46.5**	**47.7**	**47.1**	**43.3**	**42.7**	**43.0**	**36.7**	**36.7**	**36.7**	**33.0**	**33.0**	**33.0**	**789**	**772**	**780**	**766**	**774**	**770**
RMS			2.51						0.903						748			
	Prot[2]		Strain		Sex		Prot		Strain		Sex		Prot		Strain		Sex	
P-value	0.005		<.001		<.001		<.001		<.001		ns		0.011		ns		ns	

[1]Feed protein content (g/kg); [2]Protein

M/F = Average sex value, n = number of observations, ns = Non significant, RMS = Residual mean square.

Table 3.3: Mean food intake (g/d), average daily gain (g/d) and feed conversion efficiency, FCE, (g gain/ kg feed consumed) for broilers from 21 to 42 d (n=48)

	Food intake (g/d)						Average daily gain (g/d)						FCE (g gain/kg feed consumed)					
	Cobb			Ross			Cobb			Ross			Cobb			Ross		
Protein[1]	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F	F	M	M/F
166.5	115	127	121	119	127	123	57.7	61.4	59.6	57.0	62.0	59.5	501	483	492	478	489	484
176.9	111	125	118	123	129	126	54.8	63.5	59.1	58.7	63.1	60.9	492	508	500	480	489	484
187.3	111	123	117	122	130	126	56.7	65.5	61.1	59.0	63.5	61.3	511	535	523	481	490	486
197.6	113	121	117	122	131	127	57.7	66.4	62.0	59.1	65.5	62.3	512	548	530	483	501	492
208.0	108	123	116	123	132	127	56.9	67.4	62.2	58.3	66.6	62.5	525	547	536	475	507	491
218.4	108	123	116	125	131	128	58.4	68.0	63.2	59.4	65.5	62.5	546	551	548	476	500	488
Mean	**111**	**124**	**117**	**122**	**130**	**126**	**57.0**	**65.3**	**61.2**	**58.6**	**64.4**	**61.5**	**515**	**529**	**522**	**479**	**496**	**487**
RMS	19.46						12.84						1057					
	Prot[2]	Strains	Sex	Strain x Sex			Prot	Strains	Sex				Prot	Strains	Sex			
P-value	Ns	<.001	<.001	0.055			ns	ns	<.001				Ns	<.001	ns			

[1]Feed protein content (g/kg); [2]Protein

M/F = Average sex value, n = number of observations, ns = Non significant, RMS = Residual mean square.

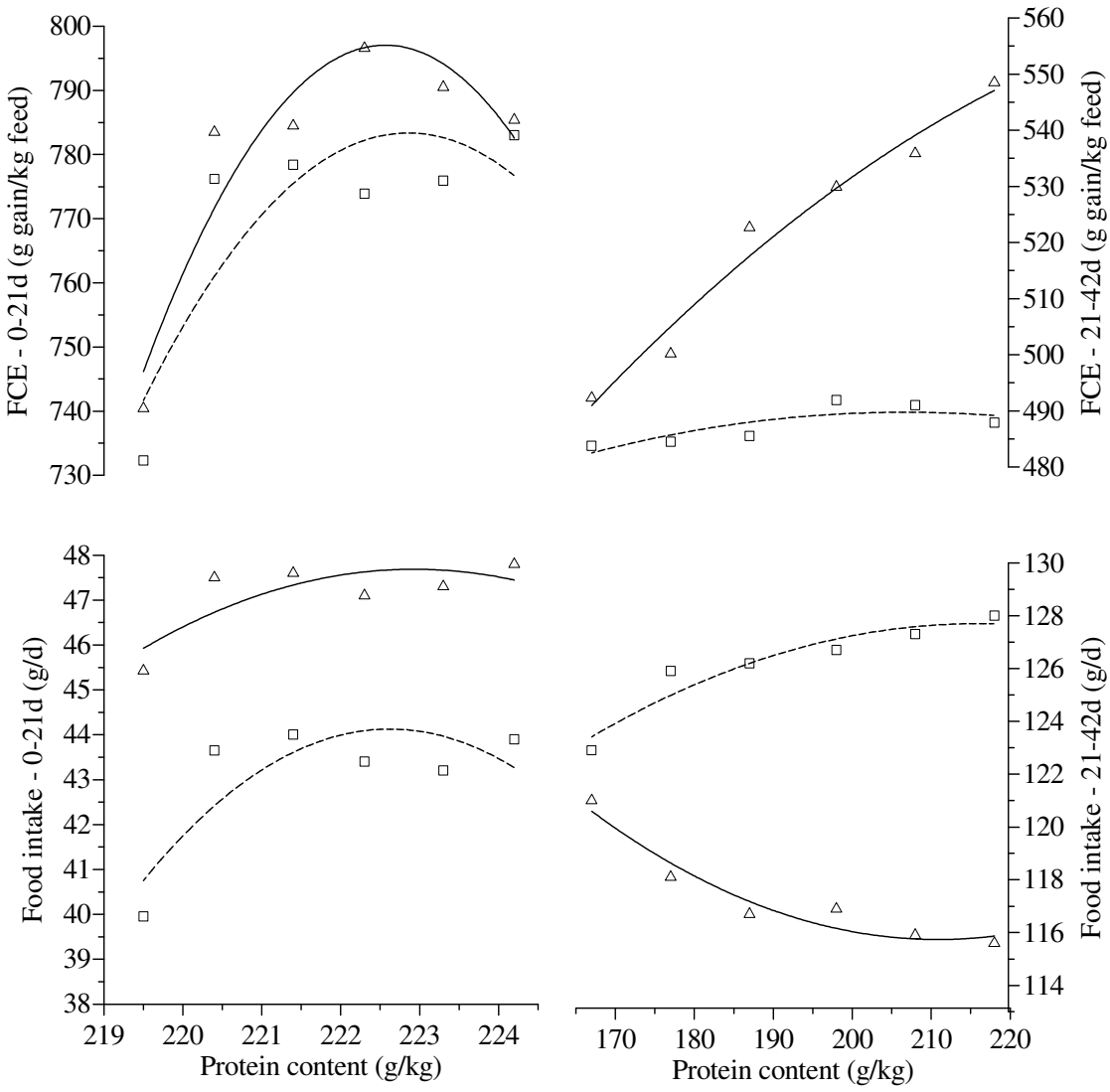

Figure 3.1: Effect of feed protein content on food intake (g/d) (bottom) and feed conversion efficiency, FCE, (g gain/kg feed) (top) of Cobb (△, response relationship ─) and Ross (□, response relationship – –) broilers from 0 to 21d and 21 to 42d of age.

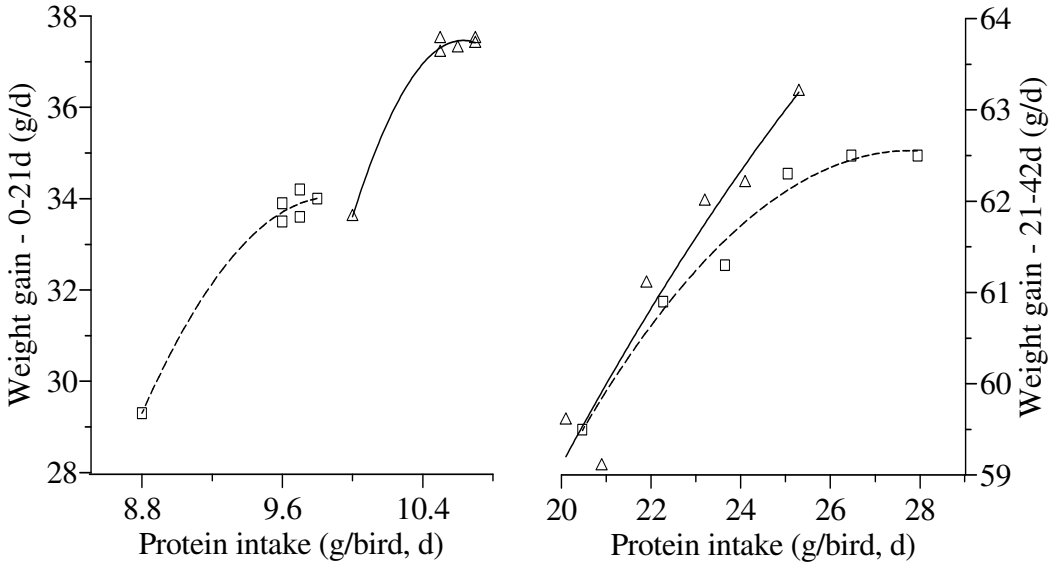

Figure 3.2: Effect of feed protein intake on weight gain of Cobb (△, response relationship ─) and Ross (□, response relationship – –) broilers from 0 to 21d and 21 to 42d of age.

Table 3.4: Regression coefficients of food intake (g/d) and feed conversion efficiency (g gain/ kg feed) on protein content feed over the period of 0 to 21d, with strain as a group

	Food intake (g/d)			FCE (g gain/kg feed)		
Variables	Estimates	SE	P-value	Estimates	SE	P-value
Constant	-12146	4919	0.018	-189390	78890	0.021
Protein (P)	109.5	44.3	0.018	1706	711	0.021
P x P	-0.2456	0.1	0.018	-3.83	1.6	0.021
Sex (M)	0.279	0.46	Ns	-4.7	7.3	Ns
Strain R	-4.162	0.46	<0.001	-8.32	7.3	Ns
R^2	68			37		

SE =Standard error, ns = Non significant, M = Male, R = Ross broilers, R^2 = coefficient of determination,

Table 3.5: Regression coefficients of on food intake (g/d) and feed conversion efficiency (g gain/ kg feed) on protein content feed over the period of 21to 42d, with strain as a group

	Food intake (g/d)			FCE (g gain/kg feed)		
Variables	Estimates	SE	P-value	Estimates	SE	P-value
Constant	116.19	8.4	<.001	379.1	44.5	<.001
Protein (P)	-0.0915	0.042	0.035	0.624	0.221	0.007
P x P						
Sex (M)	12.58	1.47	<.001	14.82	7.75	0.062
Strain R (S)	-17.4	11.9	ns	-35.21	7.75	<.001
P x (S)	0.1755	0.0593	0.005			
Sex x S	-5.13	2.08	0.018			
R^2	78.6			39		

SE =Standard error, ns = Non significant, M = Male, R = Ross broilers, R^2 = coefficient of determination,

Table 3.6: Regression coefficients indicating the change of weight gain (g/d) on protein intake over the period of 0 to 21d and 21 to 42d, with strain as a group

	0 to 21d Daily gain (g/d)			21 to 42d Daily gain (g/d)		
Variables	Estimates	SE	P-value	Estimates	SE	P-value
Constant	73.7	42.7	Ns	39.08	3.82	<.001
Protein intake (P)	-10.98	8.26	Ns	0.596	0.181	0.002
P x P (P^2)	0.729	0.405	0.07			
Sex (M)	-1.251	0.512	0.019	5.78	0.902	<.001
Strain R	-149.8	53	0.007	-0.878	0.889	Ns
P x Strain R	30.4	10.5	0.006			
P^2 x Strain R	-1.571	0.529	0.005			
Sex x Strain R	1.61	0.682	0.023			
R^2	82.4			62.2		

SE =Standard error, ns = Non significant, M = Male, R = Ross broilers, R^2 = coefficient of determination,

Table 3.7: Mean coefficient of variation, CV, (%) and Mortality (%) of Cobb and Ross broilers from 0 to 42 days. Transformed values are in parentheses.

	CV (%)		Mortality (%)[2]	
Protein[1]	Cobb	Ross	Cobb	Ross
1(Low)	10.5	11.1	0.78 (4.89)	0.46 (3.66)
2	9.1	9.2	0.20 (3.20)	0.39 (3.01)
3	9.1	9.4	0.91 (5.15)	0.26 (1.99)
4	8.4	9.4	0.45 (3.80)	0.32 (2.18)
5	8.5	9.0	1.20 (6.09)	0.32 (2.67)
6(High)	8.8	9.4	1.15 (5.91)	0.52 (4.06)

[1]Feeding program from 0 to 42 d of age.

[2]There was no dietary effect on mortality (%) but there is a difference between strains ($P<0.01$).

Table 3.8: Effect of dietary protein content on carcass portions of female (F) and male (M) broilers of Cobb and Ross strains at 42d[1]

	Total breast meat				Drum meat				Feather weight				Thigh meat				Wing meat			
	Cobb		Ross		Cobb		Ross		Cobb		Ross		Cobb		Ross		Cobb		Ross	
Protein[2]	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
1 (Low)	236	256	253	217	161	192	170	179	101	99	99	95	184	210	188	202	148	165	158	169
2	253	279	247	242	162	196	172	191	100	96	86	95	193	237	196	206	158	182	156	161
3	290	326	261	253	171	214	169	189	103	123	86	86	197	232	190	204	172	189	168	163
4	267	269	246	284	167	186	163	212	95	120	99	120	202	208	184	215	156	163	159	182
5	296	314	276	284	171	201	163	206	109	107	109	101	204	235	188	210	167	183	158	175
6 (High)	341	302	280	305	178	192	183	202	107	108	107	122	212	220	205	220	171	177	160	186
RMS	1472				393				767				611				265			
CV (%)	14				11				26				12				10			
	Protein		S	Sex	Protein		S	Sex	Protein		S	Sex	Protein		S	Sex	Protein		S	Sex
P-value	<.001		<.001	ns	ns		ns	<.01	ns		ns	ns	ns		0.01	<.001	0.025		ns	<.001

[1]All the measurements are in grams, [2]Feeding program from 0 to 42 d of age. CV = Coefficient of variation, ns = Non significant,

RMS = Residual mean square, S = Strain

Table 3.9: Effects of feed protein content on the weights of water (g), lipid (g) and protein (g) at 42 d in Cobb and Ross broilers.

	Water				Lipid				Protein			
	Cobb		Ross		Cobb		Ross		Cobb		Ross	
Protein[1]	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1 (Low)	1129	1255	1115	1168	352	387	387	370	274	305	275	289
2	1133	1381	1164	1213	341	397	349	348	278	333	287	302
3	1194	1464	1202	1281	373	400	348	344	295	359	292	310
4	1122	1219	1140	1317	354	330	329	350	275	316	281	341
5	1238	1406	1226	1373	345	339	319	333	305	354	305	350
6 (High)	1292	1316	1261	1326	353	361	319	306	329	331	309	346
RMS		15036				3404				1080		
CV (%)		9.8				16.8				10.6		
	Protein	Strain	Sex		Protein	Strain	Sex		Protein	Strain	Sex	
P-value	<0.001	Ns	<0.001		ns	0.009	ns		<0.001	ns	<0.001	

[1]Feeding program from 0 to 42 d of age. CV = Coefficient of variation, ns = Non significant, RMS = Residual mean square

Table 3.10a: Log[1] linear regression estimates and goodness of fit criteria for the allometric relation between physical and chemical components of the carcass and body protein for Cobb and Ross strains and sex

		Females		Males			
Variables		Cobb	Ross	Cobb	Ross	Pooled SE	R^2
Body water	*ln*(a)	1.776[a]	1.768[a]	1.792[b]	1.891[b]	0.065	
	b	0.940[a]	0.941[a]	0.937[b]	0.918[b]	0.013	0.996
Thigh meat	*ln*(a)	-0.605[a]	-0.559[a]	-0.596[a]	-0.415[b]	0.091	
	b	1.039[a]	1.031[a]	1.037[a]	1.003[b]	0.018	0.993
Wing meat	*ln*(a)	-0.406[a]	-0.376a	-0.315[b]	-0.290[b]	0.071	
	b	0.971[a]	0.965[a]	0.949[b]	0.946[b]	0.014	0.995
Total breast	*ln*(a)	-1.431[a]	-0.975[b]	-1.090[c]	-0.783[d]	0.082	
Meat	b	1.248[a]	1.155[b]	1.166[b]	1.100[c]	0.016	0.995

[a-d] values within a row with no common superscript differ significantly (P<0.01)

[1]Natural logarithm, ln (y) = ln(a) + b × ln(x), where ln = natural logarithm, y = any variable (g), a = scale parameter, b = allometric slope and x = protein weight (g). SE = standard error, R^2 = Coefficient of determination

Table 3.10b: Dietary protein effect on the allometric relationships of body lipid, lipid to protein ratio (LP:PR) and drum with body protein.

	Body lipid				LP:PR				Drum meat			
Protein	*ln*(a)	SE	b	SE	*ln*(a)	SE	b	SE	*ln*(a)	SE	b	SE
1(Low)	-1.620[a]	0.213	1.343[a]	0.042	-0.264[a]	0.064	0.302[a]	0.013	-1.026[a]	0.189	1.103[a]	0.037
2	-1.617[a]	0.221	1.322[a]	0.043	-0.235[b]	0.108	0.286[b]	0.021	-1.047[a]	0.071	1.097[a]	0.014
3	-1.481[b]	0.308	1.285[c]	0.060	-0.273[c]	0.092	0.245[c]	0.018	-0.938[b]	0.091	1.075[b]	0.018
4	-1.442[b]	0.116	1.276[c]	0.023	-0.220[b]	0.034	0.226[d]	0.007	-0.992[b]	0.080	1.084[b]	0.015
5	-1.181[c]	0.136	1.213[d]	0.026	-0.011[d]	0.080	0.198[e]	0.015	-0.795[c]	0.158	1.044[c]	0.031
6(High)	-1.116[d]	0.127	1.200[d]	0.025	-0.174[d]	0.045	0.204[e]	0.009	-0.716[c]	0.103	1.030[c]	0.020

[a-e] values within a row with no common superscript differ significantly (P<0.01)

[1] Natural logarithm, ln (y) = ln(a) + b × ln(x), where ln = natural logarithm, y = any variable (g), a = scale parameter, b = allometric slope and x = protein weight (g). SE = standard error, R^2 (coefficient of determination) was 0.99 for all the power functions.

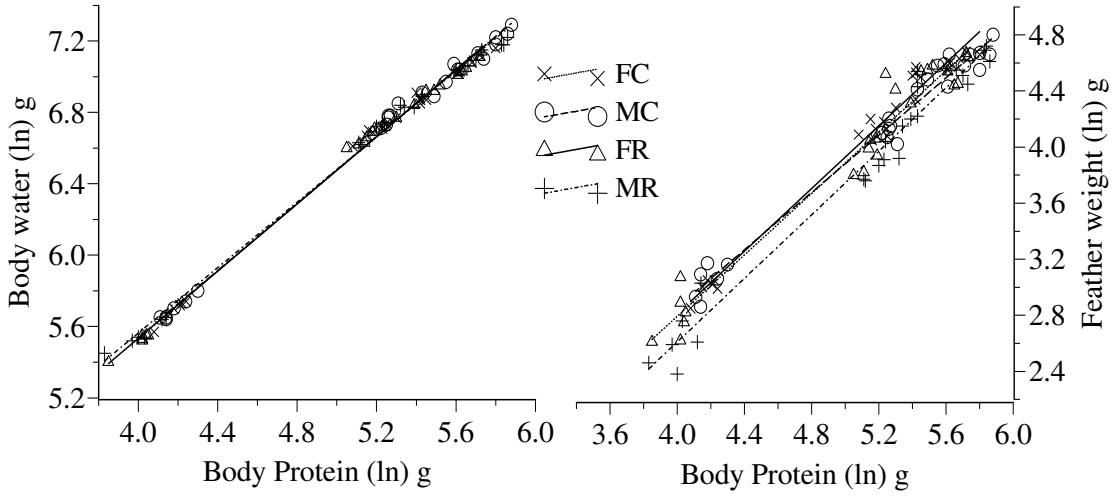

Figure 3.3: Allometric relationships for water and feather weights with protein weight in carcass of female Cobb, FC (X), male Cobb, MC (O), female Ross, FR (Δ) and male Ross, MR (+) broilers fed six levels of balanced protein and slaughtered at 14, 28, 35 and 42d of age. There was no dietary effect on the relationships, therefore, values represent pooled mean of dietary treatments.

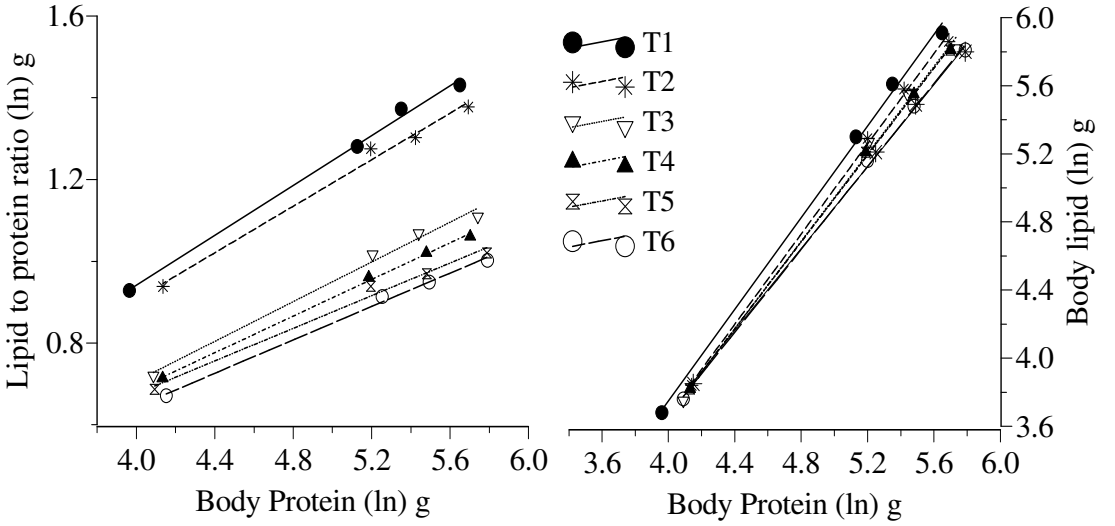

Figure 3.4: Effect of dietary treatments on allometric relationships for lipid to protein ratio and body lipid with protein weight in carcass of broilers fed six levels of balanced protein and slaughtered at 14, 28, 35 and 42d of age. Values represent pooled mean of both strains of female and male broilers.

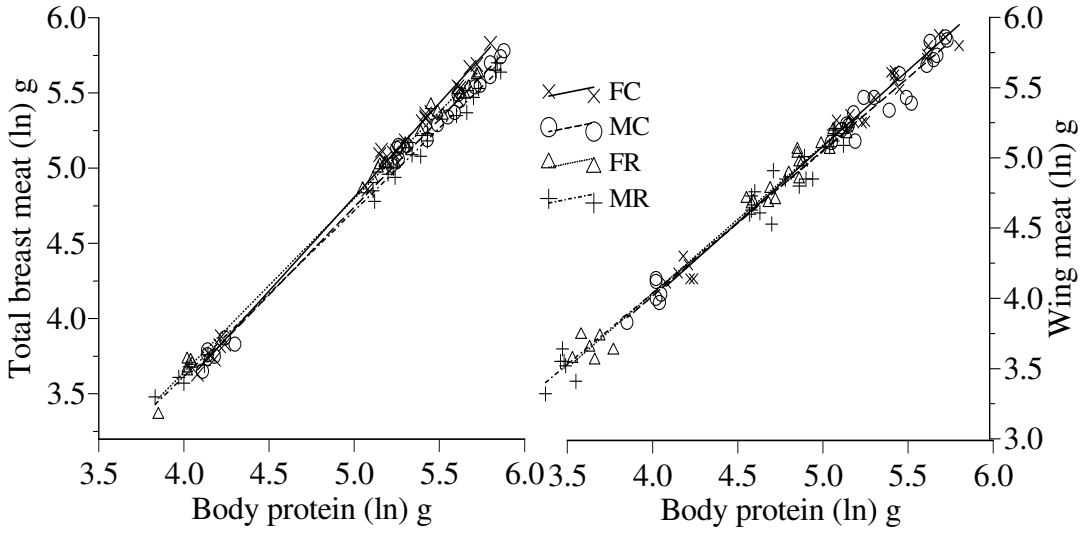

Figure 3.5: Allometric relationships for total breast meat and wing meat weights with protein weight in carcass of female Cobb FC (X), male Cobb, MC (O), female Ross, FR (Δ) and male Ross, MR (+) broilers fed six levels of balanced protein and slaughtered at 14, 28, 35 and 42d of age. There was no dietary effect on the relationships, therefore, values represent pooled mean of dietary treatments.

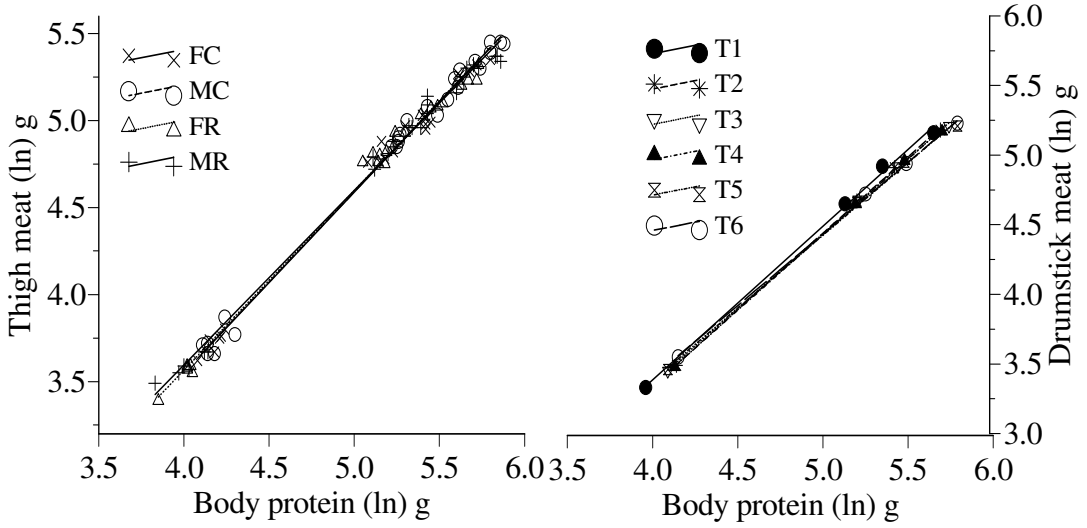

Figure 3.6: Relationships for thigh meat weight with body protein (left) in carcass of female Cobb, FC (X), male Cobb, MC (O), female Ross, FR (Δ) and male Ross, MR (+) broilers; and effect of dietary treatment on the relationships between drum meat weight and body protein (right) in carcass of broilers fed six levels of balanced protein and slaughtered at 14, 28, 35 and 42d of age.

3.4 Discussion

One of the basic purposes of a body composition experiment is to investigate the relationships between components under different situations (genotype, nutrition and environment). Wang *et al*. (1992) reported that the stability of these relationships is of fundamental scientific interest. These allometric relationships may be used in growth models to predict the weights of different body parts (Emmans, 1981b, Emmans and Fisher, 1986; Emmans, 1988; Hancock *et al*., 1995; Gous *et al*., 1999). However, it is not clear whether the level of protein might influence these relationships in broilers. In the present study, the effect of protein level on the allometric relationships and the performance of Cobb and Ross strains were evaluated.

Growth performance

The effect of feed protein content on food intake was a quadratic response for both strains and this is in agreement with Skinner *et al*., 1992; Smith and Pesti (1998); Smith *et al*., 1998. That is, food intake was reduced when the protein content of the diet was very low and high. In the finisher period, there was no dietary effect on food intake but mean intake differed significantly between the two strains (17.4 g/d, Table 3.5) and the pattern of response also differed. This is because strains differ in their ability to deposit protein or lipid as a result of food intake level (Orr *et al*., 1984; Smith and Pesti, 1998; Smith *et al*., 1998; Dozier and Moran 2001). Furthermore, this is partly due to the feathering effect of the strains. According to the results of this study, Cobb strains have greater feather cover than Ross broilers. Rapid feathering reduces food intake more than does slower feathering rate (Berhe and Gous, 2004) especially at high temperatures. However, in the starter period feather cover was not enough to affect the food intake of Cobb relative to Ross strains. Also, Cobb broilers might have a potentially higher food intake capacity than Ross broilers. The interaction between nutrition and strain for food intake (Table 3.4) and weight gain (Table 3.5) implies that the protein requirement for each strain varied and this subsequently influenced performance. Considering the overall performance, weight gain and feed conversion efficiency for Cobb broilers was higher than for Ross broilers regardless of the feeding programs. That is, Cobb broilers can perform better than Ross at low protein content of the feed as well as at high protein content with less food intake. It

can be concluded from these results that the feed and feeding programme of broilers should be both strain and sex specific (Emmans, 1995; Smith and Pesti, 1998).

Uniformity is a measure of the variability of, for example, bird size in a flock. It is an important measure of performance when optimising the feeds and feeding programme of a population of broilers, as it relates to the spread of product yield in the processing plant. According to the results of this experiment, uniformity was greatest in both strains when they were fed the highest protein feeds, with this declining as the protein level decreased. This is in agreement with the results of Corzo *et al.* (2004). These authors suggested that reduced variability in live production, ready to cook whole carcasses, or cut-up parts for supermarkets or fast food restaurants is desirable. Concerning mortality, there was no significant difference among the feed treatments, but there was a significant difference between strains ($P<0.01$), with a higher mortality in the Cobb strain, especially at low and high protein contents. Both Rezaei *et al.* (2004) and Kemp *et al.* (2005) have published similar results. This might be due to heat stress arising from feeding bulky feed to satisfy the nutrient requirements at low protein levels, and the heat stress might be aggravated due to the higher feathering rate of the Cobb strain. Furthermore, there may be some inexplicable effect on mortality of having a high intake of a low quality food. On the other hand, feeds with a high protein content support rapid growth, which Classen (2000) suggests might result in problems not seen in slower growing birds, such as skeletal and cardiovascular disease (sudden death syndrome, ascites).

Carcass analysis

It is well recognized that feed protein content can significantly affect the weight of the carcass portions and chemical components of the body (Bartov and Plavnik, 1998; Smith and Pesti, 1998; Smith *et al.*, 1998). These authors reported that all these variables except body fat content were significantly increased when dietary protein content was increased, and the results of this experiment confirmed these reports using modern broilers. Simple power functions provided good descriptions of relationships between physical and chemical components with body protein (Tables 3.10a and b), with dietary treatment having no effect on the allometric relationships of carcass portions with body protein except in the case of drum meat weight. This implies the rate parameter for carcass portions and body protein is the same. Gous *et al.* (1999) reported that the value of the rate

parameter for the total breast muscles were essentially the same as those for the empty feather-free body. This helps to support the assumption of a simple allometry between the physical parts of the body and body protein content, reported by Emmans (1988).

Some differences in the allometric coefficients were evident, i.e. between strain and sex in breast meat yield, and between dietary protein contents in drum weight. The preliminary explanation for these differences is that lipid deposition occurs differentially between the strains, sexes and dietary protein contents used in this trial, and the weights of the affected carcass parts would have been influenced by the different amounts of lipid deposited. The partitioning of energy and protein in different parts of the body in different strains and sexes, and on different feed protein contents should be studied further so that models can account for these differences in allometry.

There was no effect of strain, sex or dietary protein level on the allometric relationship between body water and body protein content. This is in agreement with Emmans (1988) and Wang *et al.* (1999). Kyriazakis and Emmans (1992) suggested that under conditions that limit growth, the water to protein ratio in a given component is not changed compared with that seen in normal growth. However, Eits *et al*. (2002) reported that when birds were given feeds with a high or low ideal protein to energy ratio, there was a considerable difference in the weight of water at a given protein weight. The allometric regression coefficients in this trial ranged from 0.918 to 0.941, values that are similar to those of Gous *et al*. (1999) (0.897 to 0.917), Eits *et al*. (2002) (0.945) and Gous (unpublished) (0.910 to 0.946). It is clear that there is no marked difference among the allometric slopes. As Eits *et al*. (2002) pointed out, discrepancies in results of such studies are partly related to differences in animal characteristics, nutritional treatments, length of the experimental period and data analysis. For instance, Eits *et al*. (2002) sampled birds at target weights, whereas in the current trial birds were selected randomly for carcass analysis at predetermined ages.

It is well known that dietary treatments may have a significant effect on the deposition of lipid (Gous *et al*., 1990; 1999) and that this would alter the allometric relationship with body protein. In this study, the allometric exponents between body lipid and body protein weight differed significantly between genotypes, sexes and dietary protein contents. However, these changes can be accounted for by assuming that a bird has an inherent body

lipid to protein allometry which it strives to maintain, but that deviations from this will occur when the bird is offered a feed that requires it to overconsume energy in order to obtain sufficient of the first limiting nutrient in the feed (Gous *et al*., 1990). There is good evidence to prove that the bird will utilise this excess energy when circumstances permit this to happen (Kyriazakis and Emmans, 1991).

3.5 Conclusions

Three important points emerged from this experiment. The first is that the response in food intake to dietary protein differed markedly between the Ross and Cobb strains, especially in the finisher period, implying that the optimum dietary protein content for these two strains would differ. The second point is that uniformity in body weight, an important quality criterion, is significantly influenced by feed protein content, and that uniformity is highest on feeds containing high protein contents. Finally, it was concluded that although variation exists in the growth rate of broilers differing in strain and sex, and when offered feeds differing in protein content, nevertheless the allometric relationships between the carcass components (other than feathers and body lipid) and body protein are not influenced by any of these factors. Consequently, when predicting the growth rate of any of the physical parts of the body, the same allometric relationship may be used in all cases. The small differences in the allometry for drum weight and breast meat yield can be accounted for by assuming that differential amounts of lipid are stored in these components as a consequence of feeding marginally deficient or unbalanced feeds to different strains and sexes, and these differences need to be addressed in future research.

Chapter 4

Effect of nutrition on growth, uniformity and mortality in three broiler strains

Abstract

The objective of this trial was to gather further evidence on the effect of feed protein level on uniformity and mortality on three broiler strains. Ross 788, Ross 308 and Cobb 500 day-old sexed broiler chickens (1120 of each strain) were housed, with males and females being reared separately. Broilers were fed starter feed for three weeks and finisher feed thereafter to six weeks. Four levels of protein were used in both feeding programs. Food intake, body weight, feed conversion efficiency, uniformity and mortality were recorded. A simulation exercise was conducted to determine the variation in individual live weight between males and females of two hypothetical broiler strains (A and B) using the EFG broiler growth model.

Cobb strains consumed more food and grew faster than the other two strains in the starter period. However, in the finisher period, the Ross 308 broilers had a higher food intake but were less efficient than the Cobb strains. There were no interactions between any of the factors in any of the measures of performance. Dietary protein level influenced mortality (%) ($P = 0.05$) in the starter period but not in the growing period. Broilers fed a high protein diet exhibited a higher mortality than those on low protein diet, irrespective of strain. Dietary protein content significantly affected the uniformity of individual body weight in both feeding periods. The effect of strain on flock uniformity was observed only in the starter period and there was a protein level x strain interaction ($P = 0.044$) at 42 d. The simulation exercise confirmed a higher uniformity in broilers given feeds high in protein. It can be concluded that food intake, weight gain, uniformity and mortality, as influenced by feed protein content, differ between broiler strains suggesting that optimal dietary protein contents will differ between the strains.

4.1 Introduction

Cross breeding and selection programmes have resulted in improved broiler growth and feed efficiency as evidenced by the fact that broilers 50 years ago took more than twice as long and consumed more than twice as much food to reach the required market weight as they do today. These changes have raised issues regarding the way in which broilers should be fed to maximise profitability, and some progress has been made in this regard with the advent of simulation models and optimisation routines that address this issue. But there is more to optimisation than simply addressing the response of the average individual in a population to feeds differing in nutrient density or amino acid-to-energy ratio; evidence has been presented above that the feed protein content has an effect on the uniformity of growth in a population, and that mortality rates differ between strains and sometimes between feed protein levels (Kemp *et al*., 2005). The trial reported here was designed to address these latter issues by gathering further evidence of the effects of feed protein level on uniformity and mortality.

The stocking density, environmental temperature, experimental period, materials and methods were the same as the experiment described in Chapter 3 but in the present experiment, three strains were used. Moreover, a wider range of dietary protein levels was used in order both to confirm the previous results and to obtain better estimates of the performance of commercial broilers over a broad range of protein levels.

4.2 Materials and methods

In this experiment, 1120 Ross 788, 1120 Ross 308 and 1120 Cobb day-old sexed broiler chickens were housed in the broiler house facility at Ukulinga Research Farm, University of KwaZulu-Natal. A total of 48 pens were used with 70 chickens initially placed in each pen, and with males and females being reared separately.

4.2.1 Feeds and feeding procedure

Chicks were fed a crumbled starter feed for the first three weeks and a pelleted grower feed from three to six weeks. Two basal starter feeds were formulated, one high and the other low in protein (Table 4.1), with equal contents of ME and major minerals and using a well-

balanced amino acid mixture (WinFeed 2[3]). These two feeds were blended to produce two additional levels of protein (33H:67L and 67H:33L). Feed and water were offered *ad libitum* throughout the trial.

4.2.2 Measurements

The body weight of a representative sample of birds in each pen was measured at weekly intervals up to 42d with food consumption determined at the same time. Twenty broilers from each pen were weighed individually at 1, 21 and 42d. Mortality was monitored and recorded. Food intake values reported were adjusted for mortality. The mortality percentage was transformed in order to normalise variability over the treatments.

4.2.3 Experimental design

The study was conducted as a completely randomised design with a factorial arrangement of main effects consisting of three strains, four protein levels and two sexes. Each treatment was replicated twice. Data were subjected to statistical analyses using the analysis of variance and linear regression procedures of Genstat (2005) in order to compare the treatment effects and to determine the response in the measure of performance to protein content. Where the effect of sex did not differ significantly in the analysis, both sexes were combined. Unless otherwise noted, statements of significant differences are based on $P<0.05$.

[3] EFG Software (Natal) 25 Fairfield Ave, Pietermaritzburg 3201 South Africa Tel: +27 33 260 6805, Fax: +27 33 260 6806 e-mail: gous@ukzn.ac.za.

Table 4.1: Ingredient composition (g/kg) of high (H) and low (L) protein (P) feeds used in the trial

	Starter		Finisher	
Ingredient	**LP**	**HP**	**LP**	**HP**
Maize	532	405	630.2	484.6
Soybean full fat	266	470	265	380.5
Soybean 48	127			
Sunflower 37		33.4		22.8
Fish meal 65		55.5		
Limestone	16.9	12.4	17.6	16.9
L-lysine HCL	1.0	0.5	0.5	0.9
DL methionine	1.7	3.4	1.3	0.2.7
L-threonine		0.6		0.4
Vit+min premix	2.5	2.5	2.5	2.5
Choline chloride 60	0.7		7.6	12.9
Virbacox/Salinomycin	0.5	0.5	0.5	0.5
Zinc Bacitracin 15%			0.3	0.3
Salt	3.0	2.0	1.4	
Monocalcium phosphate	16.6	11.6	16.8	16.6
Sodium bicarbonate	3.0	2.5	6.7	8.4
Oil – soya	30.0		50.0	50.0
Calculated composition*				
AME (MJ/kg)	12.6	12.6	13.5	13.5
Crude protein	206.5	261.2	153.1	194.1
Dry matter	88.7	89.0	88.7	89.3
Lysine	10.2	14.0	7.4	10.1
Methionine	4.5	7.2	3.5	5.3
M + C	7.4	10.3	5.8	7.9
Threonine	6.8	9.2	5.0	6.7
Tryptophan	2.0	2.5	1.4	1.9
Arginine	12.8	16.0	9.0	11.9

*Digestible amino acids; M+C = Methionine + Cystine

4.2.4 Simulation exercise: effect of feed protein on live weight uniformity

A simulation exercise was conducted to determine the variation in individual live weight between males and females of two broiler strains (A and B) using the EFG broiler growth model (EFG Software, KwaZulu-Natal). These two theoretical strains differed only in the maximum lipid:protein ratio in the gain (MLG). This parameter refers to the maximum amount of lipid that a bird can deposit in one day in relation to the rate of body protein growth. The higher the value of MLG, the more lipid may be deposited, and the less heat that needs to be lost from the body. Hence, a bird with an MLG of 1.8 would be capable of depositing 1.8 times as much lipid as protein in the gain, and would thus be capable of growing faster on poor quality feed, especially at high temperatures, than would a bird with an MLG of 1.0. According to the results of Berhe and Gous (2005) and the present experiment (not shown in the text), the Cobb strain has shown a higher lipid deposition potential than that of Ross broilers.

A theoretical flock of 100 broilers of each strain and sex were randomly generated based on the mean and CV (%) of the genetic parameters used in the EFG broiler growth model (Table 4.2). The mean values of the parameters were derived from the results of different experiments or publications (such as Emmans and Fisher, 1986; Hancock *et al*., 1995; Gous *et al*., 1999). The CVs used were those suggested by Emmans and Fisher (1986) while for those not found in the literature, the results of the present study were used. The response of the same (generated) individuals to the six lysine-limiting starter and finisher feeds was simulated. The feeds were formulated in the range from 0.80 to 1.20 of the Ross specifications (Aviagen, 2002). The broilers were fed a starter feed from 0 to 21 d and finisher feed from 22 to 42 d. This range of feed protein contents includes the actual feed used in the present study. The simulation exercise was conducted at the normal environmental temperature of 31˚C for two days and was then decreased daily by 0.5˚C to 20˚C, remaining constant thereafter. The stocking density was 17 birds/m^2. No mortalities occurred over the simulation period. A total of 120 simulations (5 feeds, 2 strains, 2 sexes and 2 feeding periods with 3 replications) was conducted. Individual live weight at 21 d and 42 d was recorded for males and females. Data were subjected to a descriptive statistics procedure using Genstat (2005) and CV (%) was calculated.

Table 4.2: Distribution of stochastic parameters and feeding schedules for both starter and finisher growth periods in the simulation exercise

	Mean			Lysine (g/kg)	
Parameters	Strain A	Strain B	CV (%)	0 to 21d	21 to 42d
Rate of maturing, B^* (/d)	0.046	0.046	6.0	1.0	0.74
Feathering rate, Fr (/d)	1.23	1.23	15.0	1.16	0.84
Mature protein weight, P_m (kg)	1.42	1.42	7.0	1.26	0.91
Lipid-to protein ratio at maturity, LPR_m (g/g)	0.64	0.64	4.0	1.40	1.01
Maximum lipid gain, MLG (g/g)	1.0	1.8	15.0	1.54	1.20
Initial body weight, Wo (g)	50.0	50.0	7.0		

B^* is a scaled rate of maturing parameter = B. $P_m^{0.27}$ and is uncorrelated with P_m.

4.3 Results

The effect of feed protein content on the growth of three broiler strains of females and males is presented in Tables 4.3 and 4.4. All of the main effects significantly affected the food intake, weight gain and feed conversion efficiency (FCE) of the three strains of broilers in the starter period but in the finisher period, feed protein level and strain had no effect on food intake or weight gain. The Cobb strains consumed more food and grew faster than the other two strains in the starter period. However, in the finisher period, the Ross 308 broilers had a higher food intake but were less efficient than the Cobb strains. Sex had a significant effect on food intake, weight gain and FCE in both feeding periods, in that males benefited from the extra feed intake. There was no interaction of the main effects for all measures of performance. The regression coefficients for food intake, FCE and weight gain on feed protein content are shown in Tables 4.5. As the protein level increased, food intake and weight gain responses were quadratic but the FCE response was linear in the starter period. In the finisher period, only weight gain response was linear. The main effects of the various factors, and their interactions are presented in Tables 4.3 to 4.6.

Table 4.3: Mean food intake (g/d), weight gain (g/d) and feed conversion efficiency (FCE) of three strains of broilers from 0 to 21d (n = 48)

		Food intake (g/d)		Weight gain (g/d)		FCE (g gain/kg feed)	
Strain	Feed[1]	F	M	F	M	F	M
Cobb	195.2	53.0	55.1	41.4	43.8	781	797
	211.7	54.0	58.1	42.8	47.3	794	815
	228.7	54.1	58.5	44.4	49.4	821	846
	245.2	53.9	56.8	45.3	48.8	839	860
Ross 308	195.2	47.9	51.4	36.8	38.9	769	756
	211.7	50.9	52.2	39.3	42.5	773	813
	228.7	50.8	53.6	40.7	44.1	802	808
	245.2	50.3	52.9	40.9	44.4	812	839
Ross 788	195.2	47.5	48.5	35.0	37.1	739	765
	211.7	48.0	51.0	38.3	41.5	773	815
	228.7	49.1	54.0	39.6	43.5	806	806
	245.2	48.8	51.1	40.2	44.2	823	842
RMS		3.008		1.152		485.1	
Source of variation		P-value		P-value		P-value	
Strain		<0.001		<0.001		0.01	
Feed		0.005		<0.001		<0.001	
Sex		<0.001		<0.001		0.006	

[1]Protein content of the feed (g/kg),

n = number of observations, RMS = residual mean square.

Dietary protein level affected mortality (%) (P = 0.05) in the starter period but not in the growing period. Broilers fed a high protein diet had a higher incidence of mortality than those on low protein diet, irrespective of strain. There was a tendency of interaction (P = 0.051) between the sexes and strains in the starter period and higher mortality in the growing period. There were no mortality differences among the strains throughout the growing period but males had a higher mortality overall. The regression coefficients of mortality (%) of broilers are presented in Table 4.7. Dietary protein content had linear and quadratic effects on mortality in the starter and finisher feeding periods respectively.

Table 4.4: Mean food intake (g/d), weight gain (g/d) and feed conversion efficiency (FCE) of three strains of broilers from 21 to 42d (n = 48)

		Food intake (g/d)		Weight gain (g/d)		FCE (g gain/kg feed)	
Strain	Protein[1]	F	M	F	M	F	M
Cobb	147.8	141.0	157.9	69.2	78.5	490.6	496.1
	160.6	142.2	163.3	73.4	88.7	516.1	542.7
	173.9	143.7	162.6	72.8	92.7	507.6	570.6
	186.7	138.7	158.0	72.0	86.3	519.6	545.4
Ross 308	147.8	151.2	180.1	70.6	84.7	467.0	469.9
	160.6	157.9	179.6	74.2	90.2	469.7	502.0
	173.9	157.8	183.0	74.8	90.9	473.4	499.9
	186.7	149.5	172.2	71.6	89.2	478.8	518.4
Ross 788	147.8	151.2	169.8	73.5	81.5	486.2	480.4
	160.6	153.0	170.9	74.1	87.0	484.4	508.9
	173.9	154.6	181.4	74.1	90.2	478.8	497.9
	186.7	145.4	174.9	71.5	86.7	492.0	497.2
RMS		60.0		16.1		294.5	
Source of variation		P-value		P-value		P-value	
Strain		<0.001		ns		<0.001	
Feed		ns		0.005		0.003	
Sex		<0.001		<0.001		<0.001	

[1]Protein content of the feed (g/kg)

n = number of observations, ns = non-significant, RMS = residual mean square.

Table 4.5: Regression[1] coefficients of food intake, feed conversion efficiency (FCE) and weight gain on feed protein content in both feeding periods for three broiler strains

	Food intake				FCE				Weight gain			
	0-21d		21–42d		0–21d		21–42d		0–21 d		21–42 d	
Variables	Estimates	S.E.	Estimates	S.E.	Estimates	S.E.	Estimates	S.E.	Estimates	S.E.	Estimates	S.E.
Constant	-45.25	26.71	-273.82	156.2	515.9	32.94	-342.85	315.61	29.87	3.25	50.73	4.88
Protein (P)	0.870	0.244	5.01	1.873	1.33	0.147	9.682	4.98	0.505	0.53	0.906	0.206
P x P	-0.0019	0.0006	-0.0151	0.005			-0.027	0.015	0.054	0.023		
Ross 308	-4.163	0.52	15.5	2.349	-22.53	6.743	-38.93	6.25	-2.767	0.388	-0.8	1.39
Ross 788	-5.488	0.52	11.737	2.349	-22.84	6.743	-32.73	6.25	-3.338	0.394	-1.2	1.35
Sex	2.85	0.43	22.313	1.918	19.19	5.506	21.77	5.10	2.257	0.306	11.18	1.32
R^2	0.82		0.82		0.72		0.65		0.93		0.83	
Variables	P-value		P-value		P-value		P-value		Variables	P-value	P-value	
Constant	ns		ns		<0.001		ns		Constant	<0.0001	<0.0001	
Protein (P)	0.0009		0.0275		<0.001		0.0413		P_{in}	ns	0.0001	
P x P	0.014		0.0265				0.054		P_{in} x P_{in}	0.0233		
Ross 308	<0.0001		<0.0001		0.0017		<0.0001		Ross 308	<0.0001	ns	
Ross 788	<0.0001		<0.0001		0.0015		<0.0001		Ross 788	<0.0001	ns	
Sex	<0.0001		<0.0001		0.0011		0.0001		Sex	<0.0001	<0.0001	

[1]Cobb strains used as a reference in the analysis; P_{in} = protein intake; ns = non-significant; R^2 = coefficient of determination; S.E. = standard error.

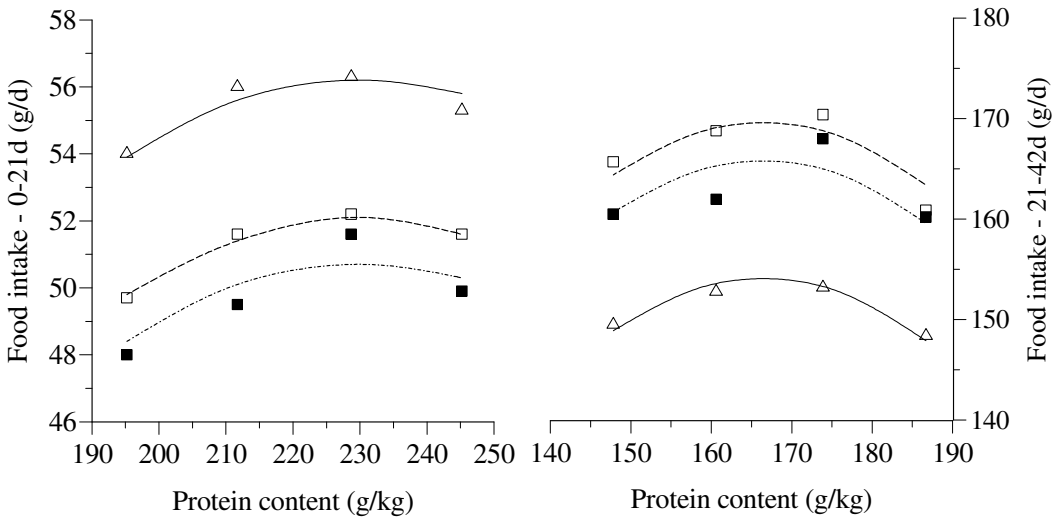

Figure 4.1: Effect of feed protein content on food intake (g/d) of Cobb (△, response relationship ─), Ross 308 (□, response relationship – –) and Ross 788 (■, response relationship – - –) broilers from 0 to 21d (left) and 21 to 42d (right) of age.

Dietary protein content significantly affected the uniformity of individual body weight in both feeding periods (Table 4.8). The effect of strain on flock uniformity was observed only in the starter period. There was a protein level x strain interaction (P = 0.044) at 42 d. The regression coefficients of individual live weight variation (%) on dietary protein content for the three strains are presented in Table 4.9. As the protein level increased, CV (%) decreased linearly in both feeding periods. In general, there was less variation in body weight in the Cobb strain than in the other two strains.

Table 4.6: Effect of feed protein content on mortality (%) in three broiler strains at different growth periods (n = 48)

		Weeks 0–3		Weeks 3–6		Weeks 0–6	
Strain	Feed	F	M	F	M	F	M
Cobb	1 (Low)	3.0	0.4	6.7	7.9	5.4	5.4
	2	3.6	5.7	9.2	10.7	7.1	8.5
	3	3.0	3.1	3.9	12.2	3.4	9.0
	4 (High)	6.3	2.2	5.9	9.2	6.9	6.5
Ross 308	1 (Low)	2.2	4.9	0.4	10.2	1.7	7.8
	2	4.9	5.0	5.7	8.0	5.7	7.2
	3	0.4	6.6	7.4	12.5	5.0	9.6
	4 (High)	3.7	7.5	4.3	8.3	4.4	7.9
Ross 788	1 (Low)	2.2	2.2	3.3	3.2	3.6	2.7
	2	0.4	6.4	9.4	9.7	6.3	8.1
	3	4.9	4.0	4.0	8.6	5.1	7.3
	4 (High)	5.7	6.3	4.4	6.9	5.1	6.6
RMS		5.67		38.45		13.95	
Source of variation		P-value		P-value		P-value	
Strain (S)		ns		ns		ns	
Feed		0.05		ns		ns	
Sex		ns		ns		0.05	
S x sex		0.051		ns		ns	

[1]Protein content of the feed (g/kg)

n = number of observations, ns = non-significant, RMS = residual mean square.

Table 4.7: Regression coefficient of mortality (%) on dietary protein content for three strains of broilers

	Mortality (%)					
	0–21d		21–42d		0–42d	
Variables	Estimates	S.E.	Estimates	S.E.	Estimates	S.E.
Constant	-8.5	4.8	-212.8	72.8	-132.8	50.9
Protein (P)	0.046	0.021	2.58	0.88	1.38	0.53
P x P			-0.0076	0.0026	-0.0035	0.0014
Ross 308	0.99	0.96	-1.11	1.07	-0.36	0.73
Ross 788	0.60	0.96	-2.02	1.07	-0.93	0.73
Sex	1.17	0.78	3.57	0.87	2.24	0.60
R^2	25.4		51.4		47.1	
Variables	P-value		P-value		P-value	
Constant	ns		0.009		0.018	
Protein (P)	0.04		0.009		0.018	
P x P			0.009		0.02	
Ross 308	ns		ns		ns	
Ross 788	ns		ns		ns	
Sex	ns		<0.001		0.001	

[1]Cobb strains used as a reference in the analysis; ns = non-significant; R^2 = coefficient of determination; S.E. = standard error.

Table 4.8: Effect of feed protein content on coefficient of variation (%) of three broiler strains (n = 960)

		Coefficient of variation (%)					
		Week 0		Week 3		Week 6	
Strains	Feed[1]	Female	Male	Female	Male	Female	Male
Cobb	1 (Low)	6.5	5.8	7.3	7.9	7.2	7.6
	2	6.5	5.8	9.1	8.4	7.1	7.1
	3	6.5	5.8	6.5	7.3	8.3	6.9
	4 (High)	6.5	5.8	6.9	6.1	6.7	6.6
Ross 308	1 (Low)	7.2	6.7	11.6	11.2	8.2	9.7
	2	7.2	6.7	9.0	11.8	8.7	8.0
	3	7.2	6.7	6.8	10.3	6.1	6.6
	4 (High)	7.2	6.7	8.0	7.7	6.5	6.3
Ross 788	1 (Low)	6.6	6.9	7.4	9.9	9.3	10.7
	2	6.6	6.9	7.1	8.9	7.8	7.8
	3	6.6	6.9	7.8	7.0	8.3	6.6
	4 (High)	6.6	6.9	5.4	7.9	6.8	6.4
RMS				1.6		0.42	
Source of variation					Probability		
Strain					0.012	ns	
Feed					0.027	<0.001	
Strain x Feed					ns	0.044	

[1]Protein content of the feed

n = number of observations, ns = non-significant, RMS = residual mean square.

Table 4.9: Regression coefficient of coefficient of variation (%) on dietary protein content and three strains of broilers

	Coefficient of variation (%)			
	0–21d		21–42d	
Variables	Estimates	S.E.	Estimates	S.E.
Constant	16.67	2.61	9.42	2.87
Protein (P)	-0.049	0.011	-0.013	0.015
Ross 308	2.11	0.52	10.54	4.06
Ross 788	0.24	0.52	12.09	4.06
Sex	0.96	0.42		
P x Ross 308			-0.061	0.024
P x Ross 788			-0.068	0.024
R^2	63		65.2	
Variables	P-value		P-value	
Constant	0.001		0.004	
P	<0.001		ns	
Ross 308	<0.001		0.017	
Ross 788	ns		0.017	
Sex	0.036			
P x Ross 308			0.02	
P x Ross 788			0.011	

[1]Cobb strains used as a reference in the analysis; ns = non-significant; R^2 = coefficient of determination; S.E. = standard error.

Simulations: effect of feed protein content on flock uniformity

The mean $\pm$ standard error (S.E.) and CV (%) of individual live weight of males and females of the two strains is presented in Table 4.10. The response in live weight was similar to the actual experiment, that is, there was a quadratic pattern of effect as the lysine level of the feed increased for both strains of broilers. As the level of lysine content of the feed increased, uniformity in body weight at 42d of age showed a quadratic response. There was greater variation in strain A relative to strain B broilers. There was also higher uniformity at a high lysine (protein) level in the feed irrespective of the strains.

Table 4.10: Predicted mean ± S.E. of live weight (g) and coefficient of variation (%) at 21 and 42d of age in females and males of Cobb and Ross broiler strains using EFG Broiler Growth Model

	Live weight (g, 21d)				Coefficient of variation (%, 21d)					
	Cobb		Ross		Cobb			Ross		
Lysine (%)	Fem	Male	Fem	Male	Fem	Male	M/F	Fem	Male	M/F
1.0	704 ± 6.5	796 ± 6.9	642 ± 5.4	699 ± 4.6	8.6	9.3	8.9	8.4	6.6	7.5
1.16	754 ± 7.7	861 ± 8.4	711 ± 7.7	805 ± 6.2	9.8	10.2	10.0	10.8	7.7	9.2
1.26	773 ± 8.8	887 ± 10.3	748 ± 8.7	867 ± 8.1	11.7	11.4	11.5	11.7	9.4	10.6
1.4	781 ± 8.7	892 ± 9.9	766 ± 8.1	884 ± 8.7	11.2	11.1	11.1	10.5	9.8	10.2
1.54	779 ± 8.7	892 ± 9.7	769 ± 8.1	889 ± 9.0	11.1	10.9	11.0	10.5	10.1	10.3
	Live weight (g, 42d)				Coefficient of variation (%, 42d)					
0.74	2384 ± 28.5	2682 ± 26.5	2011 ± 24.8	2075 ± 20.2	11.9	9.8	10.9	12.3	9.8	11.0
0.84	2406 ± 28.8	2948 ± 29.1	2115 ± 31.4	2481 ± 25.8	12.1	9.9	11.0	14.6	10.4	12.5
0.91	2421 ± 28.9	2976 ± 31.0	2232 ± 30.5	2682 ± 25.8	12.0	10.4	11.2	13.7	9.6	11.6
1.01	2424 ± 28.4	2929 ± 29.9	2256 ± 27.1	2754 ± 24.7	11.7	10.2	11.0	12.0	9.0	10.5
1.20	2422 ± 26.9	2906 ± 28.9	2265 ± 26.7	2759 ± 24.8	11.1	9.9	10.5	11.8	9.0	10.4

Fem = female, M/F = average males and females, S.E. = standard error.

4.4 Discussion

Dietary protein content affects weight gain and feed efficiency of broilers, but also has a marked effect on flock uniformity and mortality (Corzo *et al*., 2004; Kemp *et al*., 2005). Uniformity is of paramount importance in the broiler industry firstly because processing equipment is automated, hence any abnormal sized birds may not be processed well because they do not conform to the size the equipment is designed to handle, and secondly because marketing of the product is less complicated if all birds are the same size. Variation in the weight of the end-product may be caused by many factors, such as disease, overstocking and generally poor management, but has been shown here to be due also to changes in dietary protein content and genotype. The influence of dietary protein content on uniformity and mortality has implications when optimising the feeding of broilers, and was thus the objective of this study.

The results of this study generally agree with several investigations in that increased dietary protein content resulted in improved growth performance (Jackson *et al*., 1982a, b; Smith and Pesti, 1998; Rezaei *et al*., 2004). Food intake decreased quadratically as protein levels increased, a result that corresponds with Pesti and Fletcher (1984), Skinner *et al.* (1992) and Smith and Pesti (1998). Comparing the results of this study with the previous trial reported in Chapter 3, besides the broilers consuming more feed in this study; the pattern of food intake in finisher period seems different. However, considering the response of the broilers at the same range of protein content of the feed, Cobb strains perform almost similarly in both experiments, (i.e. food intake increased as the protein content of the feed decreased) whereas Ross broilers exhibited a different pattern of food intake to the corresponding range of protein levels. This is in agreement with the illustration of patterns of feed intake in response to a range of dietary protein contents in two hypothetical broiler strains differing in the dietary protein content required to meet their potential growth (Gous, 2007). He explained that the range of nutrient contents used in a response trial will determine the pattern of food intake of broiler strains. On the other hand, broilers used in the present experiment may not be identical to those in the previous experiment and as a result they may show different patterns of response due to differences in their nutrient requirements.

Birds receiving the highest protein feed in both feeding periods had the best feed conversion efficiency irrespective of strain. The maximum body weight response of both Ross broiler strains was on the highest protein feeds, which agrees with the Ross feed recommendations (Aviagen, 2002), as the high protein feeds fell within the recommended range. The Ross 308 birds consumed more feed than the Ross 788 birds in both feeding periods and they benefited from the extra intake. The Cobb broilers benefited from the extra food intake in the starter period by having a higher weight gain with less food intake relative to the other two strains in the finisher period. This pattern was similar to the previous experiments described in Chapters 2 and 3. However, higher body weights were observed in this trial compared with the previous experiments using the same strains. This might be due to more favourable environmental conditions that prevailed in the present study.

Males and females responded significantly differently ($P<0.001$) to dietary protein in both growing periods. Thus, rearing male and female broilers separately would allow producers to capitalise on the natural growth and developmental differences between the sexes and to modify their nutritional programmes accordingly. It would also enable different requirements for broilers within the same market to be met more efficiently and, by reducing variation within each broiler house, would improve the quality of the product. Different responses among the strains, therefore, imply that producers need to find the point of maximum economic efficiency for the strain of broiler they are using.

The effect of dietary protein level on uniformity was similar to that in the previous experiments (Chapters 2 and 3) in that all of the strains demonstrated poor uniformity when given feeds of low protein content. In general, variation decreased as dietary protein content increased and the highest uniformity was observed at the highest dietary protein content. This may be due to the birds depositing the least amount of lipid in the body, whereas at all other protein levels, the amount of lipid would differ depending on the ability of each bird to overconsume energy. This result is in agreement with the findings of Corzo *et al*. (2004) and Kemp *et al*. (2005). Less variation and higher body weight occurred in the Cobb than in the Ross 788 strain, which implies that rapid growth rate might improve uniformity. However, Corzo *et al*. (2004) suggested that rapid body tissue deposition is not synonymous with reduced flock variability since they found that uniformity was higher in females in spite of their growing slower than males. Rearing

sexes separately may contribute to increased body weight uniformity as nutrient and stocking density can be adjusted for faster growing and more efficient males (Veerapen and Driver, 1999). In this study, there was no significant effect of sex on flock uniformity although this was numerically higher in females. Dietary protein content appeared to affect uniformity more severely in the starter than in the finisher period, but differences between strains were more pronounced in the finisher period. This suggests that flock uniformity is influenced by both genotype and nutrition.

The effect of dietary protein on mortality (%) in the starter period was similar to that reported by Corzo *et al*. (2004) and Kemp *et al*. (2005), namely, that as the level of protein increased, mortality also increased for all strains. However, in the finisher period, broilers exhibited highest mortality on the intermediate feeds. Mortality rates were higher in this latest trial compared to the experiments discussed in Chapters 2 and 3. This might be explained by the more rapid growth of the birds in this study, especially males, and the negative correlation with mortality. Animals with high growth rates experience a higher risk of mortality than animals with low growth rates according to Classen (2000) and Mangel and Stamps (2001). They illustrated that high growth rates may lead to the formation of bodies that are more vulnerable to a variety of sources of mortality. This implies that there is some way of associating mortality with the genetic make-up of the strain. The season in which the experiments were conducted might be another factor causing variation in response as the present study was conducted in summer whereas the other experiments were carried out in spring. However, the temperature in the tunnel-ventilated broiler house was maintained at close to pre-determined levels in all experiments.

Broilers selected for high growth rate may be more susceptible to a variety of pathogens than strains selected for other traits such as high rates of egg production (Nestor *et al*., 1996; Reddy, 1996; Bayyari *et al*., 1997). Considering both feeding periods in the present study, high, medium and low mortality levels were recorded in the Cobb, Ross 308 and Ross 788 broilers respectively, these being correlated with the rates of growth of these three strains suggesting that there is a trade-off between growth and mortality. The cause of the mortality experienced here was not investigated, so it is not possible to ascribe this to infectious or metabolic causes; nevertheless it can be concluded that there is an

association between dietary protein content and mortality rate, and that this is influenced by strain of broiler.

Simulations: effect of feed protein content on flock uniformity

The simulated patterns of uniformity and body weight gain at 21d and 42d of age were similar to the experimental results obtained in this study except that uniformity increased also on the lowest protein feed. The probable cause of decreased uniformity on feeds marginally deficient in an essential nutrient is the variation in the ability of broilers to overconsume energy when faced with a deficiency. This characteristic will enable the successful birds to show little reduction in growth, whereas the food intake of others, without the capacity to deposit as much lipid, could be severely constrained, resulting in poor growth in all cases. Furthermore, the simulation exercise suggests that at both high and low (limiting) concentrations of dietary protein uniformity increases, the requirements of all individuals in the one case being met, and in the other, all individuals being similarly constrained. So it is on marginally deficient feeds that uniformity is compromised to the greatest extent, a situation that is likely to occur frequently in commercial broiler operations. Thus, uniformity in a population of birds, caused by feeds varying in essential nutrient content, may be simulated mechanistically.

Variation in final body weight may be caused by many factors other than the nutrient content of the feed. Such factors would include variation in chick weight, feed uniformity, micro-climates surrounding the birds and in the ventilation system employed in the broiler house, among others (Gous and Berhe, 2006). Where differences exist in the environmental temperature at either end of a tunnel ventilated broiler house in summer, broilers fed a marginally deficient feed would perform better in the cooler end of the house because they would be capable of overconsuming more of the limiting feed than would hotter broilers. Because of such interactions between nutrient content and these non-nutritional causes of variation, it would be rewarding to make use of a population response model when predicting responses to nutrients. Issues related to the use of population response models are raised and discussed in Gous and Berhe (2006).

4.5 Conclusions

Broiler strains appear to be affected differently by feed protein levels in terms of food intake, weight gain, uniformity and mortality. That is, they require different levels of dietary protein to maximise margin over feed cost and to express their genetic potential. In the trial reported here, Cobb broilers performed better than the Ross strains irrespective of the level of dietary protein although this has not been the case in some of the trials in which such comparisons have been made. It appears to be possible to simulate mechanistically the effect of feed protein level on flock uniformity by assuming that on very low protein contents the growth of all broilers is similarly constrained; on high protein levels all birds will be able to attain their potential growth rate; but that on intermediate, or marginally deficient levels of protein, some birds will be able to overconsume energy and grow better than those whose ability to deposit body lipid is constrained genetically, thus reducing uniformity in the flock.

There is inconsistency in the effect of dietary protein content on the rate of mortality in broiler strains, but because some strains often suffer from a higher mortality when growth rate is increased through feeding a higher protein feed, this has led to suggestions that growth rate should be slowed down in fast-growing strains through the use of lighting programs (Classen, 1990), the use of mash rather than pellets (Decuypere *et al.,* 2000), and the use of feed restriction (Decuypere *et al.,* 2000). Mortality cannot at this stage be accounted for mechanistically, as there is no mechanistic explanation for the observations made. However, it is clear that responses need to be strain-specific if these are to be of value when predicting performance with a view to optimising poultry feeds, and until a mechanistic approach has been discovered, mortality will have to be dealt with empirically.

Chapter 5

Modelling populations for the purpose of optimisation

Abstract

A number of exercises were conducted to compare individual and population responses when optimising the dietary amino acid contents and nutrient densities of feeds for broilers. The first exercise was designed to examine the consequences of using a population of 100 individuals, rather than the average individual. The optimum size of a population was then researched, in which different population sizes were simulated and their responses measured. Finally, a sensitivity analysis was conducted to determine the relative impact of altering each of the parameters describing the genotype of the broiler.

In all cases a three-stage feeding programme was used, with starter (0 – 10 d), grower (11 –25 d) and finisher (26 – 42 d) feeds being offered. For the first exercise, individuals making up six populations of 100 broilers were created using a Monte Carlo random normal distribution method, based on the mean and CV of each genetic parameter for each strain. Margin over feed cost and margin/m^2.annum were used as objective functions to optimise the amino acid contents and nutrient densities of the three feeds used in the feeding programme, for each of the strains. The results differed for the deterministic (single bird) and stochastic (population) models, the largest differences being the result of a high rate of feathering, which constrains the amount of heat that may be lost from the bird resulting in a lower feed intake especially on marginally deficient feeds and at high environmental temperatures.

Populations of 50, 100, 250, 500 and 750 individuals were generated using the means and CVs of the parameter values of one of the strains used in the previous exercise. When group size was increased from 50 to 750, the difference in the optimal dietary lysine content and nutrient density within the simulated group was small; it was only significant relative to the average individual. Consequently, there is no benefit in increasing the size of the population above 50 as long as no correlations between parameters are considered.

To determine the extent to which variation in mature body protein weight (Pm) and rate of maturing of the body (B) and of the feathers (Bfr) influenced the optimum amino acid content in each feed, body weight, feed conversion ratio (FCR), breast meat yield and margin over feed cost (or margin/m^2.annum), each of the three genetic parameters was reduced in turn by 10 and 20 %, and then increased by the same amounts. Whereas

variation in B and Pm produce means similar to those obtained from the response of an individual, variation in the rate of feather growth causes a non-linear response in performance in a population, resulting in a reduction in performance in those birds that feather more rapidly, because they are unable to lose sufficient heat to the environment to enable them to consume sufficient of the feed required to grow at their potential. The consequence is that the resultant mean response is always lower than that of an individual when variation in the rate of feather growth is included in a population model. A useful means of determining the spread in the weights of the body and its component parts in a broiler flock at harvesting would be to simulate a population of 50 individuals in which just B and Pm are made stochastic. Variation in the maximum lipid:protein in the gain is useful in simulating the observed differences between strains available to the broiler Industry at present.

These exercises are useful in determining whether or not to simulate a population of broilers rather than the more common method of using the mean individual in the population only, and of deciding which parameters to include when describing the population.

5.1 Introduction

Considerable attention has been given to the assessment of the amino acid requirements of broiler chickens and to the definition of optimal dietary amino acid balance (D'Mello, 1979). As models have been developed and applied, the traditional empirical approach to estimating nutrient requirements, such as those given by National Research Council, NRC, (1994), has been shown to be severely limiting in that it considers only the conditions under which the requirements were established. As soon as any one of the many important variables that affect nutrient requirements changes, new requirements should be established. Some researchers have made a great effort to integrate this knowledge into a unified theory.

Various methods are available for determining the optimal amino acid content and nutrient density of feeds. The most common approach is simply to make use of tables of nutrient requirements, which are usually based on the empirical evaluation of broiler performance as a function of graded levels of a particular amino acid. The approach used to measure

responses of broilers to nutrient levels is discussed in Gous and Morris (1985), and an analysis of the way in which such results are interpreted is in Morris (1999). However, fixed requirement values fail to take into consideration genetic variation within and between commercial broiler strains (Gous, 1986; 1998). Furthermore, each time an experiment is conducted, different conditions prevail in the research facility, and different genotypes are used. Interactions between the birds, the environment and the feed used are of great importance and cannot be resolved in any one experiment. Broiler genotypes are constantly changing not only in growth rate but also in important characteristics such as in their response to dietary balanced protein (Kemp *et al*., 2005; Gous *et al*., 2006). Hence, feeding programmes should be strain-specific (Emmans, 1995; Smith and Pesti, 1998). According to a review by Oviedo-Rondón and Waldroup (2002), single fixed numbers of requirements are not useful to apply in an accurate cost-benefit analysis. Because the responses of birds to dietary energy, protein and amino acids are a diminishing-returns phenomenon, they should be evaluated as such to estimate economic optimum levels, rather than as biological maxima (Fisher *et al*., 1973; Fawcett, 1986; Pesti and Miller, 1997). Gous (1986; 1998) suggested that simulation modelling techniques are the only defensible way in which nutritionists can optimise the feeds and feeding programmes for broilers.

Simulation models allow the effects of a range of environmental and other variables on animal performance to be considered simultaneously in a way that would otherwise require enormous resources by way of research facilities and in some cases would not be possible by direct experimentation. As a result, the limiting factors within a system can be identified by such models and areas needing further research highlighted. However, most of the broiler growth models available have been developed at the level of the individual bird whereas commercially, it is whole populations that are being managed and fed. That is, making a decision (such as on nutrient content of the feed supplied during the growth period and the length of each feeding time in the feeding program) based on the output from a deterministic model may not be entirely satisfactory when optimising the feeding of a population of broilers. It would be useful therefore to distinguish between the response of the average bird and that of the population. The average bird is defined as that individual having the average characteristics of the population and the response of the average individual is therefore that of a single broiler. The population response is the mean of all the individuals within the population.

The optimum feeding programme for broilers is that which results in the highest profit for the enterprise, so the choice of nutrient levels in the feeds offered is an economic decision. Such choices include determining the optimal concentration of amino acids relative to energy in each feed, the optimal nutrient density, and the optimal length of time for each feeding period. This idea replaces the concept that broilers have characteristic requirements which should be met under all conditions. Consequently, the information required for optimisation consists of feed costs at different levels of amino acid provision, a description of all the relevant responses, both fixed and variable costs affecting the production system, and details of revenue (Gous, 2002). These variables are then combined to calculate optimal nutrient density or concentration of amino acids to energy in each feed that will maximise profit.

In this chapter, two simulation exercises are described, these being designed to examine whether it is necessary to generate a population, rather than using the average individual, when optimising feeds and feeding programmes for broilers, and if so, what the optimum size of this population should be.

5.2 Simulation exercises

5.2.1 Description of genetic parameters and feeds used

The EFG Broiler Optimiser (EFG Software, Natal) requires the broiler genotype to be described, for the male only, in terms of mature empty body weight, mature lipid content, rate of maturing, rate of feathering and whether or not the genotype is feather sexable. The model then derives the following parameters for each of the sexes: mature protein (P_m), mature lipid-to-protein ratio (LPR_m), mature lipid, water, ash and feathers, rates of maturing of body protein (B_{BP}) and feather protein (B_{FP}), and lipid allometry (b), the latter being the slope of the allometric relationship between body lipid and protein. The value MLG (maximum lipid:protein in the gain) is a constant in the program, but for these exercises it was possible to modify its value.

Base values of W_0, P_m, LPR_m, B_{BP} and Fr used in these simulations were derived from publications (Emmans and Fisher, 1986; Emmans, 1988; Hancock *et al*., 1995; Gous *et al*., 1999), but the mean MLG was derived by a process of iteration, making use of food

intakes measured on marginally deficient feeds. CVs used were those suggested by Emmans and Fisher (1986), and for MLG and Fr, by Gous (unpublished).

A three-stage feeding programme was used, with starter (0–10 d), grower (11–25 d) and finisher (26–42 d) feeds being used. Revenue was generated on a dressed basis only, at R12/kg. Feed ingredient availability and price were set at the current South African conditions. It was assumed that the clean-out period between batches would be seven days, and that the fixed production costs were R21/m^2/year and variable costs R6.6/bird/cycle. Mortality was set at 4%. The simulation exercise was conducted at a normal environmental temperature, 31˚C for three days, then decreasing every day by 0.5˚C to 20.5˚C, remaining constant thereafter. The stocking density was 17 birds/m^2. These inputs were maintained for all simulations.

The optimiser predicts the amino acid content of each of the feeds in the feeding programme specified that will either maximise or minimise the objective function specified, by considering the potential protein growth rate of the broiler, the feeding schedule, environmental temperature, stocking density, the fixed and variable costs and revenue. The process followed by the optimiser is to calculate the income and expenditure for an array of feeds, as defined by the user, and then to choose the combination of feeds that maximise (or minimise) the objective function. The array consists of a range of lysine contents or nutrient densities within each feeding period, making up a grid that defines the number of simulations required. The interval size and number of points is user-defined.

5.2.2 Comparing the average individual with the mean of a population of 100 broilers

Six parameters were used to describe the genotypes of six 'strains' of broilers using different combinations of values for these parameters (Table 5.1). The rate of maturing parameter, B, was scaled to Pm to produce the scaled rate parameter B^*, which was given three values, 0.0439, 0.0444 or 0.0461; Pm was given two values, namely, 1.224 and 1.416; the two values for Fr were 0.049 and 0.052, and the two values for MLG were 1.0 and 1.8 (see Chapter 4). Single values were used to describe initial body weight (Wo) and lipid-to-protein ratio at maturity (LPRm). These six parameters were regarded as being uncorrelated.

Individuals making up the six populations of 100 broilers were created using a Monte Carlo random normal distribution method, based on the mean and CV of each genetic parameter for each strain in Table 5.1. No covariance terms were introduced when generating the population. Two base populations were generated for each strain and sex, and these were maintained throughout the simulation exercises.

Margin-over-feed cost and margin/m^2/annum were used as objective functions to optimise the amino acid contents and nutrient densities of the three feeds used in the feeding programme, for the six strains. This resulted in a total of 96 simulations (6 strains x 2 replications of each strain x 2 objective functions x 2 optimisations x 2 sexes).

5.2.3 Population size

In the exercise above, a population of 100 broilers was generated in order to compare the response of the average individual in the population with the mean of the population when optimising the feeds for broilers. In this exercise populations of five different sizes were used to determine the effect of increasing numbers of individuals making up the population on the optimum amino acid content and nutrient density in the feeds (Table 5.2). Populations of 50, 100, 250, 500 and 750 individuals were generated using the means and CVs of parameter values for Strain 1 in Table 5.1. Three populations of each size were generated to increase the number of replications, using the technique described above. Once again, margin over feed cost and margin/m^2/annum were used as objective functions. This resulted in a total of 120 simulations (5 population sizes x 3 replications x 2 sexes x 2 objective functions x 2 optimisations).

5.2.3 Sensitivity analysis

The technique proposed by Morris (1991) of varying one factor at a time was used to determine to what extent variation in Pm, B, and Fr would influence the optimum amino acid content in each feed, the final body weight, feed conversion ratio (FCR), breast meat relative to body weight and margin over feed cost (or margin/m^2.annum). Each of the three genetic parameters was reduced in turn by 10 and 20 %, and then increased by the same amounts. For the sensitivity analysis, the exercises were conducted at a normal temperature

profile, 31˚C for three days, then decreasing every day by 0.5˚C to 20.5˚C, remaining constant thereafter and at hot temperature, 32˚C for three days decreasing each day by 0.4˚C to 25˚C, remaining constant thereafter. The responses and genetic parameters of strains 3 and 4 (Table 5.1) were used as a reference for the sensitivity analysis exercise. In order to complete the exercise, 256 simulations were conducted.

5.3 Results

5.3.1 Comparison between individual and population response

The results of the nutrient density (ND) optimisation for the average individual and the mean of the population for the two objective functions are in Tables 5.3 and 5.4. The predicted optimum nutrient density differed for the deterministic and stochastic models, although in some cases the difference was small. This difference was observed in the optimum nutrient density of the grower diet, where this was lower for the average individual than for the population. The optimum nutrient density in the finisher diet was in all cases lower than that in the starter and grower diets. The performance of the average individual was higher, with a lower abdominal fat percentage, than the population performance at the optimum ND's.

The results of the optimisation of the amino acid contents in the starter, grower and finisher diets for the average individual and for the mean of the population, using different objective functions, are in Tables 5.5 and 5.6. The optimum lysine contents and the production parameters were marginally different for the two groups. In general, the lysine contents were higher, especially for the grower and finisher phases, for the mean of the population than for the average individual. As a result, profit margins were higher for the average individual. This difference depended on the objective function and genotype of the birds.

Table 5.1: Genetic parameters used to simulate six populations of male and female broiler, with coefficients of variation (CV)

	Strain 1		Strain 2		Strain 3		Strain 4		Strain 5		Strain 6		CV (%)
Parameters	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	
B^* (/d)	0.0461	0.0429	0.0461	0.0429	0.0444	0.0412	0.0444	0.0412	0.0439	0.0409	0.0439	0.0409	6.0
P_m (kg)	1.416	1.007	1.416	1.007	1.224	0.870	1.224	0.870	1.416	1.007	1.416	1.007	7.0
Fr (/d)	0.052	0.055	0.052	0.055	0.052	0.055	0.052	0.055	0.049	0.053	0.052	0.053	15.0
MLG (g/g)	1.0	1.0	1.8	1.8	1.0	1.0	1.8	1.8	1.0	1.0	1.8	1.8	15.0
LPR_m (g/g)	0.636	1.272	0.636	1.272	0.636	1.272	0.636	1.272	0.636	1.272	0.636	1.272	4.0
Wo (g)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	7.0

B^* = scaled rate of maturing ($B^*=BPm^{0.27}$), P_m = mature protein weight, Fr = rate of maturing of feathers, MLG = maximum lipid:protein in gain, LPR_m = lipid-to-protein ratio at maturity, Wo = initial body weight, CV = coefficient of variation.

5.3.2 Effect of population size

The average time taken to determine the optimum amino acid contents in the grower and finisher feeds, and the optimum nutrient density in the starter, grower and finisher feeds, for different group sizes, is presented in Table 5.2. As group size increased, the time taken to complete each optimisation increased significantly in both cases: for a 15 % increase in population size, the average optimisation time increased by 12.5 %. The effect of population size on predicting the optimum energy content of starter, grower and finisher feeds is presented in Tables 5.7a and 5.7b. The sizes of the populations were significantly affecting the optimum energy values. These values were altered when the objective functions and sexes changed. For instance, the optimum requirements for the three feeding phase program (starter, grower and finisher) were varied significantly with the size of the populations when MFC was objective functions but only grower feeding phase varied significantly for the case of margin/m2/annum. In general, the optimum energy requirements were lower when the population size was represented by the average individual (one bird) and the predicted responses at this optimum values were significantly higher irrespective of the objective functions. Besides, the optimum feeding programme for the average individual was the same irrespective of the objective function but when there was variation among the birds (50, 100, 250, 500 and 750), the feeding programme changed with the objective function. The optimum energy and production parameters at the optimum levels were almost similar as the population size increased. In general, the margin (margin over feed cost and margin/m2/annum) decreased as the size of the population increased. There was an interaction between different-sized populations and sexes on abdominal fat percentage for both objective functions.

In the case of the amino acid optimiser, the simulation was designed to determine the effect of population size on grower and finisher feeds and the response at the optimum level of these feeds, as there was no effect on starter feeds (Tables 5.4 and 5.5). The results of this exercise are presented in Tables 5.8a and 5.8b. The size of the population has significantly affected the optimum level when the objective function was marging/m2/annum, but not for MFC. The model optimises different optimum level for females and males irrespective of the objective functions. Incase of the production performance at the optimum level, the model predicted a better performance for one bird. However, the optimum level was higher

when the model optimises for 500 and 750, although the difference was not economically important comparing that of the other group-sizes. In general, the optimum lysine percentage and production performance at the optimum level were similar when the model optimises for group of individuals, except not for one individual bird, irrespective of the objective functions.

5.3.3 Sensitivity analysis

The results of the sensitivity analysis for B, Pm and BFr at normal and hot environmental temperatures are presented in Tables 5.9a and b, 5.10a and b, 5.11a and b, 5.12a and b. Only the statistically significant results of the sensitivity analysis are shown in these tables. The majority of responses were linear with increases in the values of genetic parameters, although the responses to changes in B and BFr were in some cases significantly quadratic, irrespective of the objective function. In general, responses to changes in the genetic parameters were higher when the objective function was margin/m^2.annum. All responses to changes in Pm were linear throughout the simulation exercise for both strains and sexes. The regression coefficients indicated that the responses by the two strains were not the same. In general, the responses by Strain 3 were greater than by Strain 4 for most of the simulation outputs. The effect of changing the genetic parameters was greater when the environmental temperature was normal for all measures of performance and lysine requirements. For instance, the effects on the optimum lysine content in the grower feed, and on FCR, of changing B were considerably lower at high than at normal temperatures. Margin over feed cost increased with increasing values of B, but decreased with increasing values of BFr. Furthermore, the ranking in sensitivity of the stochastic parameters and the patterns of response were similar for both strains and sexes.

Breast meat yield increased significantly with an increase in B, the response in some cases slowing down at higher B values. Conversely, yield decreased with increases in both Pm and BFr, the effect of the latter being significantly greater, and in many cases becoming increasingly more severe at higher BFr values; the effect was even greater at high temperatures. These patterns were not affected by the objective function chosen. The overall R^2 values of the regression analysis ranged from 0.45 to 0.99.

Table 5.2: The average time taken to optimise amino acid contents of grower and finisher feeds, and nutrient density of starter, grower and finisher feeds, for five group sizes

	Time (hours)	
Group size	Amino acid optimisation	Nutrient density optimisation
50	0.5	2.0
100	1.1	6.0
250	2.6	11.0
500	5.0	15.5
750	7.3	24.0
Regression coefficient for		
Group size	0.010**	0.029*
SE	0.0001	0.003
R^2	99.9	96.7

*P<0.01, **P<0.001, ns = non significant, SE = Standard error, R^2 = Coefficient of determination. Data were pooled from both sexes since there was no significant difference between sexes.

Table 5.3: Optimum nutrient density (measured by AME) in starter, grower and finisher feeds to 42d for, and performance of, the mean individual (Ind) and mean of the population (Pop) of males and females of six simulated strains of broiler. The objective function was to maximise margin over feed cost

Factors			Optimum AMEn (MJ/kg)			Mean performance				
Strain	Sex	Method	S	G	F	BWT	FCR	BRM	ABF	MFC
1	F	Ind	11.08	11.2	11.5	2758	2.09	18.2	2.00	2499
1	F	Pop	11.07	12.3	11.5	2130	2.11	17.8	1.60	1876
1	M	Ind	11.08	12.1	11.5	3291	1.93	18.0	0.90	2963
1	M	Pop	11.07	12.3	11.5	2643	1.97	17.6	0.90	2339
2	F	Ind	11.15	11.18	11.50	2754	2.09	18.2	2.00	2497
2	F	Pop	11.15	12.26	11.50	2321	2.07	17.7	1.70	2053
2	M	Ind	11.08	11.00	11.50	3362	1.93	18.0	1.40	3062
2	M	Pop	11.12	12.26	11.50	2876	1.92	17.4	1.10	2565
3	F	Ind	11.08	11.22	11.00	2466	2.21	18.3	2.00	1867
3	F	Pop	11.07	11.00	11.00	2100	2.25	17.7	1.60	1559
3	M	Ind	11.08	11.22	11.00	2944	2.07	18.0	0.90	2218
3	M	Pop	11.07	11.22	11.00	2600	2.08	17.5	0.90	1936
4	F	Ind	11.18	11.22	11.00	2466	2.21	18.3	2.00	1868
4	F	Pop	11.14	12.29	11.00	2314	2.13	17.6	1.80	1727
4	M	Ind	11.08	11.3.0	11.00	2996	2.01	18.0	1.30	2288
4	M	Pop	11.27	12.30	11.00	2871	1.96	17.4	1.20	2158
5	F	Ind	11.08	11.22	11.00	2576	2.15	18.0	1.90	1950
5	F	Pop	11.07	12.33	11.00	2106	2.17	17.7	1.70	1564
5	M	Ind	11.08	11.22	11.00	3070	2.03	17.7	0.90	2305
5	M	Pop	11.07	11.24	11.00	2601	2.08	17.5	0.90	1937
6	F	Ind	11.18	11.22	11.00	2576	2.14	18.0	1.90	1951
6	F	Pop	11.11	12.27	11.00	2316	2.13	17.6	1.80	1729
6	M	Ind	11.08	11.45	11.00	3139	1.97	17.7	1.30	2393
6	M	Pop	11.27	12.33	11.00	2874	1.96	17.4	1.20	2162

F = female, M = male, Ind = individual, Pop = population, S = starter, G = grower, F = finisher, BWT = body weight (g), FCR = feed conversion ratio (g feed/g gain), BRM = breast meat (%), ABF = abdominal lipid (%), MFC = margin over feed cost.

Table 5.4: Optimum nutrient density (as measured by AME) in the starter, grower and finisher feeds, and performance of the average individual (Ind) and mean of the population (Pop) for males and females of six 'strains'. The objective function used was to maximise margin/m^2/annum

Factors			Optimum AME (MJ/kg)			Mean performance				
Strain	Sex	Method	S	G	F	BWT	FCR	BRM	ABF	Margin
1	F	Ind	11.08	11.23	11.23	2756	2.13	18.2	2.00	2225
1	F	Pop	11.07	12.33	11.00	2104	2.17	17.7	1.60	1650
1	M	Ind	11.08	11.20	11.00	3289	2.02	17.9	0.90	2646
1	M	Pop	11.07	11.22	11.00	2600	2.08	17.5	0.90	2050
2	F	Ind	11.08	11.25	11.50	2754	2.08	18.2	2.00	2228
2	F	Pop	11.09	12.22	11.50	2313	2.07	17.6	1.80	1826
2	M	Ind	11.10	11.25	11.50	3371	1.94	17.9	1.50	2746
2	M	Pop	11.16	12.25	11.50	2871	1.92	17.4	1.20	2289
3	F	Ind	11.08	11.25	11.50	2452	2.14	18.3	2.10	2482
3	F	Pop	11.07	12.25	11.50	2116	2.13	17.8	1.70	2125
3	M	Ind	11.08	11.25	11.50	2930	2.02	18.0	1.00	3016
3	M	Pop	11.07	11.25	11.50	2621	2.04	17.6	0.90	2677
4	F	Ind	11.18	11.22	11.00	2466	2.21	18.3	2.00	1979
4	F	Pop	11.18	12.33	11.00	2314	2.12	17.6	1.80	1827
4	M	Ind	11.08	11.24	11.00	2996	2.02	18.0	1.30	2429
4	M	Pop	11.09	11.00	11.00	2868	2.03	17.4	1.20	2288
5	F	Ind	11.08	11.22	11.00	2576	2.15	18.0	1.90	2068
5	F	Pop	11.07	12.33	11.00	2106	2.17	17.7	1.70	1653
5	M	Ind	11.08	11.22	11.00	3070	2.03	17.7	0.90	2447
5	M	Pop	11.07	11.22	11.00	2601	2.08	17.5	0.90	2051
6	F	Ind	11.09	11.26	11.00	2576	2.14	18.0	1.90	2069
6	F	Pop	11.11	11.00	11.00	2310	2.19	17.6	1.80	1824
6	M	Ind	11.18	11.22	11.00	3139	1.98	17.7	1.30	2540
6	M	Pop	11.03	11.75	11.00	2874	1.99	17.4	1.20	2293

F = female, M = male, Ind = individual, Pop = population, S = starter, G = grower, F = finisher, BWT = body weight (g), FCR = feed conversion ratio (g feed/g gain), BRM = breast meat (%), ABF = abdominal fat (%).[1]Margin = margin/m2/annum.

Table 5.5: Optimum lysine content in the starter, grower and finisher feeds, and performance of the average individual (Ind) and mean of the population (Pop) for males and females of six 'strains' of broilers to 42 d of age. The objective function was to maximise margin over food cost

Factors			Optimum lysine content (%)			Mean performance				
Strain	Sex	Method	S	G	F	BWT	FCR	BRM	ABF	MFC
1	F	Ind	1.23	1.00	0.92	2682	1.79	18.2	2	2409
1	F	Pop	1.24	1.04	0.90	2523	1.83	18.0	1.7	2231
1	M	Ind	1.23	1.14	1.10	3199	1.61	17.9	0.9	2847
1	M	Pop	1.24	1.18	1.10	3073	1.64	17.8	0.8	2702
2	F	Ind	1.23	1.00	0.90	2704	1.78	18.2	2.0	2440
2	F	Pop	1.24	1.00	0.90	2541	1.82	18.0	1.9	2261
2	M	Ind	1.24	1.00	0.90	3413	1.75	17.9	2.0	3076
2	M	Pop	1.24	1.04	0.90	3208	1.74	17.7	1.7	2865
3	F	Ind	1.25	1.13	0.90	2394	1.84	18.3	2.1	2162
3	F	Pop	1.25	1.22	0.94	2522	1.81	18.0	1.7	2248
3	M	Ind	1.23	1.24	1.07	2863	1.65	18.0	1.0	2556
3	M	Pop	1.25	1.27	1.12	3070	1.62	17.8	0.8	2720
4	F	Ind	1.25	1.18	0.90	2409	1.83	18.3	2.1	2178
4	F	Pop	1.25	1.18	0.90	2538	1.81	18.0	2.0	2281
4	M	Ind	1.25	1.18	0.90	3017	1.74	18.0	1.8	2732
4	M	Pop	1.25	1.18	0.90	3195	1.73	17.7	1.7	2873
5	F	Ind	1.23	1.14	0.90	2504	1.8	18.0	1.9	2252
5	F	Pop	1.24	1.22	0.90	2123	1.86	17.9	1.8	1880
5	M	Ind	1.23	1.23	1.07	2990	1.62	17.7	0.9	2661
5	M	Pop	1.24	1.27	1.08	2632	1.67	17.7	0.8	2317
6	F	Ind	1.24	1.04	0.90	2518	1.79	18.0	1.9	2275
6	F	Pop	1.24	1.04	0.90	2198	1.87	18.0	2.1	1970
6	M	Ind	1.24	1.09	0.90	3172	1.75	17.7	1.9	2861
6	M	Pop	1.24	1.09	0.90	2773	1.78	17.8	1.6	2484

F = female, M = male, Ind = individual, Pop = population, S = starter, G = grower, F = finisher, BWT = body weight (g), FCR = feed conversion ratio (g feed/g gain), BRM = breast meat (%), ABF = abdominal fat (%), MFC = margin over feed cost.

Table 5.6: Optimum lysine content in starter, grower and finisher feeds, and performance of the average individual (Ind) and mean of the population (Pop) of males and females of six 'strains' of broiler to 42d. The objective function was to maximise margin/m^2.annum

Factors			Optimum lysine (%)			Performance				
Strain	Sex	Method	S	G	F	BWT	FCR	BRM	ABF	Margin[1]
1	F	Ind	1.24	1.20	1.00	2685	1.77	18.2	2.0	2421
1	F	Pop	1.24	1.20	1.00	2525	1.8	18.0	1.7	2246
1	M	Ind	1.23	1.24	1.12	3199	1.59	17.9	0.9	2868
1	M	Pop	1.24	1.27	1.11	3072	1.63	17.8	0.8	2723
2	F	Ind	1.24	1.09	0.90	2704	1.77	18.2	2.0	248
2	F	Pop	1.24	1.04	0.90	2545	1.83	18.0	2.1	2294
2	M	Ind	1.24	1.09	0.90	3398	1.75	17.9	2.0	3084
2	M	Pop	1.24	1.13	0.90	3200	1.74	17.7	1.7	2880
3	F	Ind	1.24	1.20	1.00	2398	1.83	18.3	2.1	2150
3	F	Pop	1.24	1.20	1.00	2127	1.84	17.9	1.7	1875
3	M	Ind	1.23	1.21	1.08	2863	1.65	18.0	1.0	2556
3	M	Pop	1.23	1.27	1.08	2633	1.67	17.7	0.8	2318
4	F	Ind	1.24	1.00	0.80	2463	1.89	18.3	2.6	2251
4	F	Pop	1.24	1.00	0.80	2213	1.92	17.9	2.4	1996
4	M	Ind	1.24	1.09	0.89	3040	1.77	18.0	1.9	2756
4	M	Pop	1.24	1.09	0.89	2775	1.79	17.8	1.7	2485
5	F	Ind	1.24	1.20	1.00	2507	1.78	18.0	1.9	2381
5	F	Pop	1.24	1.20	1.00	2127	1.84	17.9	1.7	1987
5	M	Ind	1.24	1.20	1.07	2988	1.62	17.7	0.9	2828
5	M	Pop	1.23	1.27	1.08	2633	1.67	17.7	0.8	2461
6	F	Ind	1.24	1.00	0.80	2605	1.86	18.0	2.6	2525
6	F	Pop	1.24	1.00	0.80	2357	1.89	17.7	2.3	2248
6	M	Ind	1.23	1.09	0.88	3178	1.76	17.7	1.9	3045
6	M	Pop	1.24	1.09	0.89	2926	1.76	17.4	1.7	2777

F = female, M = male, Ind = individual, Pop = population, S = starter, G = grower, F = finisher, BWT = body weight (g), FCR = feed conversion ratio (g feed/g gain), BRM = breast meat (%), ABF = abdominal fat (%). [1]Margin = margin/m2/annum.

Table 5.7a: Optimum nutrient density (as measured by AME) in starter, grower and finisher feeds, and performance of male and female broilers of six simulated population sizes. Objective function was to maximise margin over feed cost (MFC, c/bird)

		Optimum AME (MJ/kg)			Performance				
Sex	Size	S	G	F	BWT	FI	BRM	ABF	MFC
F	1	11.6	10.4	11.4	2665	5745	18.1	1.90	1617
F	50	12.1	11.7	11.0	2374	5076	17.7	1.60	1419
F	100	12.0	12.2	11.2	2314	4834	17.6	1.60	1380
F	250	11.2	11.7	11.5	2265	4708	17.6	1.55	1349
F	500	11.8	11.6	10.9	2532	5247	17.4	1.20	1510
F	750	11.4	12.0	11.3	2299	4806	17.6	1.55	1370
M	1	11.5	9.3	10.1	3155	6980	17.8	0.85	1915
M	50	12.0	10.8	9.7	2881	6300	17.4	0.80	1730
M	100	11.7	11.0	11.0	2796	5648	17.4	0.90	1672
M	250	11.5	11.0	11.5	2816	5568	17.4	0.85	1682
M	500	11.4	11.2	10.9	2778	5624	17.3	0.90	1658
M	750	11.7	11.0	11.0	2790	5662	17.4	0.90	1668
RMS		0.085	0.087	0.09	11711	49272	0.003	0.017	4262
CV (%)		2.5	2.6	2.7	4.1	4	0.3	10.6	4.1
					P-Value				
Size		0.04	<0.001	0.005	0.003	<0.001	<0.001	ns	0.001
Sex (S)		ns	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Size x Sex		ns	ns	0.02	0.458	ns	0.109	0.034	0.445

RMS = residual mean square, CV = coefficient of variation, ns = non significant at 5% level, BWT = body weight (g), Cum FI = Cumulative feed food intake (g), BRM = breast meat percentage, ABF = abdominal fat percentage.

Table 5.7b: Optimum nutrient density (as measured by AME) in starter, grower and finisher feeds, and performance of male and female broilers of six simulated population sizes. Objective function was to maximise margin/m^2.annum (Margin, Rand).

Factors		Optimum AME (MJ/kg)			Performance				
Sex	Size	S	G	F	BWT	Cum FI	BRM	ABF	Margin
F	1	11.6	11.0	11.4	2665	5639	18.1	1.90	1941
F	50	11.5	12.1	11.8	2313	4672	17.6	1.60	1653
F	100	11.6	12.1	10.9	2373	5082	17.7	1.55	1697
F	250	11.2	11.7	11.6	2252	4650	17.6	1.55	1603
F	500	12.0	12.0	11.2	2276	4756	17.6	1.55	1623
F	750	11.8	12.1	11.5	2298	4726	17.6	1.55	1640
M	1	11.5	9.3	10.1	3155	6994	17.8	0.80	2321
M	50	11.3	10.1	9.4	2795	6491	17.3	0.65	2013
M	100	11.5	10.8	10.7	2833	5868	17.4	0.85	2050
M	250	11.5	10.9	10.7	2806	5798	17.4	0.85	2031
M	500	11.5	11.1	11.0	2776	5610	17.4	0.85	2004
M	750	11.7	11.1	11.0	2792	5654	17.4	0.90	2017
RMS		0.096	0.271	0.381	1378	55742	0.005	0.007	868
CV (%)		2.7	4.7	5.6	1.4	4.3	0.4	6.7	1.6
					P-value				
Size		ns	0.019	Ns	<0.001	<0.001	<0.001	0.044	<0.001
Sex (S)		ns	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001
Size x Sex		ns	ns	Ns	ns	ns	ns	0.011	ns

RMS = residual mean square, CV = coefficient of variation, ns = non significant at 5% level, BWT = body weight (g), Cum FI = Cumulative feed food intake (g), BRM = breast meat percentage, ABF = abdominal fat percentage.

Table 5.8a: Optimum lysine content (%) in grower (G) and finisher (F) feeds, and performance of male and female broilers of six simulated population sizes. Objective function was to maximise margin over feed cost (MFC, c/bird)

Factors		Optimum lysine content (%)		Mean performance				
Sex	Size	G	F	BWT	Cum FI	BRM	ABF	MFC
F	1	1.161	0.898	2645	4894	18.10	2.00	1600
F	50	1.188	0.929	2328	4348	17.75	1.70	1380
F	100	1.169	0.872	2390	4469	17.85	1.75	1427
F	250	1.165	0.866	2345	4404	17.75	1.75	1397
F	500	1.225	0.900	2311	4274	17.70	1.70	1373
F	750	1.203	0.883	2324	4324	17.70	1.70	1382
M	1	1.233	1.080	2108	5122	17.80	0.90	1863
M	50	1.250	1.075	2890	4814	17.55	0.75	1710
M	100	1.250	1.075	2843	4714	17.50	0.80	1682
M	250	1.250	1.075	2848	4730	17.50	0.75	1686
M	500	1.255	1.076	2858	4742	17.55	0.80	1691
M	750	1.255	1.075	2870	4760	17.50	0.80	1699
RMS		0.0004	0.00050	1154	3216	0.0038	0.0017	506
CV (%)		1.6	2.3	1.3	1.2	0.3	3.2	1.4
				P-value				
Size		0.07	ns	<0.001	<0.001	<0.001	<0.001	<0.001
Sex		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Size x Sex		ns	ns	ns	0.028	ns	0.038	ns

RMS = residual mean square, CV = coefficient of variation, ns = non significant at 5% level, BWT = body weight (g), Cum FI = Cumulative feed food intake (g), BRM = breast meat percentage, ABF = abdominal fat percentage.

Table 5.8b: Optimum lysine content (%) in grower (G) and finisher (F) feeds, and performance of male and female broilers of six simulated population sizes. Objective function was to maximise margin/m^2.annum (Margin, Rand)

Sex	Size	G	F	BWT	Cum FI	BRM	ABF	Margin
F	1	1.163	0.894	2645	4898	18.1	2.0	1920
F	50	1.260	0.939	2289	4225	17.7	1.7	1618
F	100	1.167	0.832	2341	4473	17.8	1.8	1665
F	250	1.221	0.895	2350	4343	17.8	1.7	1673
F	500	1.188	0.900	2312	4280	17.7	1.7	1645
F	750	1.217	0.897	2326	4312	17.7	1.7	1655
M	1	1.217	1.087	3107	5114	17.8	0.9	2256
M	50	1.260	1.076	2818	4679	17.5	0.8	2013
M	100	1.260	1.077	2837	4730	17.5	0.8	2026
M	250	1.260	1.075	2866	4745	17.5	0.8	2054
M	500	1.255	1.069	2845	4723	17.5	0.8	2036
M	750	1.260	1.075	2842	4706	17.5	0.8	2034
RMS		0.0003	0.0009	1084	1444	0.004	0.004	806
CV (%)		1.4	3.0	1.3	0.8	0.4	4.8	1.5
					P-value			
Size		<0.001	0.2940	<0.001	<0.001	<0.001	<0.001	<0.001
Sex (S)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Size x S		0.019	ns	ns	0.003	ns	ns	ns

F = female, M = male, BWT = body weight (g), FCR = feed conversion ratio (g food/g body weight), BRM = breast meat percentage, ABF = abdominal fat percentage, ns = non significant at 5% level.

Table 5.9a: Regression coefficients describing the change in optimum lysine content in grower and finisher feeds, and in breast meat yield, with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 3, at normal and hot environmental temperatures when the objective function was to maximise margin over feed cost

	Grower				Finisher				Breast meat			
	Male		Female		Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	0.49^{*}	0.11^{ns}	0.389^{***}	0.153^{**}	0.42^{**}	0.096^{ns}	0.16^{*}	-0.129^{ns}	0.24^{***}	0.158^{*}	0.230^{***}	0.138^{***}
				-0.014^{**}	-0.009^{*}		-0.0094^{*}		-0.002^{*}	-0.083^{**}	-0.0024^{*}	-0.004^{**}
Pm	0.154^{*}	-0.119^{ns}	0.105^{**}	0.097^{ns}	0.316^{**}	0.118^{ns}	0.241^{*}	0.285^{*}	-0.04^{**}	-0.083^{**}	-0.03^{*}	-0.056^{**}
BFr	0.109^{***}	0.074^{ns}	0.241^{*}	-0.197^{*}	0.321^{**}	0.0^{ns}	0.148^{ns}	-0.333^{*}	-0.05^{*}	-0.131^{**}	-0.155^{ns}	-0.238^{**}
			0.0108^{*}						-0.003^{*}	-0.006^{**}		-0.009^{*}

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering.
$^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$ and ^{ns} = non-significant.
[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

Table 5.9b: Regression coefficients describing the changes in feed conversion ratio and margin over feed cost with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 3, at normal and hot environmental temperatures when the objective function was to maximise margin over feed cost

	Feed conversion ratio				Margin over feed cost			
	Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	-0.271** 0.009**	-0.01^{ns}	-0.134* 0.008*	0.039^{ns}	1.092^{ns}	0.717^{ns}	1.22*	0.632^{ns}
Pm	-0.295**	-0.131^{ns}	-0.231**	-0.242**	0.549^{ns}	0.357^{ns}	0.575^{ns}	0.435^{ns}
BFr	-0.341**	-0.053^{ns}	-0.383*	-0.025^{ns}	-0.156^{ns}	-0.693* -0.0339*	-0.432^{ns}	-0.943^{ns}

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering *P<0.05, **P<0.01, ***P<0.001 and ^{ns} = non-significant.

[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

Table 5.10a: Regression coefficients describing the change in optimum lysine content in grower and finisher feeds, and in breast meat yield, with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 4, at normal and hot environmental temperatures when the objective function was to maximise margin over feed cost

	Grower				Finisher				Breast meat			
	Male		Female		Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	0.205 ^{ns}	0.099^{ns}	-0.085^{ns}	-0.051^{ns}	0.122^{ns}	0.28^{ns}	-0.222 ^{ns}	0.084^{ns}	0.24*** -0.002*	0.152** -0.005**	0.23*** -0.003*	0.144*
Pm	-0.017 ^{ns}	0.147*	-0.141^{ns}	-0.081^{ns}	0.22^{ns}	0.372**	0.0 ^{ns}	0.427*	-0.04**	-0.068**	-0.025*	-0.079**
BFr	0.026^{ns}	-0.214*	-0.084^{ns}	-0.131^{ns}	0.405*	0.065^{ns}	0.0 ^{ns}	0.0^{ns}	-0.05* -0.002*	-0.181*	-0.114* -0.0059*	-0.244*

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering.
*P<0.05, **P<0.01, ***P<0.001 and ^{ns} = non-significant.
[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

Table 5.10b: Regression coefficients describing the change in feed conversion ratio and margin over feed cost with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 4, at normal and hot environmental temperatures when the objective function was to maximise margin over feed cost

	Feed conversion ratio				Margin over feed cost			
	Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	-0.115^{ns}	-0.059^{ns}	0.003^{ns} 0.018*	0.005^{ns}	1.262*	0.627^{ns}	1.403*	0.67
Pm	-0.193*	-0.259**	-0.148^{ns}	-0.215*	0.684^{ns}	0.415	0.798^{ns}	0.495
BFr	-0.309*	0.004^{ns}	-0.232*	-0.035^{ns}	-0.174^{ns}	-0.761	-0.347^{ns}	-1.048

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering.
*P<0.05, **P<0.01, ***P<0.001 and ^{ns} = non-significant.
[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

Table 5.11a: Regression coefficients describing the change in optimum lysine content in grower and finisher feeds, and in breast meat yield, with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 3, at normal and hot environmental temperatures when the objective function was to maximise margin/m^2.annum

	Grower				Finisher				Breast meat			
	Male		Female		Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	0.565^{***}	0.11^{ns}	0.39^{***}	0.119^{**}	0.687^{*}	0.096^{ns}	0.157^{*}	0.074^{ns}	0.24^{***}	0.158^{*}	0.23^{***}	0.144^{**}
	-0.008^{*}			-0.017^{**}			-0.01^{**}		-0.002^{*}		-0.0024^{*}	-0.005^{*}
Pm	0.186^{*}	-0.123^{ns}	0.119^{ns}	0.088^{ns}	0.282^{ns}	0.137^{ns}	0.243^{ns}	0.263^{*}	-0.035^{ns}	-0.078^{*}	-0.03^{*}	-0.051^{*}
	0.005^{ns}											
BFr	0.112^{**}	0.0^{ns}	0.253^{*}	-0.197^{*}	0.322^{**}	0.0^{ns}	0.141^{ns}	-0.334^{*}	-0.05^{*}	-0.14^{*}	-0.115^{ns}	-0.238^{**}
									-0.003^{*}	-0.006^{**}		-0.009^{*}

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering.
$^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$ and ^{ns} = non-significant.
[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

Table 5.11b: Regression coefficients describing the changes in feed conversion ratio and margin over feed cost with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 3, at normal and hot environmental temperatures when the objective function was to maximise margin/m^2/annum

	Feed conversion ratio				Margin over feed cost			
	Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	-0.436^{ns}	-0.019^{ns}	-0.136** 0.009**	-0.025^{ns}	1.65** -0.019*	0.677^{ns}	1.311**	0.937^{ns}
Pm	-0.259*	-0.124^{ns}	-0.214^{ns}	-0.212^{ns}	0.604^{ns}	0.359^{ns}	0.615^{ns}	0.41^{ns}
BFr	-0.342**	-0.048^{ns}	-0.382*	-0.023^{ns}	-0.041^{ns}	-0.663^{ns}	-0.464^{ns}	-1.014^{ns}

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering.
*P<0.05, **P<0.01, ***P<0.001 and ^{ns} = non-significant.
[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

Table 5.12a: Regression coefficients describing the change in optimum lysine content in grower and finisher feeds, and in breast meat yield, with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 4, at normal and hot environmental temperatures when the objective function was to maximise margin/m^2/annum

	Grower				Finisher				Breast meat			
	Male		Female		Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	0.324^{ns}	0.112^{ns}	0.0^{ns}	-0.071^{ns}	0.086^{ns}	0.328^{ns}	0.0^{ns} -0.036^{*}	0.076^{ns}	0.24^{***}	0.155^{*}	0.318^{*}	0.135^{*}
Pm	0.014^{ns}	0.146^{*}	0.0^{ns}	-0.06^{ns}	0.203^{ns}	0.463^{**}	0.0^{ns}	0.329^{*} 0.039^{**}	-0.04^{*}	-0.068^{**}	-0.037^{*}	-0.078^{*}
BFr	-0.028^{ns}	-0.241^{ns}	-0.10^{ns}	-0.149^{ns}	-0.09^{ns}	-0.09^{*}	0.0^{ns}	0.448^{ns}	-0.052^{*}	-0.184^{**}	-0.114^{*} -0.006^{*}	-0.243^{**} -0.008^{*}

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering.
$^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$ and ^{ns} = non-significant.
[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

Table 5.12b: Regression coefficients describing the changes in feed conversion ratio and margin over feed cost with changes in value of the genetic parameters B, Pm and BFr, in male and female broilers of Strain 4, at normal and hot environmental temperatures when the objective function was to maximise margin/m^2.annum

	Feed conversion ratio				Margin over feed cost			
	Male		Female		Male		Female	
Parameters[1]	Normal	Hot	Normal	Hot	Normal	Hot	Normal	Hot
B	-0.089^{ns}	-0.052^{ns}	-0.081^{ns} 0.019**	0.016^{ns}	1.747**	0.886*	1.3*	0.67^{ns}
Pm	-0.186*	-0.252**	-0.144**	-0.218** -0.008**	0.681^{ns}	0.420^{ns}	0.771^{ns}	0.494^{ns}
BFr	-0.278^{ns}	-0.023^{ns}	-0.224**	-0.031^{ns}	-0.241^{ns}	-0.241^{ns}	-0.34^{ns}	-1.043^{ns}

B = rate of maturing, Pm = mature protein weight at maturity, BFr = rate of feathering.
*P<0.05, **P<0.01, ***P<0.001 and ^{ns} = non-significant.
[1]each of three genetic parameters was decreased and increased by 10% and 20% from the base value, whilst holding the remaining two genotype parameters constant.

5.4 Discussion

Broiler producers aim at maximising the return on their investment. The net return depends on many factors associated with the bird, feed, environment, the available capital and labour, and the interaction between these variables. Determining the nutrient content of feeds for broilers is one of the main challenges affecting the profitability of the production system. The amino acid requirements of broilers (NRC, 1994) and the prediction of performance for various combinations of factors have been documented (Jackson *et al*., 1982a; Skinner *et al*., 1992; Smith and Pesti, 1998; Corzo *et al*., 2004). However, with this fixed list of requirements it is impossible to optimise feeds and feeding programmes for broilers due in part to changes in the genotypes available and producers' preferences. Moreover, the optimum nutrient contents in feeds for broilers are probably at variance with the objective functions of the enterprise. Oviedo-Rondon and Waldroup (2002) reviewed intensively the problem of determining accurately the amino acid requirements for broilers. According to these authors, the optimum feeding programme for broilers could be

determined using simulation models. Based on the reports of Gous (1998), Oviedo-Rondon and Waldroup (2002), and Gous and Berhe (2006), it is apparent that estimates of the nutrient requirements of a population of animals using dynamic, stochastic and mechanistic models are more meaningful than those in which deterministic models are used. However, what has not yet been determined is the extent of variation between the various models when predicting optimum amino acid requirements and nutrient density for broilers, especially when the objective function is varied. Two simulation exercises were conducted, these being designed to examine whether it is necessary to generate a population, rather than using the average individual, when optimising feeds and feeding programmes for broilers, and if so, what the optimum size of this population should be.

According to the results of the first exercise, the difference in response when comparing the deterministic (single bird) and stochastic (population) models depended almost entirely on the CV of the rate of feathering (see Sensitivity Analysis below). The population responses in food intake, live-weight gain, margin over feed cost and margin/m^2.annum were in virtually all cases lower than for the mean individual, and this difference was greater at high temperatures. If the population were fed according to the average individual, half the birds would try to increase their food intake to satisfy their requirements, if the temperature allowed them to do so. As a result, both the biological and economic performances of the population would differ from the performance expected of the individual. This result is in agreement with the findings of Gous (1998) and Pomar *et al*. (2003) that variation among individuals affects the optimal nutrient content. Where nutrient density was optimised, there was no significant difference between the average individual and the mean of the population in the starter and finisher feeds, but the optimum energy content of the grower feed varied for the two responses, resulting in a significant difference between the two responses in economic performance. Concerning the objective functions, there were no important economic differences in optimum feeding programmes and production parameters between the two objectives used in this study.

Determining the number of individuals that describes a population of broilers during simulations of a stochastic model is a very important task because samples that are too large may waste time when running the simulations, while samples that are too small may lead to inaccurate results. Based on the results of the simulation exercise, the number of individuals that describes a population has an interesting effect on the optimal amino acid

concentration in the grower and finisher feeds when the starter feed is fixed for all population sizes (Tables 5.8a and b). The optimal amino acid contents in the grower and finisher feeds for the different group sizes were greater than for the average individual for both objective functions, which supports the above conclusion that the average individual underestimates the optimal value. However, when the group size was increased from 50 to 750, the difference in optimal lysine content between the simulated groups was small; it was only significant relative to the average individual (one bird). The time taken to simulate the optimum lysine contents and nutrient densities for a group size of 750 individuals was 24 and 12 times of that of 50 individuals, respectively. It is clear that it is unnecessary to use more than 50 individuals in order to account for variation within a strain with a view to optimising the feeding of a population of broilers.

In case of nutrient density optimisation, the model predicted almost the same optimum AME contents when the population size increased from 50 to 750 individuals, resulting in similar performance responses at these optimum levels. Abdominal fat content showed the largest difference between the two population sizes, with females always having higher fat weights at small population sizes, as well as larger differences over the range of population sizes used, whilst males showed little difference in abdominal fat weight at different population sizes, and in some cases showing a higher weight of fat at higher population sizes. This might be due to the nature of randomly-generated individual distribution within a population, for instance, the live weight at 42d of age of 50 individuals was negatively skewed compared to that of 750 individuals. The random generating process could result in a bigger difference between the maximum and minimum values within the population. This could affect the optimal amino acid and energy values and the effects of such variation may be more pronounced for body composition. Pomar *et al* (2003) reported that variation among pigs has little effect on the feed intake of a population of pigs but there was a significant effect on body composition.

The size of the population does appear to affect the optimal amino acid contents and the optimum nutrient density in broiler feeds. However, as will be revealed below, this difference is the result of the constraining effect of a high rate of feathering on food intake on marginally deficient feeds, especially at high temperatures.

Sensitivity analysis

The sensitivity analysis indicated that the parameter having the greatest effect on the simulated performance of the broilers was the rate of maturing parameter, B. However, because the change in response was linear in most cases, the mean response would remain largely the same no matter what coefficient of variation was used in describing this parameter. A slight reduction in performance would result from the significant but small negative second-order term describing the response in some cases (breast meat yield, for example), and a small reduction in performance at higher temperatures. Similarly, changes in Pm resulted in equal and opposite changes in the optimal lysine contents of starter, grower and finisher diets and the economic responses, irrespective of the temperature and economic objectives. This suggests that these genetic parameters do not contribute substantially to variations in optimal amino acid contents and economic performance of a population. However, increasing and decreasing the effects of Fr resulted in totally different responses in optimal lysine contents for grower and finisher diets as well as biological and economical responses.

Changes in feathering rate do not result in linear responses in performance. Low feathering rates appear to have little effect on performance: it is assumed that the bird will require more energy for maintenance if kept in low temperature conditions, but as long as food is supplied ad libitum the bird will be able to achieve potential performance, which will not change with feathering rate. However, as feathering rate increases so it becomes increasingly difficult for the bird to lose heat to the environment, resulting in an increasingly severe decrease in performance. This decline in performance is particularly evident at higher temperatures. These observations are in agreement with the findings of Gous and Berhe (2006) who showed that the consequence of this was that the response of the population was always lower than that of an individual. This begs the question of what mean and CV are appropriate for a population, given that the mean of a simulated population should be closer to that of the average individual than was demonstrated here.

The effect, on the optimum amino acid content and nutrient density of feeds for broilers, of differences in the maximum amount of lipid in the gain was measured by comparing the responses of Strain 3 (equivalent to a lean strain) and 4 (equivalent to a fat strain). The optimal lysine content in the feeds, and their economic performance, except for breast meat

yield, differed between the two strains. In general, the change in optimum dietary lysine content was greater in Strain 3 than in Strain 4, implying that leaner broilers are more sensitive to changes in the parameters than fatter strains. Birds from the fatter strain consumed more feed and were hence able to perform adequately on feeds of a lower lysine content and they benefited from this extra intake with higher body weights, margin over feed cost and margin/m^2.annum. Abdominal fat content was, as a result, higher for Strain 4 considering their greater potential to deposit lipid. This observation was reported previously (Berhe and Gous, 2005).

The differences in response, and in the optimum dietary amino acid contents, of the two strains differing only in maximum lipid: protein ratio in the gain implies that the manner in which these two strains should be fed for maximum profitability differs between the strains. Strain 3 should be fed a higher protein feed throughout their lives as they would benefit from this additional dietary protein because of their inability to overconsume energy on lower protein feeds, which would otherwise enable them to consume sufficient protein to grow at their potential. On the other hand, the protein content of feeds offered to Strain 4 could be reduced increasingly over time, reducing feed cost, imposing less nutritional stress on the birds and thus increasing the profitability of the enterprise. However, from the results presented here, there is still considerable variation between the sexes within the same strain, which makes it difficult to optimise the feeding of a mixed population of broilers. Body composition has been regarded as being the key to predicting whether different broiler strains have different amino acid requirements (Peisker, 1999), but it would appear that their ability to overconsume energy in the face of a marginally deficient feed is an equally important criterion.

The optimal feeding programme for broilers is that which results in maximum profitability for the enterprise. Because so many interacting factors have to be considered before the optimal feeds and feeding programme can be determined, the use of simulation models should be encouraged to make these biological and economic decisions both rapidly and accurately (Gous, 1998).

5.5 Conclusions

A population model, used to simulate performance of broilers and to determine the optimum amino acid contents and nutrient densities in feeds for these birds, that considers variation in the rate of maturing parameter, B, and the mature protein weight, Pm, will produce means similar to those obtained from the response of an individual. In addition, a spread of responses will be obtained that will give a reasonable estimate of the variation that can be expected in flock performance. This is a useful way of determining the spread in the weights of the body and its component parts in a broiler flock at harvesting. Variation in the rate of feather growth, however, causes a non-linear response in performance in a population, resulting in a reduction in performance in those birds that feather more rapidly, because they are unable to lose sufficient heat to the environment to enable them to consume sufficient of the feed required to grow at their potential. The consequence is that the resultant mean response is always lower than that of an individual when variation in the rate of feather growth is included in a population model.

By altering the maximum permissible lipid:protein in the gain, close approximations to realistic differences can be simulated of the ability of strains to overconsume energy when faced with feeds marginally deficient in an amino acid. Where this ratio is low, the optimum amino acid content in feeds is higher, and body lipid content is lower, than where birds are able to store more body lipid in the gain. This mechanism enables model users to simulate observed differences between strains available to the broiler Industry at present.

Considering the time taken to simulate populations of different sizes and to predict the optimum dietary amino acid contents and nutrient densities, it may be concluded from the exercise to determine the optimum size of a simulated population, that 50 individuals adequately represent the variation within a strain when no correlations between traits are considered.

The exercises in this chapter have assisted in determining whether or not to simulate a population of broilers rather than the more common method of using the mean individual in the population only, and of deciding which parameters to include when describing the population.

Chapter 6

Variation in the nutrient content of poultry feed: A review

Abstract

Uniformity is of considerable importance in all production processes. This review will address the variation in the day-to-day levels of nutrients consumed by a broiler, brought about by the procedure for analysing the nutrient content of the ingredient, mixing efficiency, efficiency of delivery of the mixed feed and pellet quality. Each case contributes different levels of variation in the completed mixed feed. Considering the complexity of the experiment required to determine the effect of the above sources of variation, use of simulation models is the most appropriate way of estimating the effect and optimising the feeding program accordingly.

6.1 Introduction

Uniformity is of considerable importance in all production processes. It was Deming (1986) who first suggested that it was crucial to have a good understanding of customer needs, because that knowledge is essential if the production process is to be improved, as opportunities for improving quality are determined by the difference between a customer's needs and what a business provides. He emphasised the importance of the system or process with reference to achieving quality, stressing the importance of a proper understanding of variation, because its measurement and analysis were fundamental to controlling and improving both quality and performance of all systems. All systems display variation over time, which Deming described under two headings; the first, inherent or common cause variation**,** arising from the natural spread in the process, which only changes when the system is changed either by design or some other cause. The second, he described as a non-random cause, or special cause variation, which has an identifiable cause that can be corrected, but seldom eliminated. Special cause variation arises from variation in factors such as operator performance, husbandry routines, machine

or equipment calibration and adjustment, machine maintenance, etc. and is not the subject of discussion here.

Common cause variation refers to the many sources of variation that are inherent in the process: in the case of broiler production this variation might be in genotype, shed design and layout, feeding and drinker equipment, the system of ventilation, environmental control equipment, nutrient specifications, and hygiene and health programmes. Differences in variation arising in this manner may be large or small, but they are always present. When considered as a group the variation among individuals in a population can be described statistically, with a mean and variance. Inherent variation is built into the system, and can only be reduced by management action: no amount of adjustment by farm, hatchery, sales or office staff will either reduce, or remove it. According to Deming (1986) common cause variation is responsible for about eighty to ninety percent of quality problems, and can only be reduced if management modify or alter the system. This chapter deals with common cause variation in relation to the quality of feed being presented to broilers in a commercial rearing unit.

It is well documented that variation exists in the physical and chemical characteristics of grains used in poultry feeds, sources of which include variety, seasonal effects, growth sites (Metayer *et al*., 1993), crop treatment and grain fumigants, post-harvest storage conditions and period of storage and processing (Dale, 1996; Hughes and Choct, 1999), rainfall and environmental temperature patterns during the period of grain maturation, genetic effects, level of fertiliser usage (Metayer *et al*., 1993; Hughes and Choct, 1999) and inclusion rate (Senkoylu and Dale, 1999).

Poultry nutritionists spend much of their time formulating feeds to meet certain predetermined nutrient specifications, and then attempting to ensure that the mixed feed conforms to those specifications. Because of the variation in quality mentioned above, incoming feedstuffs are analysed in various ways and the results are used to predict the quality of these raw materials. Sampling procedures and the prediction equations used will introduce some degree of error in the predicted composition, and this will be compounded when the final mixture is made. Feed may then be treated in various ways, such as being heated and/or pelleted (McCracken *et al*., 1997), which in itself can affect its nutrient uniformity (Reece *et al*., 1986; Behnke, 1996), before being transported to the broiler farm

during which time some separation of ingredients may take place. The methods used to transfer feed from the transport vehicle to the bulk tanks and from there into the feeder lines will cause different degrees of separation of feed particles, as will the feeder lines themselves. The composition of feed consumed by the broiler may thus bear little resemblance to that formulated earlier, and the composition of the feed at one end of the house may well differ from that at the other.

Nutrient variability is a common problem for feed manufacturing enterprises. This variability has different sources which result in inconsistent nutrient levels in the completed mixed feed. It is valuable to examine this variation especially if the nutrient distribution is not normal. Much research has been conducted assuming a normal distribution of nutrients within feed ingredients.

The Animal and Poultry Science nutrition laboratory at the University of KwaZulu-Natal collected and analysed a large number of samples of feedstuffs commonly used in broiler feeds, from 1993 to 2001, and these analyses may be used to determine the extent of variation in the nutritive value of ingredients. Twelve ingredients were chosen for this study and analysed using Genstat (2005) (Table 6.1). In general, the ingredients varied remarkably; the coefficient of variation (CV) being greater than 10% over the sampling period. According to the results, some of the nutrients were not normally distributed: for instance, protein was positively or negatively skewed in wheat middlings, wheat bran, soya oil cake, full-fat soya, maize and groundnut oil cake.

Kirby *et al*. (1993) tested the distribution of protein in some of the common ingredients (such as corn, meat and bone meal, and soybean) and found that protein content in corn as well as meat and bone meal was not normally distributed. This agrees with the results presented in Table 6.1. That is, feed formulation programmes that assume normality may not be appropriate for formulating least cost rations.

Table 6.1: Uniformity and normality tests of a variety of feed ingredients

Feedstuff	Nutrient[1]	N	Mean	SEM	CV	Min	Max	Skewness	P-value[2]
WM	Protein	51	16.40	0.13	5.62	15.00	19.57	1.12	0.034
	Threonine	51	0.53	0.01	8.59	0.41	0.64	0.00	0.280
	Methionine	51	0.21	0.00	10.56	0.16	0.28	0.29	0.030
	Lysine	51	0.73	0.01	10.40	0.56	0.92	0.62	0.054
	Arginine	51	1.05	0.02	12.69	0.71	1.53	0.66	0.116
	Moisture	51	10.14	0.23	16.53	7.20	14.10	0.41	0.225
	AME	51	9.14	0.20	15.36	7.18	16.86	3.60	<0.005
FM	Protein	123	64.11	0.33	5.70	52.28	74.50	-0.26	0.205
	Threonine	121	2.63	0.02	9.84	1.91	3.29	-0.50	0.056
	Methionine	118	1.90	0.02	13.38	0.68	2.75	-1.49	0.005
	Lysine	118	5.01	0.06	12.30	2.26	6.69	-1.39	0.005
	Arginine	118	3.71	0.04	10.88	2.75	4.86	0.34	0.460
	Moisture	118	8.81	0.14	17.68	3.40	13.35	-0.12	0.186
	AME	111	13.14	0.12	10.01	8.38	16.08	-1.38	0.005
Gluten 60	Protein	45	65.75	0.50	5.06	56.75	72.55	-0.33	0.801
	Threonine	45	2.08	0.03	8.38	1.54	2.34	-0.77	0.221
	Methionine	45	1.65	0.02	9.96	1.36	1.99	0.07	0.472
	Lysine	45	1.07	0.01	8.68	0.85	1.27	0.07	0.812
	Arginine	45	1.98	0.03	11.48	1.53	2.80	0.95	0.038
	Moisture	45	7.29	0.20	18.63	3.90	11.15	0.24	0.019
	AME	42	15.92	0.11	4.60	14.61	18.58	1.12	0.035
WB	Protein	14	13.59	0.32	8.87	11.11	14.73	-1.30	0.015
	Threonine	21	0.48	0.01	9.65	0.38	0.56	-0.10	0.658
	Methionine	21	0.19	0.00	11.70	0.15	0.24	-0.10	0.904
	Lysine	21	0.65	0.02	13.94	0.39	0.79	-1.40	0.022
	Arginine	21	1.00	0.03	15.87	0.72	1.26	0.13	0.270
	Moisture	14	10.93	0.57	19.68	6.85	16.15	0.70	0.313
	AME	14	9.21	0.30	12.29	7.65	11.93	1.36	0.025
SOC	Protein	79	38.62	0.31	7.23	31.01	44.08	-0.50	0.064
	Threonine	81	1.37	0.02	10.05	1.02	1.70	-0.25	0.305
	Methionine	81	0.64	0.01	16.49	0.39	0.99	0.32	0.147
	Lysine	81	1.53	0.02	9.64	1.19	1.97	0.45	0.015
	Arginine	81	3.09	0.04	10.31	2.23	3.77	-0.06	0.892
	Moisture	77	8.33	0.17	17.88	4.90	12.35	0.17	0.135
	AME	72	8.54	0.14	13.59	6.39	13.84	1.65	<0.005
SFF	Protein	144	36.64	0.16	5.50	29.41	42.36	-0.52	<0.005
	Threonine	152	1.39	0.01	8.29	0.70	1.64	-1.41	<0.005
	Methionine	152	0.41	0.00	10.60	0.32	0.54	0.53	0.01
	Lysine	152	2.41	0.02	9.32	0.69	2.79	-3.63	<0.005
	Arginine	152	2.67	0.02	10.80	1.01	3.18	-2.11	<0.005
	Moisture	120	8.25	0.17	23.77	3.20	14.34	-0.27	<0.005
	AME	110	14.72	0.08	6.19	11.77	17.29	0.14	0.342

[1]All values are in percentages. [2] The distribution of nutrients was tested at a 95% confidence level.
WM = wheat middling, FM = fishmeal, WB = wheat bran, SOC = soya oil cake, SFF = full-fat soya

Table 6.1: (continued)

Feedstuff	Nutrient	N	Mean	SEM	CV	Min	Max	Skewness	P-value
Sorghum	Protein	38	8.47	0.24	17.32	5.67	10.86	-0.07	0.698
	Threonine	39	0.29	0.01	18.54	0.21	0.46	0.88	0.376
	Methionine	39	0.13	0.00	19.59	0.08	0.19	0.20	0.279
	Lysine	39	0.21	0.01	20.16	0.11	0.38	1.20	<0.005
	Arginine	39	0.34	0.02	30.13	0.23	0.86	3.81	<0.005
	Moisture	37	10.63	0.21	12.04	7.80	13.65	-0.13	0.713
	AME	35	13.82	0.10	4.32	12.46	15.28	-0.32	0.174
Maize[a]	Protein	28	9.60	0.17	9.24	7.16	11.97	0.09	0.122
	Threonine	31	0.37	0.01	7.87	0.30	0.43	-0.18	0.393
	Methionine	31	0.14	0.00	13.88	0.09	0.18	-0.34	0.265
	Lysine	31	0.44	0.01	12.36	0.32	0.55	-0.47	0.187
	Arginine	31	0.55	0.01	14.56	0.38	0.75	-0.01	0.66
	Moisture	27	10.62	0.42	20.71	4.75	15.85	-0.46	0.234
	AME	27	12.52	0.20	8.50	10.43	14.57	0.02	0.788
Maize	Protein	129	7.95	0.08	11.79	5.61	11.77	0.79	0.014
	Threonine	106	0.29	0.00	13.38	0.21	0.45	0.72	0.106
	Methionine	106	0.15	0.00	18.33	0.06	0.21	-0.30	0.094
	Lysine	106	0.27	0.00	16.43	0.17	0.45	1.42	<0.005
	Arginine	106	0.40	0.01	19.58	0.26	0.62	1.17	<0.005
	Moisture	129	10.36	0.18	19.55	5.25	15.28	-0.30	0.02
	AME	121	14.13	0.06	4.49	10.95	15.69	-1.60	0.005
Lupins	Protein	53	33.11	0.48	10.56	27.32	42.91	0.46	0.088
	Threonine	57	1.06	0.02	11.25	0.83	1.34	0.26	0.814
	Methionine	57	0.19	0.00	15.60	0.15	0.29	0.84	0.005
	Lysine	57	1.68	0.04	19.42	1.33	3.86	5.42	<0.005
	Arginine	57	3.41	0.07	15.84	2.05	4.55	0.08	0.237
	Moisture	53	7.09	0.27	28.03	3.25	12.65	0.16	0.394
	AME	51	11.28	0.21	13.59	7.41	14.56	0.09	0.134
GOC	Protein	29	44.87	0.68	8.20	30.92	51.52	-1.93	<0.005
	Threonine	29	1.17	0.02	9.37	0.89	1.37	-0.37	0.517
	Methionine	29	0.40	0.01	12.86	0.21	0.50	-1.73	0.014
	Lysine	29	1.55	0.03	10.19	1.26	1.94	0.15	0.855
	Arginine	29	4.73	0.11	12.08	3.27	5.67	-0.85	0.14
	Moisture	29	7.41	0.31	22.80	4.00	10.73	-0.38	0.168
	AME	29	11.75	0.40	18.27	8.84	20.12	2.11	0.006
BG	Protein	32	25.01	0.62	14.16	16.33	30.09	-0.87	0.071
	Threonine	32	0.89	0.02	14.48	0.63	1.24	0.24	0.325
	Methionine	32	0.38	0.01	22.29	0.20	0.54	-0.38	0.525
	Lysine	32	0.75	0.04	32.11	0.29	1.16	-0.24	0.015
	Arginine	32	0.98	0.04	21.78	0.53	1.30	-0.36	0.181
	Moisture	32	8.23	0.28	19.63	5.75	11.95	0.72	0.007
	AME	28	10.04	0.32	17.09	7.06	16.12	1.39	0.034

[a]Maize germ 10% fat, GOC = groundnut oil cake, BG = brewers grain.

Roush *et al.* (1996) stated that this type of variation may be dealt with in the formulation process through non-linear stochastic programming. They explained that the stochastic method evaluates feed ingredients based on variability, reduces the waste associated with over-formulation by linear programming, reduces variation in meeting the requested nutrient levels in a formulated ration and lowers the cost of feed when compared to the linear programme with adjusted mean values. However, the level of nutrients in the formulated feed may also vary from day to day due to variation in ingredients for the feed mix, in mixing quality, analytical procedures, weighing errors, pellet quality, and efficiency in delivery of mixed feed from the mixing point to the birds. This kind of variation would need to be modelled differently. There is presently insufficient published material on the effects of these sources of variation on feed manufacturing and bird performance. Fawcett *et al.* (1992) suggested that enhanced descriptions of variability are valuable because they could facilitate predictions of the consequences of fractionation before investing in the necessary equipment.

This review will address the variation in the day-to-day levels of nutrients consumed by a broiler, brought about by the procedure for analysing the nutrient content of the ingredient, mixing efficiency, efficiency of delivery of the mixed feed and pellet quality.

6.2 Variation in feed mixing efficiency

The objective of mixing is to create a completely homogenous blend. Although insufficient mixing time is often implicated as a source of variation in complete feeds, numerous other factors may have an influence. Particle size and shape, ingredient density and static charge, sequence of ingredient addition, amount of ingredients mixed, mixer design, cleanliness of the mixer, wear or maintenance of the mixer, over- and under-filling could all affect the performance of the mixing system (Behnke, 2005). According to a study by Cromwell *et al.* (2003), neither the mixer nor mixer capacity influenced blending uniformity. However, each variable or step contributes a different source of variation during the mixing process. Mixer performance can be tested using micro ingredients such as salt or sodium (McCoy *et al.*, 1994), synthetic amino acids (Wicker and Poole, 1991), phytase (Johnston and Southern, 2000), coloured iron filings (McCoy *et al.*, 1994) or crude protein (Duncan, 1988). These authors found that feed variability showed a quadratic response ($P<0.001$) as the mixing time increased. The results of a study by Wicker and Poole (1991) showed that

only half of the feed tested would be of satisfactory uniformity (CV<10%). About 30% had a CV of 10 to 20% and the remaining 20% of the feed samples had a CV of >30%. Stark *et al*. (1991), cited by Behnke (1996), conducted a similar experiment but with a different test ingredient (salt) and found that 42% of the samples had a CV of <10%, 46% between 10 to 20% and 12% >20%. Recently, a study was conducted to assess the degree of uniformity of feed blending at 25 stations, analysed by three laboratories (Cromwell *et al*., 2003). It was found that crude protein varied from 11.8 to 14.6% (P<0.001), Zinc by 71 to 182 ppm (P<0.001), Calcium by 0.52 to 0.85% (P<0.001) and Phosphorus ranged from 0.47 to 0.58% (P<0.001).

Despite an extensive review of the literature, little quantitative data documenting the effects of feed uniformity on broiler performance could be found. McCoy *et al*. (1994) reported that mixing time, which influences feed uniformity, affected feed conversion ratio (P<0.09) in the 24-day growth study but had no effect on average daily gain. In the finisher period, quadratic responses were observed for average daily gain (P<0.04), and feed conversion ratio (P<0.07) increased as mixing treatment was increased from poor to intermediate, with no further increase as the mixing treatment increased from intermediate to adequate. They concluded that optimal growth performance in broiler chicks could be supported even when the CV in the feed was as high as 23%. On the other hand, Johnston and Southern (2000) reported that increasing phytase CV from zero to 103% had little effect on growth performance, whereas bone ash and breaking strength decreased only at the most extreme level. It is not possible to draw useful conclusions from these two trials, although it does appear that CVs as high as 20% (twice the current industry recommendation) may be adequate for maximum growth performance in broiler chicks.

A more systematic approach to the problem would be to address the issue by simulation: create feeds differing in quality (different levels of amino acids, for example) and allocate these randomly, and for varying lengths of time, to a simulated flock of broilers and predict performance of the flock. Such an exercise is used in the following chapter.

6.3 Variation in efficiency of delivery of mixed feed

The benefits of providing a well-balanced diet may be lost if adequate care is not taken in its delivery to the feed trough. The nutrient content of the feed can vary due to ingredient

separation after mixing and during transportation. Ingredient segregation can occur when particles of different sizes and bulk densities are blended together and transported or handled. Fawcett *et al*. (1992) suggested that particle separation might occur prior to pelleting and that this would contribute another source of variability that cannot be segregated from random residual variation without a properly designed statistical investigation. Whenever feed is conveyed either by chain or by blower, fine particles separate from coarse particles, particularly when the feed is conveyed in a mash form, and when the quality of pellets is poor with a high proportion of fine particles. Many feed pellets are damaged by loading, storage, augering or transferring to feed pans. Recently, Tang *et al*. (2006) conducted an experiment to determine feed segregation on the performance and egg quality of laying hens, and they found that two segregation patterns occurred while mash feed was delivered through the drag-chain feed trough, when there were no birds in the house: the first pattern consisted of fine and dense particles percolating to the bottom of the trough, whereas larger and less dense particles rose to the top. The second pattern: side -to-side segregation where larger particles moved to the sides of the feed trough, whereas smaller particles stayed at the centre. According to these authors, segregation leads to non-homogenous distribution of nutrients along the trough in the direction of feed delivery. Thus, the bird's daily nutrient requirements may not be met, depending on selection and consumption of larger or small particles. Besides, the degree of segregation effect varies between the delivery systems (auger *vs.* drag-chain)

According to Gous and Berhe (2006), this latter type of variation is likely to be systematic: if pellets are of a poor quality the consequence could be that birds at the start of the feeder line would be presented with whole pellets, but these would deteriorate whilst being transported such that only mash would be available towards the end of the feeder track. Because birds spend more time consuming mash than pellets (Jensen *et al*., 1962) the maintenance requirements of birds at the far end of the feeder line would be higher and hence their feed conversion efficiency would be worse. Because this kind of variation is systematic it may be quantified and either eliminated or at least reduced. Depending on the extent to which this source of variation influences the performance of broilers, a decision could be taken by management to invest in an alternative system that will result in less variation in performance, thereby increasing profit.

6.3.1 Pellets and crumbles

Broilers are generally supplied with pelleted or crumbled feed because of the positive effect of this feed form on growth rate and feed efficiency (Hussar and Robblee, 1962; McNaughton and Reece, 1984; Plavnik *et al*., 1997). However, the benefits of pelleted feed depend on the quality of the pellet. Soft pellets can easily break during the feeding process, resulting in the segregation of micro ingredients from macro ingredients. According to Nir *et al.* (1994), large particle sizes in pellets provide natural breaking points. As a result, the nutrient content of each bite will be different. Growth and performance has been shown to decrease as the proportion of fine particles increases (Proudfoot and Hulan, 1982; Moran, 1989, Tang *et al*., 2006). This is not the result of the heat generated during pelleting, which is sometimes regarded as being responsible for improved feed efficiency when comparing mash and pellets, as these researchers compared whole and re-ground pellets. Pellets can break into small pieces during road transportation, when being transferred from the truck to the silo, from the silo into the feeder system, and along conveyor belts within the broiler house.

6.3.2 Simulation exercise: effect of ingredient segregation along conveyer belt-type feeding systems on broiler performance

One of the advantages of simulation modelling is being able to identify those aspects of the animal that are covered by assumptions and which need experimentation. Fawcett (1992) attempted to determine the response of birds to different degrees of variation in feed nutrient content using growth model and bivariate probability distribution. However, this approach does not simulate the day-to-day variation in feed nutrient content to which broilers are subjected in practice, where nutrient composition varies throughout the rearing period. Stochastic programming (SP), which accounts for such variation, would be useful in feed formulation and for predicting responses although it needs adjustment for systematic variation in nutrient content brought about by separation during road, rail, auger and chain transportation. According to D'Alfonso *et al.* (1992; 1993) linear programming with a margin of safety (LPMS) and SP are commonly used to account for nutrient variability. Although the SP method was the most profitable and has been recommended by many investigators, including D'Alfonso *et al.* (1992; 1993) and Roush *et al.* (1996), it

is not until recently that it has been available for commercial use. Surprisingly, no mention has been made in the literature of the sources of variation brought about by ingredient segregation during transportation and on conveyer belt-type feeding systems. Thus, a great deal of research is required to determine the effects of these variables on the level of uniformity and the knowledge obtained could be useful when formulating feeds and optimising feed and feeding programmes for birds.

A simulation exercise was conducted to determine the effects of variation in environmental temperature, dietary protein content and the proportion of 'fines' (the extent to which pellets break up into mash as a result of abrasion and damage) on broiler performance. This was accomplished by simulating the conditions that might prevail in three sections (front, middle and back) of a longitudinally ventilated broiler house. At the front (air inlet) end of the house birds were subjected to a cold temperature profile, to the highest dietary protein content and to a pelleted feed with 0 % fines. At the far end (back) of the house, the environmental temperature was assumed to be higher, the feed protein content was assumed to be lowest, and the pellets had been reduced to mash (100 % fines). Conditions in the centre of the house were intermediate in all three respects. To account for the interaction between the three sources of variation, at each position, a factorial arrangement was used in the simulation exercise.

A theoretical flock of 50 male and female broilers was randomly generated, based on the mean and CV (%) of the genetic parameters used in the EFG broiler growth model (Table 4.2, Chapter 4). The mean values of the parameters were derived from the results of different experiments or publications (such as Emmans and Fisher, 1986; Hancock *et al*., 1995; Gous *et al*., 1999). The CVs used were those suggested by Emmans and Fisher (1986) while for those not found in the literature, the results of this project were used. The same simulated population was used for each of the simulated treatments.

To account for the change in dietary protein content along the length of the house, starter crumbles (0-10 d), grower pellets (11-25 d) and finisher pellets (26-42 d) were formulated to contain dietary ideal protein that was either 0.1 higher (high protein) or 0.1 lower (low protein) than the recommended reference levels of digestible lysine (Aviagen, 2002). It was assumed that birds near the front of the house chose pellets of the highest quality, containing the highest protein content.

In the case of environmental temperature, the low temperature profile (front of house) started at 25^{o}C, decreased every second day by 0.5 to 18.0^{o}C, and remained constant thereafter; the normal profile (middle) started at 30^{o}C, decreasing daily by 0.5 to 20^{o}C, remaining constant thereafter; whilst the high temperature profile decreased from 34^{o}C at the same rate as the normal profile, until it reached 24^{o}C after which it remained constant. The stocking density used was 16 birds/m^2 and this was maintained throughout the simulation period (no mortalities). To summarise, the factorial experiment consisted of three dietary protein levels, two feed forms, three environmental temperature profiles and two sexes. A total of 36 simulations was conducted on broilers between the ages of 0 and 21d and from 22 to 42d. In each simulation food intake, weight gain, protein gain, final body lipid content and feed conversion efficiency (FCE) were recorded.

As there was no significant effect of the proportion of fines along the feed trough on broiler performance, values for this variable were not included in the tables of means. The effects on food intake, weight gain and FCE of the horizontal temperature gradient in the house, and deviations of dietary protein content from the specification due to segregation of ingredients in the feed trough in male and female broilers in the earlier growth period (0 – 21d) and later growth period (22 – 42d), are presented in Table 6.2, and the effects on body protein gain and final lipid content in Table 6.3.

Statistically, there were highly significant ($P<0.001$) effects of location within the house on all measures of performance, influenced by both environmental temperature and feed protein content. Average daily food intake during both feeding periods increased linearly as dietary protein content decreased where birds were subjected to the low temperature profile, but under normal temperature conditions food intake decreased when protein intake was both increased and decreased from the normal level. At the far end of the house, where the temperature profile was hot, food intake decreased with protein level in the young broilers, and increased then decreased as protein content was decreased in the older birds. These interactions are illustrated in Fig. 6.1. Broilers are expected to decrease food intake as temperature increases (Yahav *et al*., 1996; Furlan *et al*., 2004) and to increase food intake as dietary protein content declines, but the significant interaction between protein content and temperature is of considerable importance. As a consequence of the changes in food intake, weight gain (Fig. 6.2) and FCE (Fig 6.3) were similarly significantly affected by trough position in both sexes. A similar experiment was

conducted on commercial laying hens by Tang *et al.* (2006), who reported that bird weight and egg weight were not significantly different depending on the birds' location but there was a significant difference in albumen height, Haugh unit and shell thickness. They suggested that body weight-related nutrients may be distributed uniformly along the feed trough, whereas egg quality-related nutrients were not uniformly distributed, but did not comment on which nutrients were involved in either process.

In spite of the significant interaction between feed trough location (dietary protein content) and environmental temperature in food intake and weight gain, no interactions were evident in body protein gain or final lipid content during either feeding period (Table 6.3). Body protein gain decreased linearly with protein content whilst body lipid content increased. The inhibitory effect of low feed protein content on protein gain was greatest on the high temperature profile. The results of this simulation exercise agree with those of Furlan *et al*. (2004) who reported that high environmental temperature has a significant deleterious effect on bird performance and carcass quality. Of particular interest here was the observation that high environmental temperature had an even greater negative effect on broiler performance when low protein diets were fed, demonstrating the inability of broilers at high temperatures to overconsume energy in an attempt to obtain sufficient of the amino acids required for growth. Small differences in environmental temperature have been shown to have significant negative effects on bird performance at the end of the production cycle (Al Homidan *et al.,* 1997).

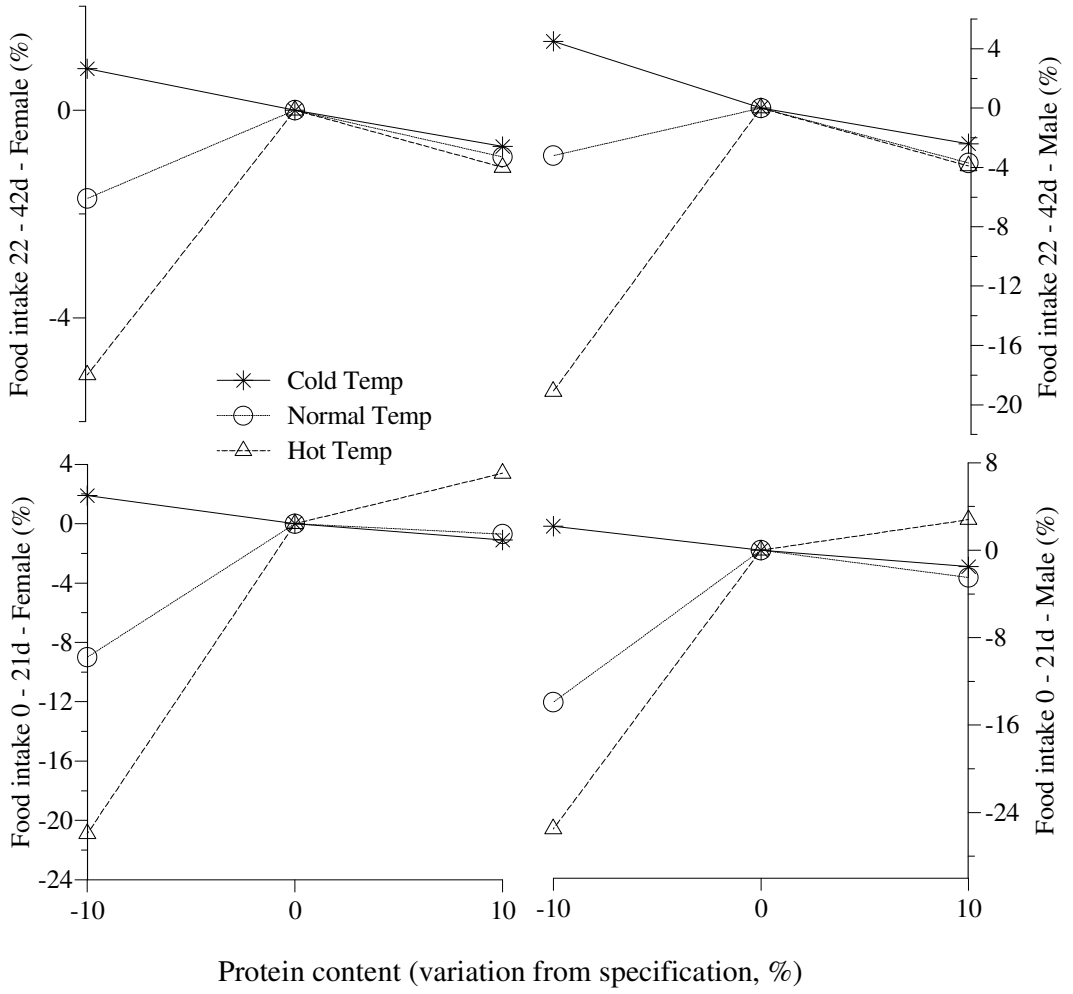

Figure 6.1: The relative effect on daily food intake (g/d) in female and male broilers during 0 to 21d and 22 to 42d of age, fed on a lysine limiting feed in which the protein content was increased or decreased by 10% to simulate the segregation of ingredients along the feed trough, while the temperature increased from cold to normal and then hot in the longitudinal ventilated broiler house.

Table 6.2: Effect of dietary protein content and environmental temperature due to ingredient segregation along the feeder line and due to temperature gradients along the length of the broiler house on food intake (g/d), weight gain (g/d) and feed conversion efficiency (FCE, g gain/kg feed) in female and male broilers from 0 to 21 d and from 22 to 42 d of age.

		Food intake (g/d)				Weight gain (g/d)				FCE (g gain/kg feed)			
		Female		Male		Female		Male		Female		Male	
Temp	Protein	0 - 21d	22 - 42d	0 - 21d	22 – 42d	0 - 21d	22 - 42d	0 – 21d	22 - 42d	0 - 21d	22 - 42d	0 - 21d	22 - 42d
Cold	10%	56.8	192	62.4	211	38.1	85.7	44.9	106	670	447	720	504
	Normal	57.5	193	63.4	216	37.7	85.7	44.5	107	657	444	702	494
	-10%	58.6	195	64.8	226	35.3	84.0	40.2	101	603	431	620	448
Normal	10%	51.6	176	56.8	194	37.5	82.5	44.4	104	726	470	781	535
	Normal	52.0	177	58.3	201	36.6	82.8	43.2	105	704	468	741	520
	-10%	47.3	174	50.2	195	29.2	79.7	31.8	90.5	618	457	635	465
Hot	10%	40.9	143	44.5	163	32.4	73.6	38.1	94.3	792	514	856	579
	Normal	39.5	145	43.3	170	29.5	74.0	33.5	93.4	748	511	773	551
	-10%	31.3	138	32.3	137	19.9	66.5	21.1	66.8	637	484	653	487

	FI (0-21d)	FI (22-42d)	WG (0-21d)	WG (22-42d)	FCE (0-21d)	FCE (22-42d)
RMS	0.085	1.497	0.0378	1.246	12.5	29.47
Temp	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Protein (P)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sex (S)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Temp x P x S	<0.001	<0.001	<0.001	<0.001	0.002	ns

RMS = residual mean square, Temp = Temperature, ns = not significant.

Table 6.3: Effect of dietary protein content and environmental temperature due to ingredient segregation along the feeder line and temperature gradient along the length of the house on daily protein gain (g/d) and final body lipid content in female and male broilers from 0 to 21 d and from 22 to 42 d of age.

		Protein gain (g/d)				Body lipid (%)			
		Female		Male		Female		Male	
Temp	Protein	0 - 21	22 - 42	0 - 21	22 - 42	0 - 21	22 – 42	0 - 21	22 - 42
Cold	10%	5.9	13.8	7.1	18.5	6.0	11.9	4.6	7.7
	Normal	5.9	13.7	7.1	18.3	6.3	12.6	4.8	8.7
	-10%	5.4	13.1	6.1	16.7	7.2	14.0	6.2	10.4
Normal	10%	5.9	13.5	7.1	18.1	6.0	11.4	4.6	7.5
	Normal	5.7	13.3	6.8	17.8	6.3	12.4	5.2	9.0
	-10%	4.4	12.3	4.8	14.6	7.3	14.3	6.1	10.9
Hot	10%	5.1	12.5	6.1	16.6	5.4	9.2	4.4	6.5
	Normal	4.5	12.0	5.1	15.6	6.5	11.2	5.9	9.6
	-10%	2.9	10.0	3.1	10.4	7.0	14.4	6.2	11.1
	RMS	0.002		0.013		0.005		0.150	
	Temp	ns		<0.001		Ns		0.002	
	Protein (P)	<0.001		<0.001		<0.001		<0.001	
	Sex (S)	<0.001		<0.001		<0.001		<0.001	
	Temp x P x S	<0.001		<0.001		<0.001		ns	

RMS = residual mean square, Temp = Temperature, ns = non significant

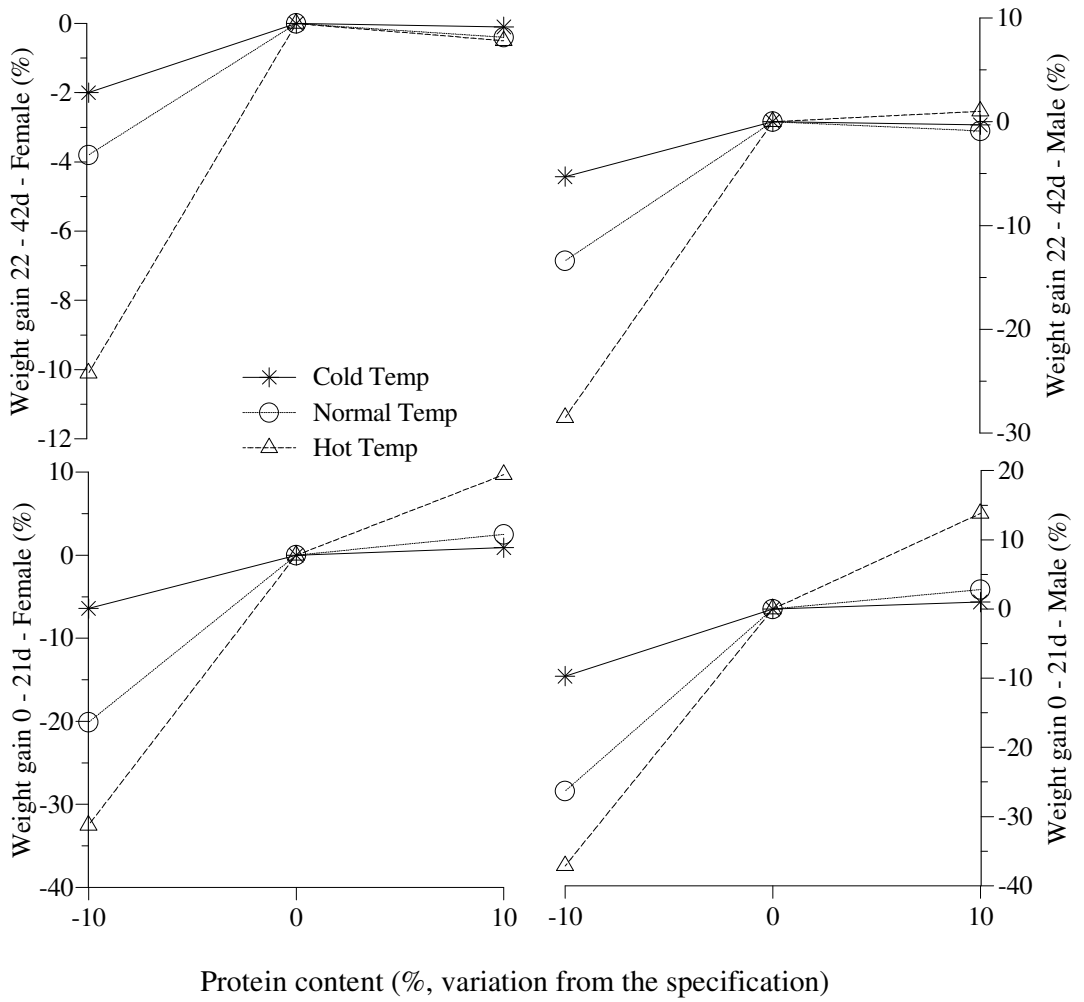

Figure 6.2: The relative effect on daily weight gain (g/d) in female and male broilers during 0 to 21d and 22 to 42d of age, fed on a lysine limiting feed in which the protein content was increased or decreased by 10% to simulate the segregation of ingredients along the feed trough, while the temperature increased from cold to normal and then hot in the longitudinal ventilated broiler house.

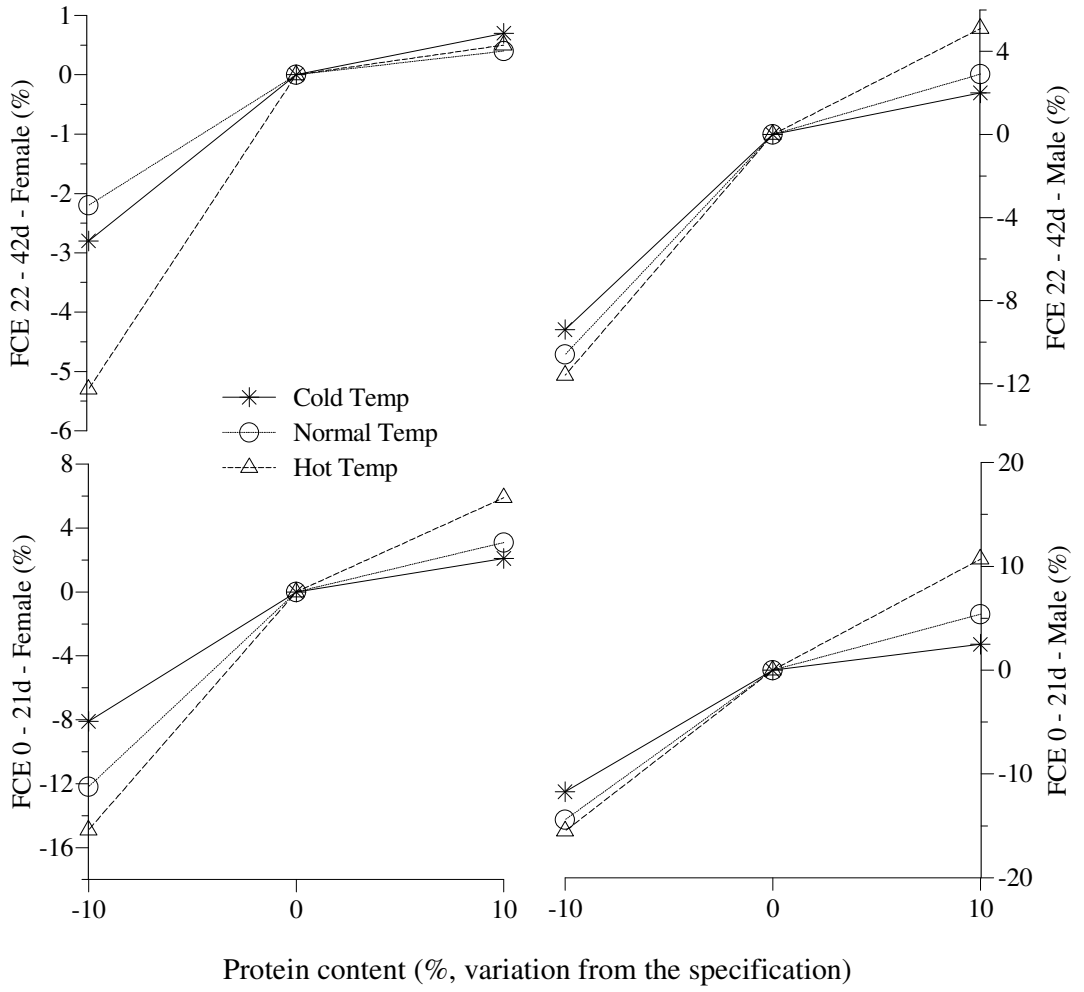

Figure 6.3: The relative effect on feed conversion efficiency (FCE, g gain/Kg feed) in female and male broilers during 0 to 21d and 22 to 42d of age, fed on a lysine limiting feed in which the protein content was increased or decreased by 10% to simulate the segregation of ingredients along the feed trough, while the temperature increased from cold to normal and then hot in the longitudinal ventilated broiler house.

6.4 Effect of friction in the feed trough on pellet quality

To measure the effect of friction in a chain feeding system on pellet quality along the feed trough, feed was sampled in the feed delivery vehicle, and then at the beginning, middle and end of a chain feeder (90m x 20cm) in a broiler house. These samples were shaken

over a 1.4 mm sieve to determine the proportion of pellets and crumbles that remained intact. The results are presented in Table 6.4.

Compared with the initial pellet quality, the proportions of broken pellets increased by 4.1, 10.24 and 18.9 %, at the beginning, centre and far end of the chain feeder, respectively. The equivalent values for the crumbled feed were 7.2, 15.4 and 17.6 %, respectively. The initial drop in quality would have been caused by the abrasive nature of augers and hoppers whilst the feed was being delivered to the broiler houses. In addition, the increase in the proportion of broken particles as the feed advanced along the open chain feeder track would have been due to the abrasive nature of the chain feeder, but also if birds preferred to consume high quality rather than broken pellets. The distribution of large particles decreased along the length of the feed trough, and as a result the CV increased with distance from the feed hopper.

Table 6.4: Proportion of pellets and crumbles remaining on a 1.4mm sieve in feed samples taken at three positions along a chain feeder line in a broiler house.

	Pellets		Crumbles	
Position in feeder line[1]	Mean (%)	CV (%)	Mean (%)	CV (%)
Beginning	90.9	4.47	61.2	14.51
Centre	84.8	6.55	53.0	8.39
Far end	76.1	10.47	50.8	20.66
RMS	36.9		69.6	
P-value[2]	<0.001		0.05	
n	63		24	

[1]The coarse percentages for pellet and crumble feed at the factory were 95.0% and 68.4% respectively.

[2]The level of significance = $P<0.05$

CV = coefficient of variation; n = number of batches of feed tested.

According to these results, crumbled feeds are more sensitive to these sources of variation than pelleted feeds, although the feed quality towards the end of the feeder was

significantly lower for both feed forms. The performance of birds housed at different stages along the feeder line within the broiler house is bound to differ as a result of these differences in pellet quality. The problem could be addressed by changing the feeder design, so that birds do not have open access to the feed as it passes down the line, as with pan feeders being supplied through a closed pipe, or by using high speed feeders where it is impossible for birds to eat whilst the feeder is distributing feed. Pellet durability is also of importance in reducing this source of common cause variation.

6.5 Variation in analytical procedures

Although great progress has been made in standardising methods, laboratories may use different analytical techniques to measure nutrients. The variation among laboratory analyses could be assumed to be fixed because laboratories claim to be using the same analytical procedure; the procedures are often assumed to be identical or stated, however, within a laboratory could be considered random. The above idea is supported by Rymer *et al*. (2005). Besides, they reported that it may be possible to develop mathematical correlations to account for the differences between laboratories and the composition of feeds determined by different laboratories. Differences in available equipment, reagents and facilities, as well as efforts at simplification, lead to significant changes in the original procedure (Robinson *et al*., 1990). That is, it is possible to measure the error difference between laboratories.

Sampling and analytical errors become relatively small when large numbers of samples are analysed. Most feed manufacturers use the CV to measure mixer performance and feed uniformity. The CV is calculated as the standard deviation divided by the mean. A CV of 10% has become the accepted degree of variation separating uniform from non-uniform mixes (Fei, 2000). However, the magnitude of an acceptable CV will vary depending on the analytical precision used in measuring the ingredient and ingredient ratio in the diet. Nutrient analyses of feeds by experiment station laboratories have been shown to be more variable than the same ingredients grown on various sites (Cromwell *et al*., 1999; 2000; 2003). According to a study by Cromwell *et al*. (2003), the CV among laboratories was 3.6, 12.5, 10.7, and 11.1 % for CP, Ca, P and Zn respectively. They explained that this variation could be due to certain laboratories not routinely conducting mineral assays. Robinson *et al*. (1990) highlighted the importance of accurate description of procedures,

especially modifications of original procedures, and the value of inter-laboratory testing in allowing critical evaluation of numerical values used in quantitative modelling efforts. Further research is required to determine the conditions that may need to be standardised among laboratories in order to enable successful inter and/or intra-laboratory comparisons of data.

Weighing and analytical errors in the context of dynamic accuracy and variation in the nutrient content of the feed cannot be ignored. McCoy *et al*. (1994) reported that 12 to 23% of the total variation in a completed diet is brought about by analytical errors. Errors in the nutrient analysis of feed ingredients can result from poor sampling techniques on the farm, infrequent feed sampling and testing or random error in nutrient analysis (D'Alfonso *et al*., 1993). The interaction of weighing error with net raw material variation will account for a significantly greater proportion of the variability in the reported contents of the product (Fawcett, 1992).

In general, frequent analysis of final feed will help producers determine the quality of feed. Laboratory analysis is the first step in problem-solving for feed manufacturers.

6.6 Conclusion

If performance in the broiler house is to reflect the potential of the broilers being reared there, the essential nutrients in the feed should be present at the prescribed concentrations throughout the house, and the quality of the pellets should be the same throughout the house. If such feed uniformity is not achieved, uniformity in performance will suffer, and this will lead to the production of a poorer quality product. Feed manufacturers need to be aware of the causes of variation in feed quality in order to eliminate or reduce this. Simulation models may be used to assess the consequences of variation in feed nutrient quality, feed form and in the environment (Gous, 2002), as has been demonstrated here.

Chapter 7

Variation in nutrient composition and its impact on animal performance: simulation

Abstract

The EFG Broiler Growth Model version 6 (EFG Software, Natal) was used to simulate the effects on broiler performance of varying nutrient composition resulting from an inaccurate evaluation of the quality of ingredients used in the manufacture of broiler feeds. Soybean oilcake meal, with a crude protein content of 440 g/kg feed (soy 440) was used as the major source of protein in the basal starter, grower and finisher feeds. Four additional feeds were produced from each of these three basal feeds by replacing the soy 440 in each feed with soy 380, 420, 460 or 500. Regression equations (Degussa Feed Additives, 1996 and 2001) were used to determine the amino acid composition and apparent metabolisable energy contents of the soybean oilcake meals used in the trial. The rationale used in designing the treatments was that soybeans containing higher or lower protein contents than expected may inadvertently be substituted for the expected ingredient, and that this may occur with any of the feeds used. Consequently, 12 treatments were designed and compared with a control treatment in which the expected, or standard, soybean meal (soy 440) was used throughout the period. Four of these treatments involved the substitution of the four alternative soybean oilcakes in the starter period only, four involved the substitution in the grower feed only, and the remaining four were substitutions made to the finisher feed only. The simulation exercise was conducted at two environmental temperature regimes (normal *vs.* random fluctuation) in the broiler house.

Weight gain increased with protein content in the grower phase, but decreased in the starter and finisher periods. Food intake decreased when dietary protein content increased, irrespective of the feeding phase, environmental temperature or sex, the rate of change being significantly greater among males than females. FCE also increased at all stages of growth for both sexes and environmental temperatures as protein content increased. Body protein gain increased with increasing lysine intake in males in all phases, and in females only in the finisher phase. Body lipid content decreased with increasing dietary lysine contents. Differences in protein content of soybean oilcake meal result in significant changes in biological and economic responses.

7.1 Introduction

It is common practice when feeding broilers to use a number of feeds, usually progressively decreasing in protein content, for different stages of the growing period. Each of these feeds is formulated to meet the nutrient requirements of the broiler at least cost for the specified phase of growth. Depending on the accuracy of the weighing equipment and the mixing process used in the feed mill, and the quality of the ingredients used, the composition of the feed delivered to the broilers may vary considerably from that intended. Broiler performance will reflect this variation in feed composition (Duncan, 1988; Roush, 2004) and may be used to evaluate the efficiency of the system employed at the feed mill, but it is difficult to isolate this source of variation from all the others that impact on performance. Thus, simulating the effect of such variation on performance provides a useful tool to a broiler producer, as it is possible to identify and quantify the effect of each type of variation independently of any others. There are no data in the literature that describe the effects of day-to-day nutrient variation on animal performance.

Based on the review of sources of nutrient variation in poultry feeds in the previous chapter (Chapter 6), it is evident that all broiler operations are faced with the problem of day-to-day variation in nutrient composition. Various approaches have been used to address the problem, some dealing with the accuracy of feed mill equipment used, while others rely on statistical and computational methods to account for this variation when formulating the feeds. This latter approach, known as stochastic programming, has been suggested as a method for dealing with both intrinsic and extrinsic variation in order to meet the required nutrient concentrations (D'Alfonso *et al*., 1992; Cravener *et al*., 1994; Roush *et al*., 1996). Naturally, this programme is only effective when the mean and standard deviations of nutrients in the ingredients included in the feed formulation are known. But none of these approaches enables the nutritionist or the broiler producer to predict the extent to which these interventions will influence performance and hence profitability. Simulation modelling can provide this information.

Simulation models are being used increasingly in animal production to predict the effects, for example, of feed (Emmans, 1981b; Sakomura *et al*., 2005), environment (Verstegen *et al*., 1995; Blanco and Gous, 2006) and social conditions (Wellock *et al*., 2003) on performance. In the present study, the EFG Broiler Growth Model version 6 (EFG

Software, Natal) was used to simulate the effects on broiler performance of varying nutrient composition resulting from an inaccurate evaluation of the quality of ingredients used in the manufacture of broiler feeds.

7.2 Material and methods

7.2.1 Simulation setting

The values of the genetic parameters used in this exercise are the same as those used in the previous exercise (see Chapter 6) and are reproduced in Table 7.1.

Table 7.1: Stochastic distribution of genetic parameters

Parameters	Male	Female	CV (%)
B^* (/d)	0.0453	0.0421	6.0
P_m (kg)	1.32	0.94	7.0
Fr (/d)	0.052	0.055	15.0
MLG (g/g)	1.4	1.4	15.0
LPR_m (g/g)	0.64	1.27	4.0
Wo (g)	50.0	50.0	7.0

Where B^* = scaled rate of maturing ($B^* = BPm^{0.27}$), P_m = matured protein weight, Fr = rate of feathering, MLG = maximum lipid in gain, LPR_m = lipid to protein ratio at maturity, Wo = initial body weight, CV = coefficient of variation.

7.2.2 Feeds and feeding procedure

The feed specifications and feeding schedules suggested in the Ross Broiler Management Manual (Aviagen, 2002) were applied to formulate a starter (0–14 d), grower (15–28 d) and finisher (29–42 d) feed at least cost, using WinFeed (EFG Software, Natal). Soybean oilcake meal, with a crude protein content of 440 g/kg feed (soy 440) was used in the basal feeds as the major source of protein, as is common practice in most broiler producing companies in the world. Chemical composition (g/kg) of starter, grower and finisher feeds

used as a reference feeds in the simulation exercise is presented in Table 7.2. Four additional feeds were produced from each of these three basal feeds by replacing the soy 440 in each feed with soy 380, 420, 460 or 500: the feeds were not reformulated at least cost, thus due to the substitution process the amino acid and energy contents of each feed were altered.

The amino acid composition of the soybeans of different protein content was determined using regression equations 1 to 9, Table 7.3 (Degussa Feed Additives, 1996 and 2001), whilst their apparent metabolisable energy contents, corrected to zero N-retention on an as-is basis (AME_n), were determined using the European Table of Energy Values for Poultry Feedstuffs, equation 10. A calculated AME and amino acids content of the five soybean oilcake meals is shown in Table 7.4. The amino acid digestibility coefficients were assumed to be the same for all soybean sources. The dietary treatments contained the same vitamins, minerals, crude fibre and crude fat contents. The nutrient composition of the feeds used in the simulation exercise is presented in Table 7.5.

7.2.3 Simulation design

The following assumptions were made when designing the simulation exercises. Feed storage facilities on the farm were in units of six tonnes of feed, supplying a broiler house with a capacity of 30,000 broilers via a belt or screw conveyor. Based on an EFG Broiler Growth Model (EFG Software) prediction, this amount of feed is enough for 7 d in the starter growth period, 3 d in the first weeks of the grower feeding period, 1.5 d in the second week of the grower period, or 1 d in the finisher period. This implies that in order to complete one cycle, the poultry manager should order 2, 7 and 14 times this amount for the starter, grower and finisher feeds, respectively.

In this study, 12 treatments were designed to determine the effect of substituting soybean oilcake meal of higher or lower protein content than that used in the formulation on performance of broilers to 42 d of age. These 12 treatments were compared with a control treatment in which the expected, or standard, soybean meal (soy 440) was used throughout the period.

Table 7.2: Composition (g/kg) of starter, grower and finisher feeds used as reference feeds in the simulation exercise.

Ingredient	Starter	Grower	Finisher
Maize	432.2	525.6	586.1
Soybean 440	437.2	336.9	250.6
Oil – soya	77.8	72.0	74.0
Soybean full fat		20.0	
Monocalcium phosphate	18.5	16.6	15.3
Sunflower 370	2.5		46.7
Limestone	17.3	15.7	15.2
DL-methionine	3.4	02.9	1.9
L-lysine HCL	2.0	3.1	3.0
L-threonine	0.6	0.6	0.5
Salt	2.5	2.3	2.2
Sodium bicarbonate	3.6	1.9	1.9
Vitamin + mineral premix	2.5	2.5	2.5
AME_n (MJ/kg)	12.60	13.30	13.50
EE (MJ/kg)	11.44	12.04	12.38
Crude protein	226.7	179.5	170.3
Lysine	12.7	11.8	11.1
Methionine	6.3	5.5	4.5
Methionine + Cystine	9.4	8.4	7.2
Threonine	8.0	7.0	6.1
Arginine	14.7	12.5	10.9
Leucine	17.5	16.0	14.6
Phenyl.+ Tyrosine	19.1	16.4	14.1
Crude fibre	42.7	37.9	40.1
Crude fat	89.2	89.6	90.2
Calcium	10.0	9.0	8.5
Available phosphorous	5.4	4.9	4.6

AME_n = apparent metabolisable energy; EE = effective energy; Phenyl = phenylalanine.

In all treatments the standard starter feed was provided until the age of 7 d with substitutions being made only after this age: in the first four treatments, the four alternative soybean meals (S380, S420, S460 and S500) (Table 7.6) were substituted for the control feed without changing the standard grower and finisher feeds. Treatments 5 to 8 involved the grower feeds, broilers being fed the normal starter and finisher feeds but the four alternative grower feeds (G380, G420, G460 and G500) from 15 to 28 d of age. The final four treatments involved feeding birds from 29 to 42d of age one of the four alternative soybean varieties (F380, F420, F460 and F500).

Table 7.3: The amino acid composition of the soybeans of different protein content was determined using regression equations and coefficient of determination, R^2 (Degussa Feed Additives, 1996 and 2001)

Equation no.	Amino acid (%)	Equation	R^2
1	Methionine	0.0171*CP% - 0.163	61
2	Methionine + Cystine	0.0321*CP% - 0.164	65
3	Lysine	0.0508*CP% + 0.432	67
4	Threonine	0.0368*CP% + 0.090	77
5	Tryptophan	0.0118*CP% + 0.058	59
6	Arginine	0.0679*CP% + 0.290	67
7	Isoleucine	0.0455*CP% + 0.003	74
8	Leucine	0.0603*CP% + 0.699	77
9	Valine	0.0405*CP% + 0.321	63

$$AMEn\,(kJ/kg) = CP*15.15 + Cfat*35.72 + NFE*15.59 \quad \text{……Equation 10}$$

Where CP = crude protein, Cfat = crude fat (g/kg) and NFE = nitrogen free extract (g/kg),

Table 7.4: A calculated AME and amino acids content (g/kg) of the five soybean oilcake meals (Soy) used in the simulation exercise.

	Soy 380	Soy 420	Soy 440	Soy 460	Soy 500
Arginine	28.7	31.4	32.8	34.1	36.9
Isoleucine	17.3	19.1	20.1	21.0	22.8
Leucine	29.9	32.3	33.5	34.7	37.1
Lysine	23.6	25.7	26.7	27.7	29.7
Methionine	4.9	5.6	5.9	6.2	6.9
Methionine + Cystine	10.6	11.8	12.5	13.1	14.4
AME (MJ/kg)	8.5	9.0	9.3	9.6	10.1

The simulation exercise was conducted at two environmental temperature regimes in the broiler house. The first regime started at 31˚C for the first three days and decreased daily by 0.5 to 20.5˚C, remaining constant thereafter. The second regime involved a random daily fluctuation of 0 to 2˚C above or below the first temperature sequence. For this purpose, the random temperatures were generated as follows using Excel:

$(\mathrm{T}^{\circ}C + \mathrm{Rand}() * -4) + \mathrm{Rand}() * 4$.

The experimental design consisted therefore of a control feeding treatment, four alternative nutrient compositions for each stage of growth (12 treatments), two sexes and two environmental temperature regimes (13 x 2 x 2) resulting in a total of 52 simulations being conducted to determine the effects of different qualities of soybean oilcake meal on performance.

Simulations were conducted using the calculated amino acid contents of each of the feeds in the feeding programmes described above, and all weekly outputs from the model were saved for further analysis. The data were subjected to statistical analysis using the regression procedures of Genstat (2005) to determine the mean responses in food intake, weight gain, protein gain, final body lipid content and feed conversion efficiency (g gain/kg feed) to the various treatments. These variables were regressed against either the lysine content of the feed treatment or the lysine intake by birds on the various treatments.

Table 7.5: Comparison of chemical composition (g/kg) of diets as soybean meal crude protein percentage varied (38 to 50) in each feeding phase in the simulation exercises

	Starter				Grower				Finisher			
Nutrient	38	42	46	50	38	42	46	50	38	42	46	50
AMEn	12.23	12.48	12.72	12.96	13.02	13.21	13.39	13.58	13.24	13.41	13.59	13.76
EE	11.10	11.32	11.54	11.76	11.77	11.94	12.11	12.28	12.10	12.26	12.42	12.57
Crude protein	203.1	220.3	237.4	254.6	161.4	173.2	184.9	196.7	159.3	170.2	181.2	190.4
Dry matter	895.7	895.7	895.7	895.7	891.4	891.4	891.4	891.4	889.6	889.6	889.6	889.6
Lysine	11.5	12.3	13.1	13.8	10.9	11.5	12.1	12.7	9.1	9.7	10.3	10.8
Methionine	5.9	6.2	6.4	6.7	5.2	5.4	5.6	5.8	4.2	4.4	4.5	4.7
Methionine+cystine	8.7	9.2	9.7	10.1	7.9	8.2	8.6	8.9	6.7	7.0	7.4	7.7
Threonine	7.2	7.7	8.2	8.8	6.4	6.8	7.2	7.6	5.5	5.9	6.3	6.7
Tryptophan	2.1	2.2	2.4	2.6	1.8	1.9	2.0	2.2	1.6	1.7	1.9	2.0
Arginine	3.1	14.2	15.2	16.4	11.3	12.1	12.9	13.8	10.3	11.1	11.9	12.7
Isoleucine	7.8	8.5	9.2	9.9	6.8	7.3	7.9	8.4	6.3	6.8	7.3	7.8
Leucine	16.1	17.0	18.0	18.9	14.9	15.6	16.4	17.1	14.4	15.0	15.7	16.3
Phenyl.+tyrosine	19.2	19.2	19.2	19.2	16.4	16.4	16.4	16.4	15.3	15.3	15.3	15.3
Valine	8.5	9.1	9.7	10.3	7.6	8.1	8.5	9.0	7.1	7.6	8.0	8.4
Crude fibre	42.5	42.5	42.5	42.5	37.9	37.9	37.9	37.9				.
Crude fat	89.2	89.2	89.2	89.2	89.6	89.6	89.6	89.6	90.0	90.0	90.0	90.0
Calcium	10.0	10.0	10.0	10.0	9.0	9.0	9.0	9.0	8.5	8.5	8.5	8.5
Avail. Phosphorous	5.4	5.4	5.4	5.4	4.9	4.9	4.9	4.9	4.6	4.6	4.6	4.6

AME_n = apparent metabolisable energy, EE = effective energy, Avail = available, Phenyl = Phenylalanine.

Table 7.6: Feeding schedule used in the simulation exercise over a 42d growth period

Treatment	0 to 7 d	8 to 14 d	15 to 28 d	29 to 42 d
Control	S 440	S 440	G 440	F 440
1	S 440	**S 380**	G 440	F 440
2	S 440	**S 420**	G 440	F 440
3	S 440	**S 460**	G 440	F 440
4	S 440	**S 500**	G 440	F 440
5	S 440	S 440	**G 380**	F 440
6	S 440	S 440	**G 420**	F 440
7	S 440	S 440	**G 460**	F 440
8	S 440	S 440	**G 500**	F 440
9	S 440	S 440	G 440	**F 380**
10	S 440	S 440	G 440	**F 420**
11	S 440	S 440	G 440	**F 460**
12	S 440	S 440	G 440	**F 500**

S = starter soybean meal, G = grower soybean meal, F = finisher soybean meal.

7.3 Results

The results of the simulations, in terms of mean food intake and weight gain to 42 d, feed conversion efficiency (FCE) (g gain/kg feed), protein gain and final body lipid content for males and females subjected to the 13 dietary treatments and two temperature profiles, are given in Table 7.7. Performance was affected equally by the two temperature regimes, so the results of only the normal temperature profile are illustrated for FCE, protein gain and lipid content in Figures 7.1, 7.2 and 7.3 respectively.

All treatments exhibited the same mean growth rate over the 42 d growing period (Table 7.7), although the rates of change brought about by the inadvertent use of soybean oilcake meals that differed from that used in the formulations differed in the three phases and under the two environmental profiles. Under the normal temperature profile (Table 7.8), weight gain increased with lysine intake ($P<0.001$) in the grower and finisher phases, but in the starter phase only the males showed a significant ($P<0.05$) response and this was

negative. Under the fluctuating temperature profile (Table 7.9) weight gain increased significantly ($P<0.01$) in all three phases for males, but only in the first and third phases for females. Food intake decreased ($P<0.001$) as the levels of dietary protein increased in all phases, irrespective of environmental temperatures or sex, but the rate of change was greater in all cases for males than for females (Table 7.7, 7.10 and 7.11), and FCE increased in all three stages of growth ($P<0.001$) in both sexes and under both environmental temperatures regimes as the soya protein (and hence, lysine) content increased (Tables 7.7, 7.10 and 7.11). Again, the response in FCE was in most cases more pronounced for males than for females. The responses in FCE are illustrated in Figure. 7.1.

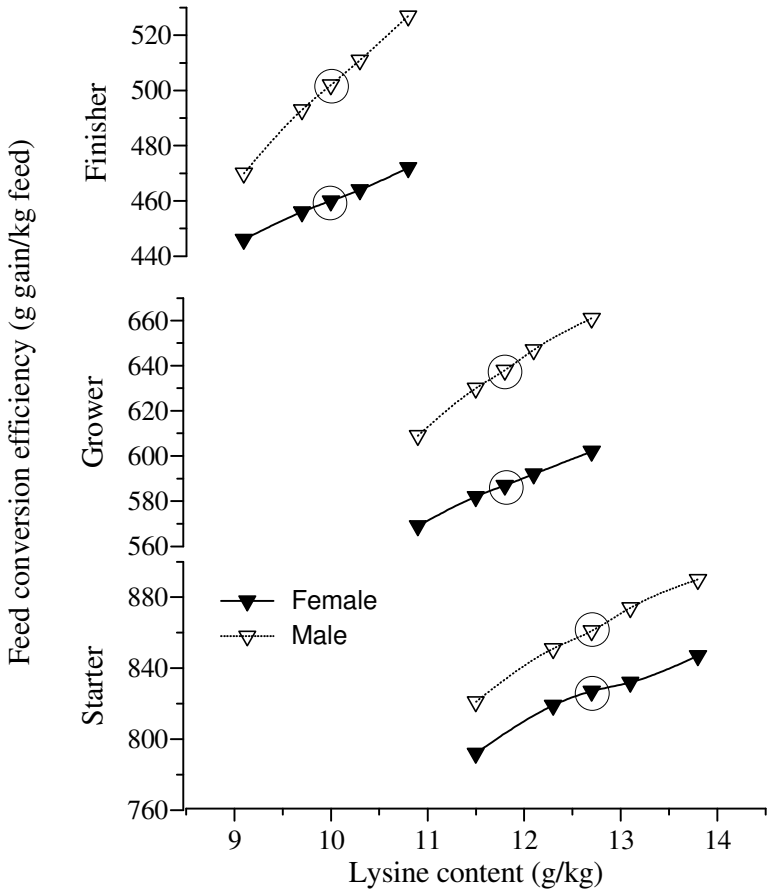

Figure 7.1: Simulated feed conversion efficiencies (g gain/kg feed) resulting from altering the quality of soybean oilcake meal of the control feed (O), during the starter, grower and finisher phases of growth, in male and female broilers reared on a normal temperature profile.

Table 7.7. Mean food intake, weight gain, food conversion efficiency (FCE), protein gain and final body lipid content of male and female broilers in response to the use of alternative soybean qualities over the 42-d growing period, using two environmental temperature regimes

			At normal temperature					With fluctuating temperatures				
Feed type	Lysine (g/kg)	Sex	Food intake (g/d)	Weight gain (g/d)	FCE	Protein gain (g/d)	Lipid content %	Food intake (g/d)	Weight gain (g/d)	FCE	Protein gain (g/d)	Lipid content %
Control	12.7	Female	96.9	52.4	541	8.55	12.3	96.2	52.2	543	8.55	12.4
		Male	111.9	65.3	584	11.12	9.4	111.2	65	585	11.10	9.4
S 380	11.5	Female	97.2	52.4	539	8.55	12.3	96.4	52.1	540	8.52	12.4
		Male	112.1	65.1	581	11.07	9.4	111.3	64.7	581	11.05	9.5
S 420	12.3	Female	97.0	52.4	540	8.55	12.3	96.3	52.2	542	8.55	12.4
		Male	112	65.2	582	11.12	9.4	111.3	65	584	11.10	9.4
S 460	13.1	Female	96.8	52.4	541	8.55	12.3	96.2	52.2	543	8.55	12.3
		Male	111.7	65.3	585	11.12	9.4	111.1	65	585	11.12	9.4
S 500	13.8	Female	96.6	52.4	542	8.55	12.3	96.0	52.2	544	8.55	12.3
		Male	111.4	65.2	585	11.12	9.3	110.9	65.1	587	11.12	9.4
G 380	10.9	Female	98.0	52.4	535	8.52	12.5	97.4	52.2	536	8.52	12.5
		Male	113.5	65.0	573	11.05	9.6	112.8	64.7	574	11.00	9.7
G 420	11.5	Female	97.2	52.4	539	8.55	12.4	96.6	52.2	540	8.52	12.4
		Male	112.4	65.2	580	11.10	9.5	111.7	65	582	11.07	9.5
G 460	12.1	Female	96.6	52.4	542	8.55	12.3	95.9	52.2	544	8.55	12.3
		Male	111.4	65.3	586	11.14	9.3	110.7	65	587	11.12	9.3
G 500	12.7	Female	95.9	52.4	546	8.57	12.2	95.3	52.2	548	8.55	12.2
		Male	110.4	65.3	591	11.14	9.2	109.7	65	593	11.14	9.2
F 380	9.1	Female	98.8	52.5	531	8.50	12.7	98.0	52.3	534	8.48	12.7
		Male	115.7	65.1	563	10.93	10.1	115	64.8	563	10.90	10.1
F 420	9.7	Female	97.4	52.5	539	8.55	12.4	96.7	52.2	540	8.52	12.4
		Male	113.1	65.3	577	11.07	9.6	112.4	65	578	11.05	9.7
F 460	10.3	Female	96.4	52.4	544	8.57	12.2	95.8	52.2	545	8.55	12.3
		Male	110.7	65.2	589	11.17	9.2	110.1	65	590	11.14	9.2
F 500	10.8	Female	95.5	52.4	549	8.60	12.0	94.9	52.2	550	8.60	12.1
		Male	108.6	65.1	599	11.21	8.7	108	64.9	601	11.21	8.8

S = starter soybean oil cake, G = grower soybean oil cake, F = finisher soybean oil cake, FCE = feed conversion efficiency (g gain/kg feed).

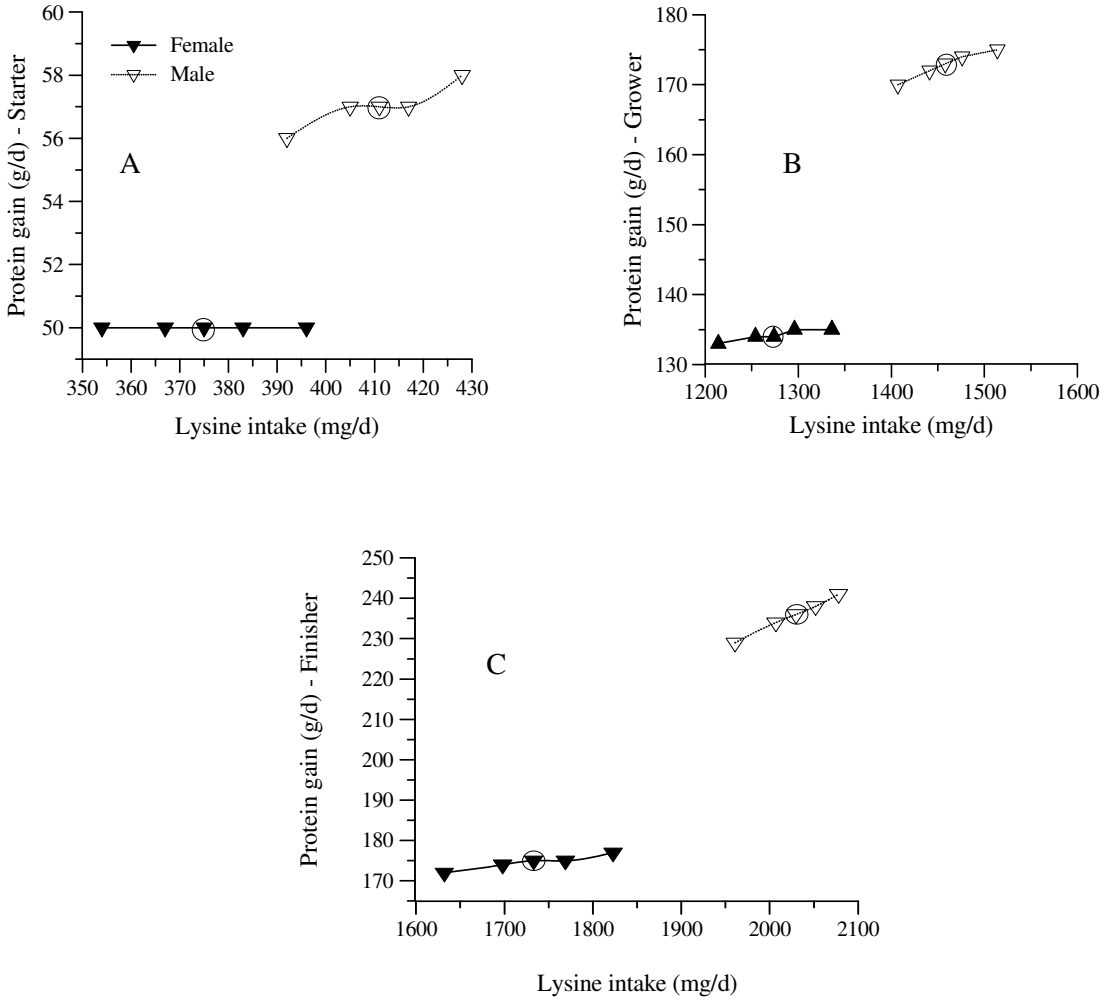

Figure 7.2: The simulated effect of lysine intake on body protein gain (g/d) as a result of altering the quality of soybean oilcake meal in the control feed (O) during the starter (A), grower (B) or finisher (C) phases, in male and female broilers reared on a normal temperature profile.

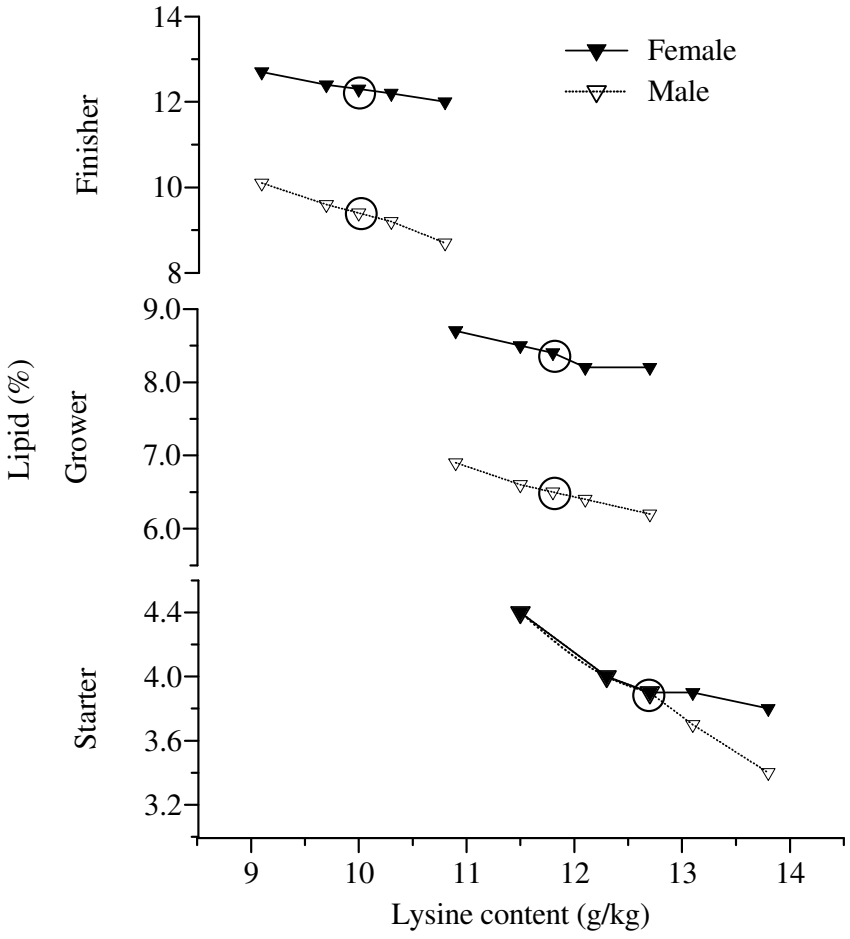

Figure 7.3: The simulated effect of dietary lysine content on final body lipid content resulting from altering the quality of soybean oilcake meal of the control feed (O) during the starter, grower or finisher phases of growth, in male and female broilers reared on a normal temperature profile.

Table 7.8: Linear regression coefficients reflecting the changes in weight gain (g/d) and protein gain (g/d) as dietary lysine intake was changed in response to the use of soybean meals differing in protein content, during the starter, grower and finisher phases, in male and female broilers reared on a normal temperature profile.

	0 to 14 (g/d)				15 to 28 (g/d)				29 to 42 (g/d)			
	Weight gain (g/d)		Protein gain (g/d)		Weight gain (g/d)		Protein gain (g/d)		Weight gain (g/d)		Protein gain (g/d)	
Parameter	B	P-Value	b	P-Value	b	P-Value	B	P-Value	b	P-Value	b	P-Value
Lysine intake (L)	-0.003	n.s.	0.00001	n.s.	0.0715	<0.001	0.017	0.006	0.0654	<0.001	0.025	<0.001
L x Sex M[1]	-0.009	0.024	0.0499	0.001			0.030	0.003			0.076	<0.001
Pooled SE	0.059		0.184		3.3		0.373		4.25		0.333	
R^2	99.9		99.8		83.5		99.9		86.4		99.99	

b = coefficient of regression, M = male, SE = standard error, R^2 = coefficient of determination.
[1] Using simple linear regression with Groups, the regression coefficient for males differs significantly from that for females.

Table 7.9: Linear regression coefficients reflecting the changes in weight gain (g/d), protein gain (g/d) as dietary lysine intake was changed in response to the use of soybean meals differing in protein content, during the starter, grower and finisher phases of growth, in male and female broilers reared on a fluctuating temperature profile.

	0 to 14 (g/d)				15 to 28 (g/d)				29 to 42 (g/d)			
	Weight gain (g/d)		Protein gain (g/d)		Weight gain (g/d)		Protein gain (g/d)		Weight gain (g/d)		Protein gain (g/d)	
Parameter	B	P-Value	B	P-Value	b	P-Value	B	P-Value	b	P-Value	b	P-Value
Lysine intake (L)	0.060	0.008	0.134	0.006	-0.001	Ns	0.026	0.004	0.065	<0.001	0.021	<0.001
L x Sex M[1]					0.006	0.029	0.031	0.011			0.076	<0.001
Pooled SE	1.260		2.100		0.127		0.488		4.29		0.222	
R 2	55.2		70.2		99.9		99.90		85.9		99.9	

b = coefficient of regression, M = male, SE = standard error, R^2 = coefficient of determination.
[1] Using simple linear regression with Groups, the regression coefficient for males differs significantly from that for females.

Table 7.10: Linear regression coefficients reflecting the changes in food intake (g/d), feed conversion efficiency (FCE) (g gain/kg feed) and body lipid content (%) as dietary lysine content was changed in response to the use of soybean meals differing in protein content, during the starter, grower and finisher phases, in male and female broilers reared on a normal temperature profile.

	Food intake (g/d)				FCE (g gain/ kg feed)				Body lipid (%)			
Parameter	B	P-Value	SE	R^2	b	P-Value	SE	R^2	b	P-Value	SE	R^2
Starter (S)	-0.90	<.001	0.065	99.6	26.58	<.001	1.92	97.4	-0.29	0.002	0.046	92.8
S x Sex M[1]	-0.45	0.013	0.092						-0.18	0.034	0.066	
Grower (G)	-3.33	<.001	0.180	99.9	18.17	<.001	1.24	99.7	-0.34	<.001	0.033	99.6
G x Sex M	-2.17	<.002	0.255		10.67	<.001	1.76					
Finisher (F)	-5.80	<.001	0.214	99.9	15.09	<.001	0.831	99.8	-0.40	<.001	0.029	99.9
F x Sex M	-8.25	<.002	0.303		18.12	<.001	1.18		-0.40	<.001	0.040	

b = coefficient of regression, M = male, SE = standard error, R^2 = coefficient of determination.
[1] Using simple linear regression with Groups, the regression coefficient for males differs significantly from that for females.

Table 7.11: Linear regression coefficients reflecting the changes in food intake (g/d), feed conversion efficiency (FCE) (g gain/kg feed) and body lipid content (%) as dietary lysine content was changed in response to the use of soybean meals differing in protein content, during the starter, grower and finisher phases, in male and female broilers reared on a fluctuating temperature profile.

	Food intake (g/d)				FCE (g gain/ kg feed)				Lipid (%)			
Parameter	B	P-Value	SE	R^2	b	P-Value	SE	R^2	B	P-Value	SE	R^2
Starter (S)	-0.82	<0.001	0.048	99.8	21.39	<0.001	1.53	99.1	-0.301	<0.001	0.0312	95.8
S x Sex M[1]	-0.44	<0.001	0.069		9.05	0.006	2.16		-0.140	0.037	0.0525	
Grower (G)	-3.53	<0.001	0.167	99.9	18.83	<0.001	1.07	99.8	-0.217	0.002	0.0403	99.7
G x Sex M	-2.08	<0.001	0.236		13.33	<0.001	1.51		-0.217	0.009	0.0569	
Finisher (F)	-5.94	<0.001	0.187	99.9	14.56	<0.001	0.69	99.9	-0.333	<0.001	0.0329	99.9
F x Sex M	-7.30	<0.001	0.264		18.11	<0.001	0.97		-0.439	<0.001	0.0465	

b = coefficient of regression, M = male, SE = standard error, R^2 = coefficient of determination.
[1] Using simple linear regression with Groups, the regression coefficient for males differs significantly from that for females.

Body protein gain increased with lysine intake in both sexes in all three phases of growth, but the male response was greater than that in females in all cases (Tables 7.8 and 7.9, and Figure 7.2). Conversely, body lipid content decreased as the lysine content in the feed was increased (Tables 7.10 and 7.11, and Figure 7.3), with males again showing a greater response than females, except in the grower period where the responses were the same under the normal temperature profile.

7.4 Discussion

Successful broiler production depends on a sound feeding program, which requires, amongst others, that the protein content of the feed is reduced at intervals throughout the growing period. The protein (or amino acid) content of each feed, and the amount that is allocated are under the control of the nutritionist. However, the capacity of the feed storage bin allocated to each broiler house constrains the amount that can be fed from the same batch of feed in a specific feeding schedule. Although the composition of the feed obtained from a feed mill should remain constant from batch to batch, mistakes are sometimes made, and the quality of the feed may differ from the previous batch obtained from the feed mill. Broilers are then subjected to a feed that differs in specification from the expected, and often this error is not discovered. This simulation exercise was designed to determine the consequences on performance of inadvertently using a soybean oilcake meal that differs from the assumed or expected. In a practical situation, such a switch could occur in any of the phases of growth, and if only one batch of feed is mistreated in this way the consequence will differ depending on the stage of growth when this occurred. In the starter period, for example, because of the relatively low daily intake of feed by each chick, the birds would be subjected to the incorrect formulation for a longer period of time than if this occurred just prior to harvesting the birds, when a feed storage bin may last for only one or two days.

The results suggest that such inadvertent changes in the protein content of broiler feeds have little or no overall effect on the growth of broilers, yet when the respective growth rates were regressed against dietary lysine intake within each period, these responses were as would be expected, namely, that growth rate, and especially body protein gain, responded positively to an increase in lysine intake (Gous *et al*., 1990; Smith and Pesti,

1998). In spite of the lack of an overall effect on weight gain, FCE to 42 d was significantly affected through an increase in food intake and hence body lipid content as the protein content of the feed was reduced.

Differences between the highest and lowest dietary lysine contents were 2.3, 1.8 and 1.7 g/kg of feed for the starter, grower and finisher feeds respectively. In spite of these small differences, differences in food intake and FCE between treatments were considerable. Males were affected to a greater extent than females, possibly because the amino acid contents in the control feed were more than adequate for females, and hence the small changes did not result in the same degree of deficiency for the females as for the males. Food intake is generally increased in an attempt by each bird to consume sufficient of the limiting nutrient to meet its requirement for that nutrient, but the limit to which food intake can be increased is dictated by the amount of heat that the bird can lose to the environment (Emmans and Fisher, 1986; Gous, 1998). If the amino acid contents in the control feed had been lower, it is likely that the females would have shown a higher rate of increase in food intake as the protein content declined.

This simulation exercise assumed all the SBM varieties used had the same amino acid digestibilities, fibre contents and lack of anti-nutritional compounds. Had these additional qualities been taken into consideration in the simulation exercise, the effect of dietary treatment on final performance would have been more pronounced. In reality, these quality characteristics do vary between SBM samples. Thus, profitability of the enterprise is likely to vary significantly when one type of SBM is substituted for another. On the other hand, the consequence of over-formulated feed could have a significant negative impact on the performance of the animal: for instance, high protein feeds increase mortality percentage as a result of fast growth rate (Classen, 2000); chick diets containing surplus protein can lead to impaired utilisation of the first-limiting amino acid (Morris, 2004); and nitrogen excretion would increase significantly because very little of this excess protein would be used for body protein deposition. Excess dietary protein increases water excretion especially when SBM is used as a protein source since SBM is rich in potassium which can lead to increased water intake. Besides, excess nitrogen is excreted as uric acid and this breaks down into water and ammonia, which could result in ideal conditions for disease organisms to multiply in broiler houses. Although broilers grown on high nutrient concentrations generally perform better than those grown on low concentrations, excessive

levels of some nutrients resulting from the incorrect formulation of feeds could cause performance to decrease, by reducing the efficiency of utilisation of essential nutrients, resulting in the build up of unfavourable environmental conditions in the broiler house.

The changes in the daily environmental temperature resulting from random fluctuations made to this profile had very little effect on mean performance, with no interactions being evident between temperature and dietary protein content. Presumably, fluctuations would need to be greater than those used in this simulation exercise before meaningful changes would be evident in performance.

In conclusion, small and short term differences in nutrient content, brought about by the inadvertent use of soybean oilcake meals differing from the expected in dietary protein content, result in changes in biological and economic responses in broiler production, even though market weight is little affected at 42 d of age. Larger differences could be found in practice, compared with those in this simulation exercise, as many of the factors that vary between SBM samples were not taken into account in this simulation exercise. The result of this exercise demonstrates the importance of quality control in a feed mill: feed mill managers should keep accurate information on the nutrient composition of all ingredients entering and being stored in the feed mill, and they should work closely with nutritionists to coordinate this information with the feeds being formulated and mixed.

General Discussion

The general problem in animal production is that of predicting growth rate and body composition (Emmans and Fisher, 1986; Emmans and Oldham, 1988; Ferguson and Gous, 1993). Simulation models have been developed that predict food intake and growth of broilers (EFG Software, 2007) and are becoming increasingly sophisticated in that it is now possible to optimise the feeds and feeding programme of broilers of a given genotype in a given environment, given the cost and availability of raw materials and the value of the product being sold. However, in most animal growth models, weight of body lipid and body protein are key state variables that can be related quantitatively to chemical and physical body composition for predicting growth response and characteristics (Emmans, 1981; Gous *et al*., 1999; de Lange *et al*., 2003, Pomar *et al*., 2003). The allometric relationships need to be defined if these components are to be estimated from protein weight. Emmans (1988) suggested that there is a strict relationship between water or ash and body protein, at maturity, independent of genotype. However, due to uncontrolled genetic selection this relationship might be affected by the current strains of broilers. Therefore, re-evaluation of these relationships among the modern genotype is a prerequisite to improve the model and to predict a realistic response. Furthermore, almost all broiler growth models have been developed at the level of one bird, yet commercially it is populations that are being managed and fed. The optimal nutrient requirement and food intake might differ between populations with different degrees of genetic variation.

In the exercise conducted in this thesis, three experiments were conducted to determine the effect of dietary protein on the performance, including mortality and uniformity and on the allometric relationships between the carcass components and body protein, of two strains of broilers available in South Africa. In all experiments, the effect of feed protein content on food intake was of a quadratic form and almost identical in both strains (starter period, 0 to 21d), with intake first increasing as protein content was reduced, and then decreasing. This tendency to increase food intake as the limiting nutrient (in this case, protein) is reduced is a corollary to the theory of food intake regulation of Emmans (1981) incorporated into the EFG Broiler Growth Model (EFG Software, 2007) and has been confirmed in experiments by Gous *et al*. (1990), Skinner *et al*. (1992), Smith & Pesti (1998) and Smith *et al*. (1998). However, in the finisher period, the two strains differed in

their response to dietary balanced protein, Ross birds reduced food intake as dietary protein was decreased, which is contrary to Emmans' (1981) theory of food intake regulation and confirming the similar observation by Kemp *et al*. (2005).

The Ross strain has been selected for improved growth and feed efficiency using high protein feeds. Such selection results in leaner carcasses (Pym & Solvyns, 1979) and perhaps a reduced ability to fatten when faced with feeds marginally deficient in an essential nutrient. If this were the case then such strains would be incapable of increasing food intake on marginally deficient feeds, as a prerequisite for this is to be able to store the excess energy consumed as body lipid unless the environmental temperature were sufficiently low as to allow the birds to lose the excess energy as heat. In the EFG Broiler Growth Model, the potential growth rate is described using a Gompertz growth curve (three parameters) and the lipid-to-protein ratio at maturity is an additional parameter used to describe a genotype. These are insufficient to describe the differences in food intake in the latter part of the growing period in response to dietary balanced protein observed by Kemp *et al*. (2005) and here. Some theoretical arguments are put forward by Gous (2007) to explain these differences, but as yet no satisfactory solution to the problem has been found.

An increasingly important characteristic of broiler production is the uniformity of body weight and conformation of birds when harvested, since consumers have become more sophisticated, demanding highly uniform whole birds and portions. According to the results of all experiments and the simulation exercise described by Gous and Berhe (2006), uniformity decreases as the feed becomes marginally deficient in protein and this is in agreement with Corzo *et al*. (2004). Results of the simulation exercise suggest that at both high and low (limiting) concentrations of dietary protein uniformity increases, the requirements of all individuals in the one case being met, and in the other, all individuals are similarly constrained. At the lowest protein levels, uniformity in the first experiment was higher than on the intermediate protein levels, probably because all birds were equally constrained by the severely deficient protein content of the feed offered. Because the feeds were not as deficient in protein in the second trial, i.e. none was severely deficient, uniformity diminished linearly throughout the range of protein levels used. Uniformity is clearly compromised as dietary protein content is reduced, a situation that is likely to occur

frequently in commercial broiler operations. Thus, uniformity in a population of birds, caused by feeds varying in essential nutrient content, may be simulated mechanistically.

In the case of the allometric relationships measured here, it is interesting that there was no effect of strain, sex or dietary protein level on most of the relationships between the physical and chemical components with body protein. The exceptions were drum and breast meat weight. This justifies the assumption of a simple allometry between the body components and body protein (Emmans, 1988). The discrepancy for drum and breast meat weight could be due to variation in the potential for lipid deposition between strains, which become more obvious on marginally deficient feeds. It is, therefore, important to consider the lipid deposition potential of different strains in future model development.

In the first simulation exercise, the response of the simulated population was lower that that of a single bird, indicating that the optimal levels of intake will differ between populations depending on the degree of genetic variation in the population. In the sensitivity analysis conducted by Gous and Berhe (2006), in which six genetic parameters were increased or decreased by 0.05, 0.1, 0.15 or 0.2 whilst holding the five remaining genetic parameters constant, it was evident that feathering rate was the only parameter that resulted in a non-linear response in food intake to a feed limiting in lysine. Therefore, the extent of variation in any of the genetic parameters other than feathering rate will not influence the mean response of a population, but where feathering rate is included as a stochastic parameter the resultant mean response will always be lower than that of an individual. This is because birds with a higher feathering rate are unable to lose sufficient heat to the environment to enable them to consume sufficient of a feed limiting in an essential nutrient, whereas the slow feathering birds in the population cannot grow faster than their potential, resulting in a curvilinear response to a limiting nutrient. Interestingly, the optimum lysine content and nutrient density of only the grower feed was significantly different between the population and individual model responses. The inconsistent variation in optimum value of lysine and nutrient density probably reflects the variation in the responses to different populations that were simulated for each optimisation.

Once the advantage of using a population model has been verified, it is important to determine the size of the population to account for the genetic variation between broilers during the optimisation process. Based on the genetic parameters that were varied in the simulation exercise, the size of the population only marginally affected the optimal amino

acid contents and the optimum nutrient density in broiler feeds. Considering the time taken to simulate the optimum levels of amino acids content of broiler feeds and nutrient density for a population of 50, 100, 250, 500 and 750 individuals, and the negligible differences in the results among these population sizes, a population of 50 individuals would be adequate to represent the variation within a strain.

Finally, several models have been developed to optimize the feeds and feeding program of animals but there is no means of assigning estimates to ingredient segregation along conveyer belt-type feeding systems and day-to-day variation of nutrient composition resulting from an inaccurate evaluation of the quality of ingredients used in the manufacture of broiler feeds. The last two simulation exercises conducted in this thesis addressed the above two sources of variation in the broiler production process. The result was that the performance of birds reared at the two extreme sides of the house differed markedly. Furthermore, day-to-day variations in the nutrient content of feed (resulting from, for instance, variation in the protein content of soybean oilcake meal) resulted in significant changes in biological and economic responses. Little attention has been given to quantifying the variation of feed quality along the feeding track and incorporating these effects into a broiler growth simulation model. This area of study should be the next step in future model development.

Implication for industry

The use of tables of nutrient requirements when formulating feeds for different classes of livestock is outdated. It is far more instructive to use some kind of theory to determine the effect of either increasing or decreasing the concentration of nutrients in the feed on growth, food intake, carcass composition or profitability of the enterprise. Models are now available that unify all the major factors (e.g. animal, feed and environment) affecting the production process. However, appropriate descriptions and quantifications of the variables that influence productivity, as well as of the genetic parameters describing the animal being simulated, are crucial for accurate model predictions. Similarly, when optimising the way in which a population of animals should be fed, it is essential to take account of genetic variation in the population, variation in raw material composition and the changes that take place to finished feeds during transportation, as well as the microclimates to which broilers are subjected in a broiler house. All this is possible with simulation models.

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