Introducing stochasticity into a model of food intake and growth of broilers

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Declaration

These studies have not been submitted in any other form to another university and, except where the work of others is acknowledged in the text, are the result of my own investigation.

E. T. Berhe

R. M. Gous

Dedication

This study is dedicated to my parents, Tesfasellassie Berhe and Medhin Teklehymanot.

Thank you!

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GENERAL INTRODUCTION

This study was designed to determine to what extent the response of an individual broiler, to a series of feeds limiting in an amino acid, differed from the mean response of a population of broilers varying in those parameters used to describe the genotype. The results of this comparison would be of considerable value to modellers in determining the direction to follow in future models of growth and food intake of growing animals. Population models would be more time-consuming to run, especially when incorporated into optimisation exercises, so it would be useful to know whether the additional time spent simulating the mean response of a population would result in more accurate estimates of the responses.

The broiler industry is highly competitive, ultimately concerned with maximising margin over feed cost. In this context, maximising economic efficiency is crucial. Since feed is the single largest item of production cost, the determination of the most profitable feeding programme in relation to broiler characteristics becomes the essential component of production efficiency. The difficulties faced by the nutritionist and the broiler producer 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. 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.

Modeling plays an increasingly important part in poultry science and research as a way of organizing 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 the growth models that are becoming more abundant in the industry, which in turn enables the nutritionist or producer to predict the performance of the animals when subjected to any feed or feeding programme. Simulation is useful for demonstrating mathematical

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models without getting too bogged down in the technical details of more formal mathematical methods. The predictions made by most of the available growth models are based on individual animals, and the results obtained are inadequate in optimising the nutrient requirements of a broiler population. Hence, broiler feeding at the level of the individual is not practicable and non-existent in large-scale production, making the need for a population model of broiler growth more critical. However, understanding the response of individual birds forms the basis for the population response, especially during the development of population modeling.

Variation of a performance trait 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.

Ambient temperature, humidity and air quality are known to affect energy expenditure, food intake, growth and physiological responses of broilers during growth. However, the temperature in the immediate environment of the birds (microclimate) is the major determining factor for broiler performance (Aerts et al., 2000). Birds reared near to air inlets perform better relative to those on the opposite side of the broiler house. Minimizing the variation in environmental conditions in a broiler house is as important as optimising body temperature of broilers. On the other hand, much research has been conducted to determine the source of variation in both physical and chemical characteristics of poultry feed ingredients. However, there is a scarcity of research on the effect of nutrient variability on bird performance. Variation associated with inadequate mixing has been shown to affect performance of broilers negatively (McCoy et al., 1994). The variation observed during and after mixing has been given less attention. The subsequent effect is the uneven distribution of ingredients throughout the broiler production period. It is evident that performance depends on the dietary nutrient content ingested by the broilers. Thus, variation in environment and feed causes variation in growth rate and hence nutrient requirement. However, these two sources of variations are not the scope of the project, this paper focus only on genetic variation.

In order to produce a population mean using an individual growth model, it is imperative that some variation is introduced to account for differences in the genotypes available. Random variation can arise in many ways. It could be categorised into internal or external sources of variation, measurement error and artificial sources (Brown and Rothery, 1994). However, there is no consensus in the literature on the method of defining genotypes that will allow for differences between individuals to be described, other than that of Taylor (1980) and Emmans (1989). These authors describe genetic variation in growth in terms of the three genetic parameters that are used to describe growth by means of the Gompertz growth curve, namely, initial weight, mature weight and the rate of maturing.

Another source of variation, at least in modelling terms, is brought about by changes in the potential growth rate of a broiler over time. When simulating the response of a broiler to a given feed, this feed may initially undersupply some of the essential nutrients, but as time passes and the bird grows, so the same feed would become adequate and would eventually over-supply these nutrients. The result is that when the response to a series of feeds limiting in an essential amino acid is simulated, a curvilinear and not a broken stick response is obtained (Gous, 1986). This curvilinear response closely approximates the response obtained in a response trial and may obviate the need to introduce stochasticity into the model. However, it is essential that the curvatures brought about by changes in a single bird over time and by a population of birds at a time are compared.

In order to study the effects of variation in the genetic parameters describing the growth of broilers, modifications had to be made to an existing broiler growth model to enable variation to be introduced in these parameters. Also, methods were investigated that would reduce the number of simulations required to predict the mean population response, thereby reducing computational time. Responses by an individual to a series of feeds limiting in an amino acid were then compared with the mean responses of a population (a) to determine to what extent variation in the parameters influenced the response, (b) whether the responses to changes in the parameters were linear or quadratic, and (c) whether the same mean response could be derived using fewer individuals to describe the population. In addition, to determine to what extent variation existed in production parameters such as growth rate and carcass yield between individuals and sexes, an experiment was conducted using Ross broilers under the same feed and environmental conditions.

CHAPTER ONE

Source of variation to be considered when developing
a model of growth in a population of broilers

1.1   Introduction

The primary objective of animal production is to maximize margin over feed cost. 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 been engaged in the investigation of
these factors, but complex interactions among these factors make it impossible for the
human mind to assess the consequence of alternative management strategies. By
transforming the concept and knowledge of biological response into mathematical
expressions and integrating them within a computer program, using simulation techniques,
profitability and control of the biological response of the production system can be
improved (Gous, 1998).

In science the purpose of a theory is to allow a prediction to be made of the response of a
system, in a given initial state, to a stimulus. In agriculture the systems of interest are
complex and when several theories are combined they are called models (Emmans, 1981a).
Animal simulation models are generally dynamic systems, whose purpose is to imitate the
behaviour of animals to different internal and external stimuli. Several mathematical
functions have been proposed in an attempt to describe food intake and growth. The
contribution of computer simulation models to the analysis of existing and projected
poultry production systems has become more important in recent years due to improved
techniques and the need for integration of experimental results from several disciplines.

The requirements for most nutrients when expressed as dietary contents (or concentrations)
decrease with age during growth due to an increase in food intake but, when expressed as a
daily intake, the requirements for nutrients invariably increase. Emmans (1987b) pointed
out that the conventional approach of direct experimentation to determine the requirements
for each nutrient has two substantial disadvantages. The first is that a huge number of
experiments would be needed because of the interaction between many nutrients, different

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environments and kinds of birds. Secondly, a particular bird is continually changing its state during the course of an experiment and the breeders are continually changing the kind of bird by selective breeding. Use of simulation techniques can overcome the above problems.

Most simulation models of animal growth (broilers or pigs) have been developed at the single animal level. For instance, Pig model (Whittemore and Fawcett, 1976), Edinburgh model (Emmans, 1981b) and EFG Pig Growth Model (Emmans *et al.*, 2002). 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). This 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 response 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.

It is not only the variation between individuals in their response to a given feed or environment that alters the response of a population of birds to a feeding programme in a given environment. Variation also exists in the composition of the feed used and in the environmental conditions to which the birds are subjected. Each of these sources of variation will be addressed in the following review.

The major objective of this investigation is to determine to what extent these different sources of variation will influence the optimum feeds or feeding programmes chosen when considering all input costs and sources of revenue in a given broiler production operation.

1.2   Uses of models

The word model implies some device for the simulation of real animal response: it requires inputs, a means of processing them, and provides outputs (Whittemore, 1981). Currently the transfer of information and ideas is by publications and seminars, which takes a long period of time before the farmer is familiar with the proposed concepts. The model user does not require doing any reading; models can summarize the entire range of current information. Models are appropriate for demonstrating gaps in knowledge and elucidating those matters, which require very detailed information, and those for which approximation is good enough (Ferguson, 1996).

Models help to identify those aspects of the animal that are covered by assumptions and which need experimentation. Moreover, they can be useful to prevent time and money being wasted on further experimentation that will produce information that is already known, and to identify areas of future research (Black, 1995).

Results of experiments allow an individual or producer to make decision by considering the risks associated with biological production system (Gous, 2002). However, there are many factors that have to be integrated before the optimum decision can be implemented. These predispose the use of simulation models to make some economic decisions rapidly and accurately. Bailleul *et al.* (2000) reported that mathematical models could predict or evaluate economic return of the simulated production system. There is no better way to obtain the optimum economic feeding strategy than by the use of simulation models (Gous, 2002).

1.3   Types of models

Model will differ from each other in the problems that they recognise and in the solutions that they give to these problems (Emmans, 1995).

Models can be defined broadly as static or dynamic, deterministic or stochastic and as either empirical or mechanistic. 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 The Reading model used for predicting nutrient responses (Fisher *et al.*, 1973) is one such model. When stochasticity is added to the inputs, it means that a sample of animals with an observed range in input characteristics are simulated individually to result in a predicted outcome for a population of animals. Population mean response refers to the mean of the individual responses within a population whereas the response of the average individual in a population is the response of only one animal.

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. A mechanistic model describes a relationship between a dependent variable 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 disadvantage of using 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 process involved (Zoons *et al.*, 1991).

1.3.1 Different approaches to predicting growth

Emmans (1981b) reported that growth includes two main aspects

1. The efficiency of a particular conversion process and
2. The rate at which this process occurs.

The growth rate of the empty body is the sum of the growth rates of protein, ash, water and lipid (Emmans, 1989). 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.

Growth curves have been constructed for different strains of broilers (Wilson, 1977; Hancock et al., 1995; Gous et al., 1999). The growth curves shown in Figure 1.1 are sigmoidal, and have the following characteristics: an accelerating phase of growth from hatching, a point of inflection in the growth curve at which growth rate is maximum, a phase where growth rate is decelerating (Wilson, 1977; Anguilar et al., 1983).
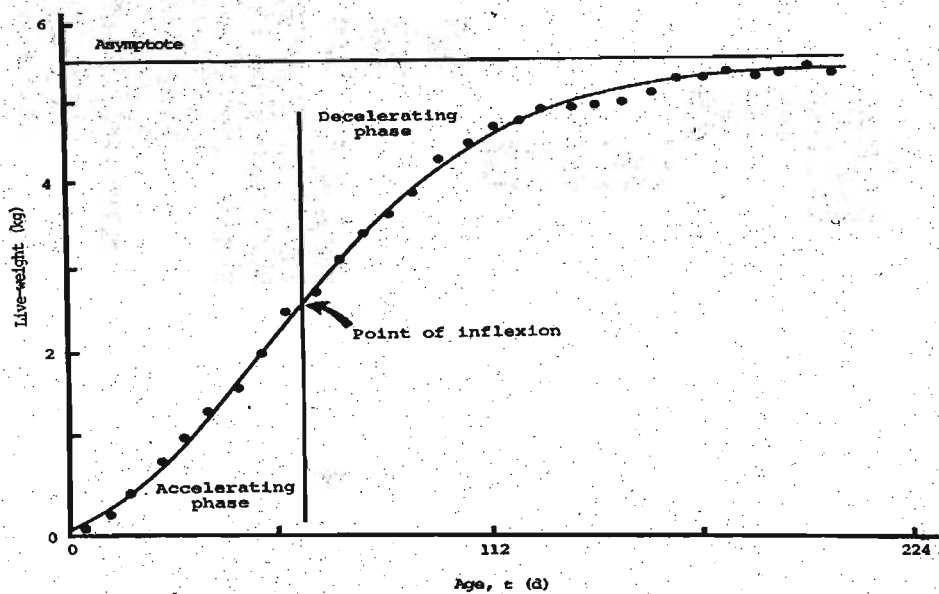
Figure 1.1   *Gompertz function illustrating the properties of a sigmoid growth curve* (Wilson, 1977).

Von Bertalanfy, Gompertz and logistic equations (Table 1.1) under-estimate mature weight (Brown et al., 1976). Richards' equation fits data accurately, but has a variable point of inflection that is very difficult to compute and also the four parameters have little biological meaning (Anguilar et al., 1983).

The Gompertz function was chosen by Emmans (1981b) for his growth model for the following reasons:

- Simplicity;
- It has mathematical properties that simulate a biological response fairly precisely;
- It fits growth data well;
- There are only three parameters, and these all have biological meaning; and
- It describes protein growth fairly accurately.

Table 1.1   *Functions commonly fitted to growth data*

Author	Function	Point of inflection[1]
Robertson:	$W = A / (1 + \exp(-KA(A - W_0) / (KA))$	
Gompertz:	$W = W_0 \exp(L/K)(1 - \exp(-Kt))$	0.368 Wmax
Brody:	$W = W_0 \exp(Ct)$ $(0 \le t \le t')$	
	$W = A(1 - \exp(-K(t - t^*)))$ $(t' \le t)$	
Von Bertalanfy:	$W = A(1 - B\exp(-Kt))^3$	0.296 Wmax
Logistic:	$W = A(1 + \exp(-Kt))^{-M}$	0.5 Wmax
Richards' family[1]	$W = Wmax(1 - Ae^{-kt})^{1/(1-m)}$	

(Adapted from Tzeng and Becker, 1981; Parks, 1982; [1]Brown and Rothery, 1994) Where W = live weight, t = age, W_0 = age at hatching, parameters: A (asymptomatic adult weight), B, C, K, L, M, t^*, t' (age of puberty) (Tzeng and Becker, 1981). The general formulation of the differential equation from these model is: $dw/dt = g(W, t)$.

The Gompertz growth function can be written:

$$Wt = A \exp(-\exp(B(t - t^*))) \quad\quad kg \quad\quad (1)$$

The growth rate, dw/dt kg / day, can be found by differentiation to be

$$dw/dt = B. W. \log_e(A/W) \quad\quad kg/day \quad\quad (2)$$

It is convenient to define a degree of maturity in weight, u_w, as

$u_w = W/A$ so that the equation (2) becomes:

$$dw/dt = B.A. u_w. \log_e(1/u_w) \quad\quad kg/day \quad\quad (3)$$

This formula fits empirical data well (Tzeng and Becker, 1981) and is mathematically rather easy to handle (Zoons *et al.*, 1991). According to Emmans (1989) equation (3) shows that, across genotypes, growth rate at a given degree of maturity is proportional to the product (BA). Growth rate is proportional to the live weight, W, which is proportional to u. There are alternative sets of assumptions that give rise to the Gompertz equation.

A number of broiler models have been developed in an attempt to integrate knowledge on broiler growth and to contribute to a greater understanding of the whole animal as a dynamic biological system. Analytical expressions that have been proposed as models for weight versus time have not been completely satisfactory (Brown *et al.*, 1976; Anguilar, *et al.*, 1983).

Over the last decade a number of broiler models have been made available to broiler producers. A few of these are summarized in Table 1.2. Harlow and Ivey (1994) reported that these models evaluate broiler growth using a wide variety of approaches ranging from the straight-forward (attaching an economic optimizer to a Gompertz growth curve) to more sophisticated ruled-based systems (information about growth is compiled into an "expert" system).

Of the currently available models, each uses a different calibration and is based on theoretical assumptions concerning growth. According to Harlow and Ivey (1994), the Edinburgh growth model (Emmans, 1981b) requires the coefficient for a Gompertz growth curve. The Edinburgh growth model was the first model to utilize projected Gompertz growth curves for broilers and partitions the response to dietary energy and amino acid requirements. These authors suggested that the Chickopt^{TM} model requires live weight data, taken weekly, so that the program can estimate the coefficients for a Gompertz equation. And also the IGM^{TM} program requires a minimum of twenty flocks of production data so that a statistical model can be adjusted to reflect the observed broiler growth. Both programs predict growth in terms of live weight and carcass composition. They reported also, the EFG models (Emmans, 1991) for broiler and turkey growth were built on the theory of the Edinburgh growth model (Emmans, 1981b, 1987a and b, and 1989). Models, like growth equations, should be chosen on their ability to simulate a population.

Table 1.2   *Descriptions of some of the models that have been available for the growth modeling of broilers*

Model Name	Brief Description	Date Available
Edinburgh Broiler	A ruled based compartmental model based upon daily growth partitioned according to growth potential and available nutrients	Early 1980's
Pesti/Brill Model	Quadratic response surface model that determines the least cost finishing ration	Late 1980's
IGM^{TM}	Statistical model based upon a large series of feeding trials, tied to an optimizer	1989
Hurwitz Broiler	Economic model, early predecessor to Chickopt^{TM}	1990
EFG Broiler	Commercial version of the Edinburgh broiler model with unspecified improvements	1991
Walla Model	Enterprise model providing economic modeling for an entire operation	Announced 1993
Chickopt^{TM}	Economic optimizer tied to a Gompertz style compartmental model	Late 1994
EFG Broiler[1]	Growth model, new approach to optimize broiler production	2002
EFG Broiler[2]	Dealing with population rather than individual broilers	2003

(After Harlow and Ivey, 1994; Emmans *et al.*, [1] 2002 and [2] 2003)

1.3.2   Approach used in the EFG Broiler Growth Model

The EFG Broiler Growth Model (Emmans *et al.*, 2002), described in this paper, can be defined as a dynamic, deterministic and mechanistic broiler growth model. The model is dynamic in that it represents the state of the system continually predicted over time; deterministic as it predicts the outcome for one animal which is assumed to represent the mean of a group of similar animals; mechanistic, as growth is represented based on its underlying principles.

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The broiler model contains all the important features that should be included in growth models that predict with reasonable accuracy the performance of broiler under defined conditions. Accurate input data are required for an accurate simulation. For the EFG Broiler Growth Model (Emmans *et al.*, 2002) the following data are required:

Broiler	**Feeds and feeding schedule**
Growth Parameters (male)	Nutrient composition of each feed
Derived Parameters (male & female)	Feeding schedule (by time or amount)
Stocking schedule	**Management**
Economics	Mortality regime
Fixed costs	Husbandry regime
Variable costs	**Cropping schedules**
Down time	Cropping by time or weight
Revenues	**Environment**
Live and dressed	Temperature
	Humidity

The model simulates the growth of a single bird taking account of genetic parameters, diet composition and feeding programme, the environment, stocking density and other factors which may affect the outcome of production decisions in practice. Growth, food intake, body composition and yield, and a variety of production indices are calculated in each simulation. The model also carries out basic economic calculations to guide commercial decisions.

1.3.3   Estimation of allometric functions between growth components

Animal growth is the sum of the growths of the component parts of the carcass, whether they are meat, bone or skin (Wilson, 1977). The empty body of an animal can usefully be seen as being composed, in chemical terms, of the lipid-free dry matter (protein, ash and a little carbohydrate), water and lipid (Emmans, 1988 and 1989). According to Emmans (1988) growth is defined as an increase in size, which raises the problems of scale of size and the rate at which it can proceed. Diagrammatic representation of body composition is shown in Figure 1.2.

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Live weight------- gut fill

------- empty body weight-------feathers-------water

---------dry matter------protein

-------ash

-------lipid

-------remainder------lipid

------lipid-free------water

-----protein

-----ash
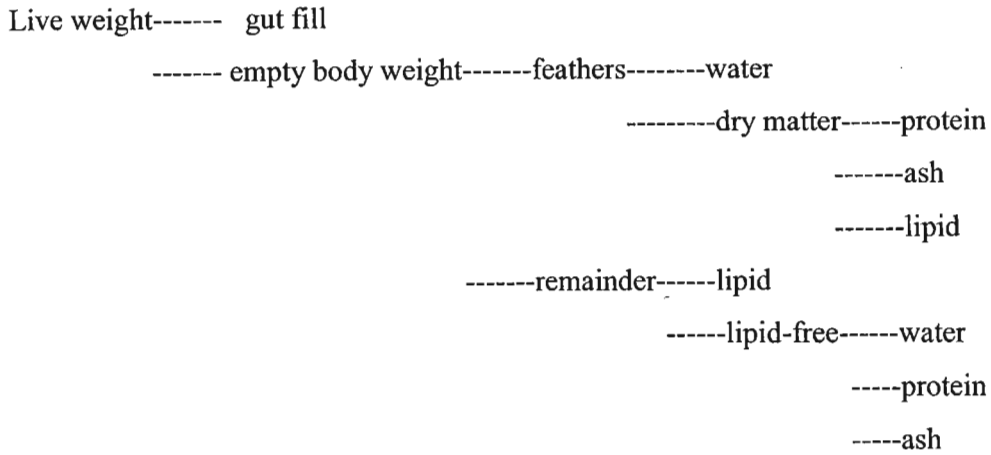
Figure 1.2 *Body composition* (Emmans, 1995).

The lipid-free dry matter can be considered as a homogenous component as its composition, mainly protein with most of the remainder as ash, does not vary between genotypes or with degree of maturity, thus it can be calculated from protein weight (Emmans, 1981b, 1988). But the lipid content of the growing chicken (Emmans, 1981b) and pig (Ferguson *et al.*, 1994) can be affected by the composition of the diet Furthermore, the water content of the lipid-free empty body weight decreases systematically during development and the lipid content of the empty body increases systematically during development (Emmans, 1981b; Hruby *et al.*, 1994).

The relationship among the different growth components was derived by Emmans (1988) by considering a system of size S, its maximum rate of growth, dS/dt and its maximum relative, or specific, growth rate, (dS/dt)/S or dlnS/dt. The assumption is that (dS/dt)/S declines linearly with lnS so that:

$$(dS/dt)/S = a - B . lnS. \qquad \text{Units/ unit day} \qquad (4)$$

At some value of S, say Sm, dS/dt = 0 so that (dS/dt)/ Sm = 0 and hence

$$a = B. ln Sm \qquad (5)$$

Substituting for a in (4) gives

$$(dS/dt)/S = B. ln (Sm/S) \qquad \text{Units/ unit day} \qquad (6)$$

Where S is the liveweight.

Equation (6) that relates growth rate to size, can be rearranged to give:

$$(dS/dt)/S = B. S. ln(Sm/S) \qquad \text{units/ day} \qquad (7)$$

This equation can be integrated to give a growth function:

$$S = Sm \exp (- \exp (- B (t - t^*))) \qquad \text{units} \qquad (8)$$

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Which is a form of the Gompertz growth equation,

Letting the degree of maturity in size be u = S/Sm, the equation becomes:

$$U = \exp(-\exp(-B(t - t^*)))\qquad(9)$$

It is presumed that an animal inherits a value of B which applies to all three of the chemical components. Emmans, 1988 stated that the degree of maturity in one chemical component- water or lipid is a simple power of the degree of maturity in another – the lipid free dry matter.

Generally if one component is a Gompertz growth curve and the weights of another component are a simple power function of its weights, then the growth curve of the second component is also a Gompertz function (Emmans, 1995).

The rate of maturing, B, is an inherited character and is therefore, specific to each animal. In order to generate a population of individuals, each bird must be allocated a value of B, which is assumed to be normally distributed in the population. This is considered further in the next section.

1.4   Introducing stochasticity into a growth model

Like other technical terms, "stochasticity" is used in the modeling literature in several senses. According to Knap (1995) stochastic simulation can be defined as producing simulation outputs that reflect not only the expected population means of the traits of interest but also their expected dispersion, as a result of deliberately introducing variation in a number of basic parameters of the simulation model. Knap (1995) outlined the reasons to consider 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

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- 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. Variation of performance traits in animals may be the result of variation in a number of factors that influence the trait. Variation should be introduced as deep in the model as possible, when basic model variables that depend on them will automatically display covariance (Knap, 1995). He explained that, depending on how realistic a reflection of the true states of nature the model is, and on how realistic the imposed variation is, this should lead to the simulation of a broiler population in terms of means and variances of the traits of interest.

A distinction is made between genetic and environmental variation. Genetic traits that could be considered as stochastic: mature protein weight (P_m), rate of maturing (B), lipid to protein ratio at maturity (LPR_m), initial body weight (W_0), maximum lipid in gain (MLG), feathering rate, (Fr) (Emmans, 1988; Emmans, 1995; Knap, 1995). Environmental traits that vary in a broiler house include: broiler house temperature and relative humidity, access to feed and feed composition (Gous, personal communication).

1.4.1 Variation between individuals in a population

Variation exists between individuals of the same sex within a flock. Each bird will have its own characteristic values of the inherited parameters that describe its potential. Systematic errors will occur if the average individual in a population is used as the basis for generating individuals from which a population response is to be simulated, although these may be small in some cases (Emmans and Fisher, 1986; Emmans, 1989). This is due mainly to variation in the bird characteristics, including variations in feedstuff utilization and in net efficiencies of nutrient utilization (Emmans, 1995) and most of the methods used to generate a population have a similar pattern of mean and standard deviation (SD) between individuals. Furthermore, the extent of the errors introduced by translating requirements from the average animal to the population will depend either on the genotype or the variations in genetic parameters within a population, and the extent of the correlation between the various parameters (Ferguson *et al.*, 1997). Emmans and Fisher (1986)

stressed the two stages which require more attention when predicting a population response:

a) Theories of individuals; and

b) Theories of population structures.

In the final stages in the development of a population model both sets of these theories are used in combination. According to this suggestion, the problem of using the individual approach is that the relationship between inputs and outputs for flocks are curves whereas the reasonable assumption of constant efficiencies for nutrient utilization does not lead to curves (Fisher et $al.$, 1973). 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 which comprise the population (Figure 1.3).

Almost all available growth models have been in terms of an individual animal with defined genetic characteristics (Emmans, 1981a). This author explained that for growth the value of the parameters u_o, B and P_m are seen as applying to an individual bird. For a population they are described by correlated distributions (Table 1.3), for example $B^* = B$ $P_m^{0.27}$ and is approximately constant. The variation in B and P_m may be appreciable within a population with suggested coefficient of variation of 80%. Taylor (1967), cited by Emmans and Fisher (1986), found B and $P_m^{-0.27}$ are likely to be correlated in such a way that the coefficient of variation of B^* may be much lower at about 2%.
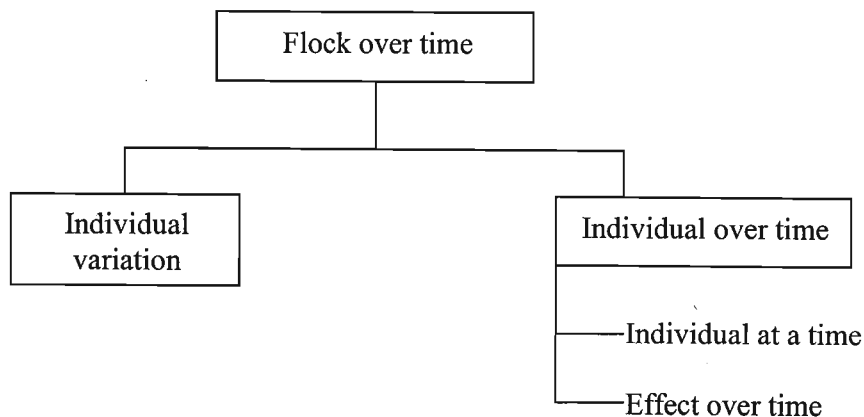
Figure 1.3   *Analysis of the problem of predicting the performance of a flock.*

The requirement of an individual bird varies with time and is described by assigning values to the inherited parameters (Emmans 1989). There are significant differences between sexes, with the implication that different requirements need to be calculated for males and females (Emmans, 1989). Research conducted by Gous et al. (1992) reported differences in mature body weight and live weight values between various commercial broiler strains and sexes. They suggested that the females had lower live weight and mature live weights than the males and carcass composition different strain-crosses and sexes is distinctly different. In addition, according to the EFG Broiler Growth Model (Emmans et al., 2002) the P_m in males is about 1.5 times that in females and the LPR_m is twice as large in females than in males.

Table 1.3 *Genetic variables, mature protein weight (P_m), rate of maturing (B), lipid to protein ratio at maturity (LPR_m), that could be used as stochastic parameters*

Genetic scaling		
Mature size	P_m. kg	
Growth parameter	B. d^{-1}	$B^* = B\,P_m^{0.27}$
Mature fatness	LPR_m. g/g	-
Coefficient of variation		P_m: 0.05
Within a strain/sex		B^*: 0.02
Population		LPR_m: 0.04

B^* = Scaled parameter

(Adapted from Emmans and Oldham, 1988)

1.4.2   Animal characteristics

The usefulness and accuracy of any theory describing animal growth and development depends on how well the animal is defined (Ferguson et al., 1994). Certain genetic characteristics of the animal need to be quantified in order to know how the animal grows.

Body protein content is used to define the current state or condition of the animal, which is then used to quantify the remaining body constituents and their respective growth rates

(Taylor, 1980). Body protein is the driving variable in the model (Emmans, 1981b). Ferguson and Gous (1993), Emmans (1995) found the Gompertz growth function to be a suitable expression for predicting protein growth.

The genetic characteristics of lipid growth are easily and readily confounded by the environment and nutrition. Feeding a balanced, ideal protein: energy ration in a thermally neutral environment will result in minimum fat deposition (Emmans, 1981b). One of the main problems with modeling growth in an immature animal is that of determining potential lipid growth (Ferguson and Gous, 1993)

Emmans (1989) stressed some difficulties in describing feather growth primarily because shed feathers are not present at slaughter and genotypes of birds may differ in feather growth. Feather weight is not a simple power function of body protein of the growing bird (Fisher, 1987). This author initially suggested that a three-phase model, a graph used to describe feather growth, should be used for broilers. However, Emmans (1989) suggested that the mature feather protein weight would likely to be related to the mature body protein weight raised to the 2/3 powers. If two parts have the same value for the rate parameter B then an allometric relationship is expected (Emmans, 1988). However, the case of mature feathering is different. Some description of mature feathering is needed, in addition to the value of the rate parameter for feathers (Gous et al., 1999). According to Emmans (1989) a rate of loss of feather can be assumed to be proportional to feather weight, at 0.01/day.

1.4.2.1 Predicting nutrient requirements

A well-founded and accurate theory of growth, body composition, food intake would allow requirements to be predicted (Gous et al., 1999). Emmans and Fisher (1986) and Emmans and Oldham (1988) reported a key element in any theoretical method for predicting requirements is the prediction of potential performance.

The values of the genetic variables, Table 1.3, for a given kind of animal and the values of the nutritional constants can be used to determine the requirements of different kind of birds (Figure 1.4).

```
       Bird state                Genotype
           |_____|
                      |
                      ▼
                Maintenance
                Protein gain    - body
                                - feather
             Lipid gain
                  |
                  |◄──────────── Nutritional
                  |              constants
                  |
                  ▼
             Requirements    - energy
                             - amino acids
```
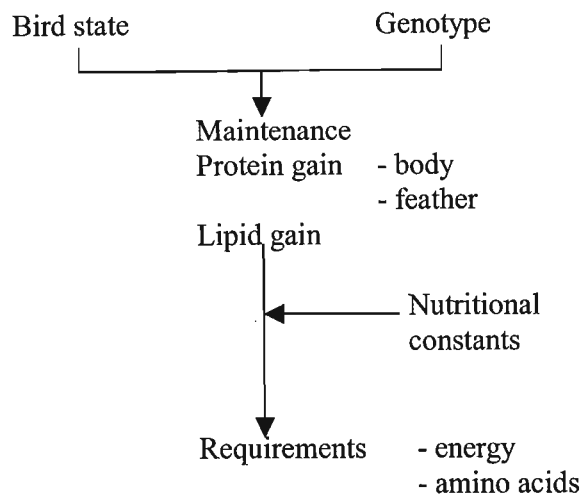
Figure 1.4   *Scheme for predicting requirements* (After Emmans, 1987b).

Emmans and Fisher (1986) suggested that a better approach to the problem of describing requirements and of expressing them quantitatively can be achieved by considering: firstly, the bird's characteristics, secondly by defining resource scales carefully and thirdly by considering the quantities of each resource needed per unit of function. This approach has a greater chance of success than attempting to measure requirements by direct experimentation.

The resources needed to meet the nutrient requirements of animals can be determined from knowledge of the growth rate and composition of the various components of the body (Gous, 1998).

1.5   Variation in Genotype

Each bird may be described in terms of the parameters of the Gompertz growth curve, the rate of feathering and the mature lipid: protein ratio in the empty body (Emmans, 1987b). Their short generation intervals, of about one year, and varied selection programs have created a large number of distinct breeds, strains and lines. Different selection criteria are used by the major breeding companies, leading to widely different genotypes being available to the broiler industry (Gous, 1998).

Emmans (1987b) outlined the two possible ways in which birds in a population or between populations may vary. The first is what they are like when mature, how big is the bird at

maturity and its composition at maturity. The second is the path of development that they take to get there. The genetic parameters that describe a genotype of species are shown in Table 1.3.

According to Gous (1998) genetic parameters values can be measured by rearing animals in environmental conditions that are as near to ideal as possible. Under these conditions, the difference among broilers genotypes can be distinguished by using growth curves (Wilson, 1977; Gous, 1998). The approach was used by Hancock et al. (1995) and Gous et al. (1999) who obtained growth curves that differentiate between breeds and strains.

1.5.1 Predicting variation in growth parameters

Emmans and Fisher (1986) and Emmans (1988) suggested for broilers general coefficients of variation (CV) for B^* of $0.02 - 0.04$ and $0.06 - 0.10$ for P_m. It would be impractical to determine experimentally the CV and correlations between B^*, P_m and LPR_m as large numbers of widely different populations of birds would have to be used and these would be required to be grown under similar conditions (Ferguson, 1996). He explained that the population means, standard deviations and correlation coefficients would be estimated from samples of different populations (Table 1.4).

Table 1.4 *Estimates of the variation in the growth parameters between individual male turkeys*

Stock	n	Mature wt. (Wm, kg)[a]		Rate parameter (B/day)[b]		Scaled rate parameter (B*)	
		Mean	CV%	Mean	CV%	Mean	CV%
8	6	17.7	7.5	0.0233	2.66	0.0507	3.27
9	8	16.3	9.4	0.0229	4.07	0.0486	3.18
Mean			8.5				3.2

(Okunuga, 1980, cited by Emmans, 1989).

[a]Estimated from weights $34 - 37$ weeks and $44 - 50$ weeks for stocks 8 & 9 respectively.

[b]From weekly weights, 1 to 6 weeks, using individual estimates of P_m.

Such variation in P_m and B^*, combined with variation in the degree of maturity at hatching and possibly, in LPR_m will lead to a population of lines (Emmans, 1989).

1.5.2 Genetic correlation and heritability between the growth parameters

Emmans (1988) reported that there is no relationship between P_m and LPR_m but varying LPR_m will have the effect of changing the slope (b). Taylor's (1980) scaling rule suggested that the so-called parameter $B^* = B\ P_m^{0.27}$, would be uncorrelated with P_m across genotypes. In chickens, 50 years ago B^*, was 0.024 and increased by appropriate selection to 0.040 (Emmans, 1988).

Genetic correlations between sexes differed significantly for parameters, maturation rate and body weight at inflection (Mignon-Grasteau et al., 1999). Simulation outputs assist in the calculation of correlation between growth parameters. The degree of importance attached to a particular value of correlation will depend on the magnitude of the total variation and on the heritability of the trait (Hocking et al., 1985).

The relationship between protein and lipid and lipid-to-protein ratio at maturity are heritable characteristics specific to the genotype of the bird (Hancock et al., 1995; Mignon-Grasteau et al., 1999). Mignon-Grasteau et al. (1999) mentioned that direct heritabilities of the growth curve parameters were moderate to high, ranging from 0.31 to 0.54; initial (W_0) and mature weight (Wm) in males exhibited significant maternal heritabilities. This implies that there is less variation between individuals but that this can be influenced by selection of broilers for characteristics that are related.

1.6   Variation in the environment

The internal environment of poultry building is a complex dynamic system influenced by many contributory factors (Al Homidan et al., 1997 and 1998). Many poultry flocks are kept in houses in which variation exists in the important variables, particularly temperature, humidity and air quality. Within recent years rapid advances in poultry nutrition and genetics have made more evident the need for increased knowledge of the effect of environmental factors on poultry performance. Controlling the physical microenvironment in an animal production house is an important element in optimizing the production process (Reece and Lott, 1982; Mitchell, 1985; Parmar et al., 1992; Aerts et al., 2000).

Abshoff (1988), cited by Van Beek and Beeking (1995), reported that temperature, humidity and, sometimes, the concentration of carbon dioxide (CO_2) or ammonia are generally monitored to regulate the climate in broiler house.

1.6.1 Variation in temperature and humidity

The vertical temperature profile in a broiler house is affected by many factors, including heat generated by heaters, the flock and radiation; microbial fermentation in the litter, heat fluxes between poultry house air and the soil, walls and roofs and due to temperature gradients; moisture loss from the litter and natural convection around broilers (Van Beek and Beeking, 1995; Boshouwers et al., 1996; Figure 1.5).
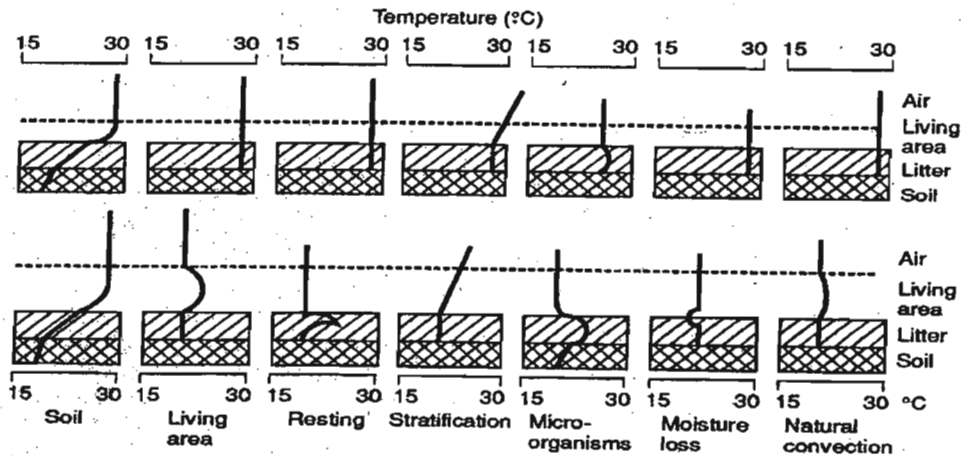
Figure 1.5   *Temperature distribution in broiler house: effect of separate factors on the vertical profile of temperature for 1-week old (top) and 6-week old (bottom) broilers* (Van Beek and Beeking, 1995).

They suggested that thermo-sensors, connected to climate computers, could control poultry house temperature by regulating heaters and ventilation devices but the heights of the sensors above the floor are often not well defined. That is, control of temperature in the vertical plane is often rather poor. According to Boshouwers et al. (1996), the temperature in the micro-climate around the chicks was found to be almost 2°C lower than temperature of air for day old chicks and did not decline at the rate recommended by the breeders. He reported also during the finishing period the temperature among the birds was much higher (about 4°C) than recommended. Influential factors for young broilers are ground temperature and stratification and for older broilers, floor construction and ground water

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table, heat production of broilers and litter, the behaviour of the broilers and air circulation in the house (Van Beek and Beeking, 1995).

Fans and complicated modern ventilation systems make it virtually impossible to predict airflows (Van Beek and Beeking, 1995). This implies that it is also difficult to predict the vertical profile. Van Beek and Beeking (1995) developed an equation to predict the vertical temperature gradient in a house, based on heat flows through walls. They reported that an air temperature gradient of about 0.5 K/m can often be measured in a broiler house.

Small differences in environmental temperature and humidity had significant effects on bird performance at the end of the production cycle (Al Homidan et al., 1997). Weaver and Meijerhof (1991) suggested that the differences in body weight between the levels of humidity were not directly related to moisture difference in the atmosphere but to differences in litter conditions and ammonia levels, which were influenced by the differences in relative humidity.

1.6.2 Air quality

Poor air quality is due to environmental contaminants such as carbon monoxide (CO), carbon dioxide (CO_2), ammonia (NH_3), and dust. Poor air quality reduces performance and increases the potential for respiratory disease.

Ammonia is a highly irritating, colorless gas, produced during the decomposition of faecal matter and, at concentrations of up to 50 ppm and beyond during the first 28-days of growth, adversely affects weight gain, food conversion, body weight and mortality rates (Reece et al., 1980; Weaver and Meijerhof, 1991) but its concentration can be influenced by litter management and ventilation rates (Al Homidan et al., 1997).

1.7 Variation in nutrient contents of ingredients

Each feed ingredient has its own unique set of attributes which affect its nutrient quality (Dale, 1996). Sources of variation in the physical and chemical characteristics of grains used in poultry diets include variety, seasonal effects, growth sites (Metayer et al., 1993) crop treatment and grain fumigants, post-harvest storage conditions and period of storage and different processing (Dale, 1996; Hughes and Choct, 1999), rainfall and environmental

temperature patterns during the period of grain maturation, genetic effects, level of fertilizers (Metayer *et al.*, 1993; Hughes and Choct, 1999) and inclusion rate, bird age and food formulation technique (Senkoylu and Dale, 1999; Table 1.5).

Table 1.5   *Summary of tests with sunflower meal in broiler diets*

Source[*]	% CP	% CF	% EE	% Inclusion	Results
Waldroup *et al.* (1970)	44	NA	NA	0-30	15-20% can be used successfully in mash, 30% in pellet
Afifi (1972)	32.4	23.4	1.5	6-18	Depressed growth at 18%, fibre was 7% at this level and energy was lower, lysine supplementation improved growth
Rad and Keshavarz (1976)	40	11.7	NA	9-37	Comparable with SBM, suggested level 17.5%
Zatari and Sell (1990)	32.6	18.4	NA	10-20	Fat supplementation improved gain and feed efficiency, suggested level 20%
Musharaf (1991)	31.2	20.6	NA	5-25	Better than SBM in gain but poorer in feed efficiency
Nir (1998)	38	NA	NA	0-30	30% SFM was efficient as 23-28% SBM in gain and feed efficiency

Soya bean meal (SBM), crude protein (CP), crude fibre (CF), ether extract (EE), not available (NA)
*sources were cited by Senkoylu and Dale, 1999.
NA = Not available

Grains not only provide the bulk of essential nutrients for commercial poultry production, but are also considered as the main source of anti-nutritive components (Hughes and Choct, 1999). Variation in the available energy and protein content of grains, legumes and oil seeds can be attributed to a wide range of anti-nutritive factors such as non-starch polysaccharides, enzyme activity (Choct *et al.*, 1999; Hughes and Choct, 1999), protease inhibitors, lectins and tannins (Gatel, 1993). The relative importance of such factors will also differ according to the type of feed (Hughes and Choct, 1999). Some ingredients vary considerably due to the above-mentioned source of variation while others do not (Table 1.6).

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Table 1.6   *Variation in nutritive value of grains due to seasons*

Ingredient	Energy (MJ/kg DM)	Protein (% DM)
Barley	10.4 – 12.2 [a]	10 – 14 (n=6)
Sorghum	16.1 ± 0.1 (n=10)	13.9 – 16.4 (n=3)
Maize	15.6 ± 0.1 (n=40)	8.8 – 12.2
Wheat	10.35 – 15.9 [a]	11.7 – 15.3 (n=7) [a]
	14.5 ± 0.2 (n=70)	NA
Oats	10.5 – 11.4 (n=40)	NA

[a]Ingredients that were inconsistent throughout the seasons, n = is number of samples.
NA = not available
Complied from several sources (Connor *et al.*, 1976; Mollah *et al.*, 1983; Metayer *et al.*, 1993; Kocher *et al.*, 1997).

1.7.1   Effect of processing on nutrient value of feeds

Foods for broilers are normally processed to reduce transmission of infection, to degrade or inactivate anti-nutritive factors (McCracken *et al.*, 1997) and to gelatinize starch to improve its digestibility (Moran, 1982). On the other hand, heat and moisture treatment can result in the formation of resistant starch and solubility of non-starch polysaccharides (Vranjes *et al.*, 1994) which has an adverse effect on animal nutrition. Over-processing of feed grains lead to a reduction in both the amount of amino acid present, particularly lysine, and its digestibility (Parsons *et al.*, 1992; Dale, 1996)

Almost all feeds used in poultry production, particularly oil seeds, are subjected to manufacturing processes and such processes can increase the amount of variation already inherent in the raw product (Dale, 1996). For instance, considerable variation has been found in ME of sunflower meals and this variation has been attributed primarily to the nature of the cultivar and method of processing (Senkoylu and Dale, 1999).

Mixing is one of the most essential and critical operations in the process of feed manufacturing, yet it is frequently given little consideration. The daily supply of nutrients that an animal receives from a feed varies from time to time due to various reasons. These sources of variation will probably cause variation in the day-to-day level of nutrition

received by an individual animal. Insufficient mixing time and filling the mixer beyond rate capacity are often implicated as common sources of variation in finished feed. Duncan (1988) reported that a 10% variation in the feed quality significantly reduced both weight gain and increase feed conversion. McCoy et al. (1994) found an improvement in FCR as mixer revolutions were increased although no differences occurred in average daily gain, average daily food intake, carcass crude protein content and carcass fat.

1.8   Discussion

Growth models have been designed to simulate the growth of individual animals over time. The description of the genotype has not taken into account the variability that can be expected in a population of birds. However, the population response to feed and environment is the ultimate goal in any simulation model. Therefore, variation between individuals should be considered during the development of population growth model. To obtain estimates of the population structure, it is important to determine the distribution parameter values that might be expected to vary between individuals and it is also important to know if any correlations exist between these parameters (Emmans and Fisher, 1986). Then it would theoretically be possible to simulate a population response to defined inputs.

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. There are numerous techniques that serve to generate random, normal variants with a computer's random number generator. Different researchers most commonly use the following: systematic sampling, random sampling, Monte Carlo technique and Box-Muller algorithm. Among these, the Box-Muller algorithm is efficient for producing normal distributions. The process generates two independent normally distributed random numbers, drawn from the standard normal distribution with a mean of zero and a standard deviation of one. In systematic sampling, the observations are made according to some predetermined pattern, usually involving a regular spacing of units or within some other ordering of the units in population. However, in some situations systematic sampling produces a more precise estimate of the population

mean than random sampling. A disadvantage is that the sampling variance of the sample mean from a single systematic sample cannot be estimated unbiasedly without making some assumptions about the nature of the variability in the population. Once the genotype is described and the outputs predicted, comparisons could be made between breeds and strains using growth curves and simulation modelling (Gous, 1998). Of particular importance when comparing growth curves is whether the equation chosen leads itself to stochasticity (Gous, personal communication). That is, whether the equation may be used to describe a population of individuals whose performance can then be predicted by means of the growth model.

Most models use only three parameters (B, P_m and LPR_m) to account for the difference between genotypes, and variation around the mean of each of these three parameters may be used to describe all the individuals within a population. There is no consensus in the literature on the methods of defining genotypes that would allow similarities and differences between animals to be compared, other than that proposed by Emmans (1988). There is also a possibility of differentiating between genotypes using feathering rate, Fr and maximum lipid in gain, MLG because these alter the response to different dietary concentration of the nutrient contents in the EFG Broiler Growth Model (Emmans *et al.*, 2002). This implies that further investigation is required to determine whether some or all of these parameters need to be made stochastic in order to simulate the kind of variation observed between individuals in a population, or whether it is also necessary to consider variation in feed quality and environmental conditions.

Feed ingredients vary considerably in their nutrient content not only across ingredients but also within a single feed ingredient. The extent of variation in those feeds used extensively in poultry nutrition is not quantified. Moreover, there is variation within feeds offered to the same flock due to improper mixing or processing. Maximum and sustained margin over feed cost can only be achieved when a population of broilers is fed a uniform feed to meet their nutritional requirements. Although different feed formulation programmes are available to meet the interest of the producers, the results of experiments differ frequently due to variation within a single feed and the above possible factors. This makes it difficult for the producers to make decision based on experimental results.

The amount of variation in growth rate in broilers is already known (just weighing broilers individually at the end of 35d will give this information) and some producers already manage this variation. For instance, by separating the sexes and rearing them in different broiler houses, the nutritionist is able to apply a feeding programme that suits each sex more accurately, thereby improving the efficiency of utilisation of nutrients supplied to the birds. However, within a single-sex population there is still some variation and knowing how to manage this variation is more difficult, as one cannot easily divide the flock any further. Hence, it is necessary to know what the optimum economic feeds and feeding programme would be for a group of birds varying in potential growth rate. Whether the sexes are separated or not; the question still arises of what the optimum economic method of feeding would be. This can only be accomplished with the use of simulation models because of the number of interacting factors contributing to the input costs and financial returns.

It is difficult to assume the mean temperature of the broiler house is the same as the living zone temperature. The vertical temperature profile in a broiler house is the result of several contributing factors (Figure 1.5). Most of the factors are correlated and it seems difficult to determine the specific effect of these parameters using experimentation and even in simulation techniques. In addition, there is always some variation in temperature and air quality through the course of a day or night, week, etc., and from one end of the house to another. These can significantly affect the performance of broilers. The possible reasons for uneven temperature are linked to unadjusted inlet box openings such as unsealed cracks, dirty fan shutters, unflapped curtains; the amount of time the fans run and total length of the timer cycle; the position of thermo-sensors and the effect of birds' body heat if birds crowd into one area instead of spreading out evenly throughout the house. Maintaining temperature consistency and uniformity throughout the house is equally as important as targeting a precise optimum temperature.

This review indicates that more research is needed in the development of population growth model. This project is concerned firstly with gathering the information that is required for accurately describing the variation that exists among genotypes within a population, and secondly, with using the EFG Broiler Growth Model (Emmans *et al.*, 2002 and 2003) simulating the consequences of different degrees of such variation, with a view to optimising the feeding of broiler at the population level.

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CHAPTER TWO

Comparison between the average individual and the mean of the population, together with sensitivity of the genetic parameters, in broilers between 8 and 21d of age.

2.1   Introduction

Considerable attention has been given to the assessment of 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 limitations of the traditional empirical approach to estimating nutrient requirements, such as those given by NRC (1994), have been shown to be severely limiting in that they consider 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 great effort to integrate this knowledge into a unified theory.

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. However, in order to predict nutrient requirements of a population over time, it is important to understand first how an individual animal within the population will respond, at a time, to increasing dietary concentrations of the nutrient (Emmans and Fisher, 1986). For example, 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.

In terms of feed evaluation and growth response experiments, it is useful to distinguish the difference between the response of the average animal and that of the population. The average animal is defined as that individual which has the average characteristics of the population and the response of the average individual is therefore of a single animal. The population response is the mean of all the individuals within the population.

The EFG Broiler Growth Model (Emmans *et al.*, 2002) is one of the recent growth models that predict changes in body composition over time, feed consumption, economic information of and nutrient requirements. Since this model simulates the response of an individual, it is not entirely satisfactory when optimising the feeding of a population of broilers. It is possible to modify this growth model to be able to simulate a number of individuals simultaneously, but many questions are raised in the process of simulating a population.

These include the following:

- Some variation must be introduced to account for differences in genotype, so it is necessary to determine to what extent the parameters chosen should be varied, and whether (and if so, to what extent) the parameters are correlated.
- Because of the time taken to simulate the performance of each individual some methodology should be introduced to reduce the number of simulations necessary to produce a population mean.

One of the steps in model development is the determination of the parameters most influential in producing the model results. Sensitivity analysis is a general technique from the field of decision theory for studying the effects of uncertainties in the parameters of a model on the outputs (Morris, 1991; Hamby, 1998). To carry out a proper sensitivity analysis is quite a task for complex models, as we must adjust the parameters singly, two at a time, three at a time, etc., as it might be that the parameter only becomes critical at a restricted set of values of the other parameters (Brown and Rothery, 1994; Hamby, 1998). The simplest approach to conceptualise is the one factor at-a-time method where sensitivity measures are determined by varying each parameter independently while all others are held constant (Morris, 1991). The main advantages of this method are: its economy in running time, isolate the most important factors from amongst a large number that may affect a particular response. It provides high level of information about the relative importance of the input factors, the nature of their effects on the output for guiding future research (Morris, 1991; Hamby, 1998).

The present study was designed to obtain possible solutions to the above questions. Thus, the objective of this research was to simulate a number of individuals over time to obtain mean, standard deviation and to determine sensitivity of the parameters.

2.2   Materials and methods

2.2.1   Description of genetic parameters used

The EFG Broiler Growth Model (Emmans *et al.*, 2002) requires the genotype description to be input in terms of growth parameters such as mature empty body weight, mature fat content, rate of maturing, rate of feathering and whether the genotype is feather sexable. Using these values for the male, the model derives the following parameters for each of the sexes: mature protein (P_m), mature lipid to protein ratio (LPR_m), mature fat, water, ash and feathers, rate of maturing for body and feathers and fat allometry (b), is the slope of the allometric relationship between body lipid and protein. For the purpose of this simulation exercise, six variables were used as a description of the genotype of individual broilers (Table 2.1).

Currently available growth models use mature protein weight (P_m), lipid: protein ratio at maturity (LPR_m) and the rate of maturing (B), to describe the animal. The Gompertz growth function used in the model requires these three parameters to describe the growth of body protein and lipid. Initial body weight (W_0), needs to be described in the Gompertz function since W_0 is in the equation used to describe the growth potential of a bird. The rate of growth of feather is described by a Gompertz equation, with the values of mature feather protein ($P_{m\ FP}$) and the rate of feather growth (B_{FP}) being derived from mature body protein ($P_{m\ BP}$) and rate of body protein growth (B_{BP}). In the EFG Broiler Growth Model (Emmans *et al.*, 2002) the rate of feather growth (B_{FP}) is determined by multiplying the B_{BP} by a factor, and this factor (F) is varied depending on whether the bird is slow or fast feathering, and it varies between males and females depending on whether the breed is a normal or fast-feathering strain. The maximum amount of lipid in gain per day (MLG) is another important parameter which describes the rate at which the bird can over-consume and deposit excess energy as body lipid. This factor has been introduced to describe the maximum amount of lipid the bird can deposit on any one day, as a proportion of the total amount of protein that can be gained.

2.2.1.1 Mature protein weight, P_m

The mature protein weight, P_m, is a chemical measure of size, and refers to the protein weight of the body when the animal reaches its final equilibrium state. Different broilers

may have the same size at maturity but they clearly differ in their form. According to Emmans (1987b) the genotype of the animal can be described in two components: the chemical state at maturity and the path that it takes over time to this mature state. The mature state is well described in terms of P_m, the mature lipid weight, Lm, mature ash weight, Am and mature water weight, Wam. Since ash and water have an essentially constant relationship with body protein, the important variables describing the mature state are P_m and Lm. Once P_m is estimated, it is possible to calculate Lm, Am and Wam by allometry. Thus the first step in describing a genotype is to determine the potential rate of body protein gain.

2.2.1.2 Initial body weight, W_0

The initial weight, W_0, is the weight of the day old broiler. This variable affects the growth rate and final weight of chicken. That is, a given kind of bird will be capable of growing at different rates depending on its initial weight. In this simulation, the same W_0 was used for both sexes.

2.2.1.3 Lipid to protein ratio at maturity, LPR_m

Birds differ in their degree of fatness at maturity, and this may be specified as the ratio of lipid weight to protein weight at maturity, LPR_m. For a given genotype, once the LPR_m has been defined then the genetically- determined degree of fatness at any given body protein weight may be calculated by allometry. However, unlike water and ash, the weight of lipid in the carcass does not remain allometrically related to the protein weight under all conditions. When protein accretion is at a genetic maximum, additional dietary energy supplied beyond the requirement to support such accretion will result in increased lipid deposition. Conversely, energy intake below requirement will result in lipid catabolism and a consequent reduction in lipid content. Nevertheless, the LPR_m has been employed to separate genotypes (e.g. Hancock *et al.*, 1995), which would, accordingly, require different energy and nutrient regimes in order to grow optimally.

2.2.1.4 Rate of maturing, B

The growth rate of all the components of the body is expressed as a rate of maturing, B (Emmans, 1987b). This genetic variable allows the prediction of the rates at which an animal is seeking to gain protein and lipid when at a given size and in its desired state. The

growth rate parameter for each component of the body is the same for a given genotype but differs for the feather components. There is a clear difference between males and females of a feather-sexable strain in the rate of feather growth and hence amino acid requirement as well as the ability to lose heat to the environment.

2.2.1.5 Maximum lipid in gain, MLG

Maximum lipid in gain, MLG, refers to the maximum amount of lipid that a bird or animal can deposit in one day in relation to the rate of body protein growth. When an animal is faced with an unbalanced feed, such that it needs to over consume energy as a means of obtaining sufficient of the first limiting nutrient, the excess energy consumed must either be deposited as body lipid or lost as heat. The higher the value of MLG, the more lipid that may be deposited, and the less heat that needs to be lost from the body. Hence, a bird with a 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 a poor quality feed, especially at high temperatures, than would a bird with a MLG value of 1.4.

2.2.1.6 Feathering rate, Fr

Feathering rate, Fr, is a multiplier, used in the model to calculate the rate of maturing of feathers (B_{FP}) from the rate of maturing of the body (B_{BP}). For normal feather growth a multiplier of 1.36 has been used. Feathers consist mainly of protein of which the composition widely different from the protein of muscle tissue. An accurate prediction of the rate of feather growth is essential when predicting the amino acid and energy requirements of growing broilers. Fast growing species of poultry, like broilers, need to be able to lose the heat they generate in order to grow at their potential and this is difficult to accomplish if they are well feathered. That is, there is an advantage in fast growing birds being slow-feathered. Males of the feather-sexable strains are more poorly feathered during the first few weeks of life than are the females, and hence are capable of growing faster on poor quality feeds, or at high temperatures.

In general, describing the kind of animal and its state allows the prediction of the rates at which it is seeking to gain protein and lipid or to predict the nutrient requirements. By bringing together the above six variables, it is possible to generate individuals which have

different values of the variables within a population. However, the variables should be assigned randomly to each individual for the six variables.

2.3   Creation of a hypothetical population

In using simulation modelling to estimate distributions of genetic parameters some basis for comparison must be available in order to determine whether the values are realistic or not. Currently, no data are available from which the distributions of the six parameters can be estimated for broilers of a given sex and strain, although Emmans and Fisher (1986) and Emmans (1988) have suggested coefficients of variation (CV) for B* and P_m of 0.02 – 0.04 and 0.06 – 0.10 respectively. Across genotypes the value of B is expected to fall linearly as the value of $P_m^{0.27}$ increases (Taylor, 1980). He explained that the value of the scaled rate parameter, B*, where B*=B. $P_m^{0.27}$, is expected not to be correlated with P_m across species, although it still varies between species. The value of B* is about 1.5 times as high in broilers and modern pigs as it is in sheep and cattle, for instance (Emmans and Oldham, 1988) and the CV, within a 'normal' population, for P_m and B* are realistic (Emmans and Fisher, 1986). The mean values of five of the six parameters were derived from publications (Emmans and Fisher, 1986; Emmans, 1988; Hancock *et al.*, 1995; Gous *et al.*, 1999) but the mean of MLG was derived by a process of iteration, making use of food intakes measured on marginally deficient feeds. CV's used were those suggested by Emmans and Fisher (1986), or, where no estimates were found in the literature, value of 10% was used. These CV's are given in Table 2.1 together with the mean, the minimum and maximum values used.

A theoretical flock of one hundred birds was created for the purpose of simulation using the EFG Broiler Growth Model (Emmans *et al.*, 2002). The RAND function in Excel returns a random value with mean 0.5 and SD 1/12. Therefore, to obtain a random value from a standardised normal distribution (mean 0, SD 1), 12 RAND functions are added together, (mean = 6 and SD = 1), so by subtracting 6 from the total, a standardised normal random number (0,1) is obtained. This is multiplied by the required SD after which the required mean is added to this value. Random values were assigned in this way to each bird in the theoretical flock, for all six parameters. It was assumed that there was no

correlation between any of the traits. The same theoretical flock was used to predict the effect of different lysine concentrations on various measures of performance.

Table 2.1 *Distribution of stochastic parameters*

Parameters	Mean		Min		Max		CV%
	M	F	M	F	M	F	
B^* (/d)	0.042	0.047	0.037	0.041	0.045	0.048	4.0
Fr (/d)	0.052	0.055	0.041	0.043	0.062	0.066	10.0
P_m (kg)	1.10	0.72	0.91	0.63	1.30	0.82	8.0
LPR_m (g/g)	1.20	2.40	0.88	1.76	1.62	3.24	12.0
MLG (g/g)	1.80	1.80	1.32	1.32	2.15	2.15	10.0
Wo (g)	45.0	45.0	37.0	37.0	53.0	53.0	8.0

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

These 100 individuals were simulated to compare the response of the average individual within a population with the mean of the population. The simulation exercise was conducted at normal environmental temperature, 31°C for three days and decreased every day by 0.5 to 20.5°C and remaining constant thereafter. The stocking density was 11.5 birds/m^2 with no mortality occurring over the period of simulations. In this exercise, growth and food intake were simulated to 21d of age, but the period from 8 – 21d was used when comparing the results.

If any interactions were found to exist between the six parameters it would be difficult to quantify the relationship between the variation of these parameters and the mean of the responses. For this reason the interactions between parameters were regarded as being independent and uncorrelated.

2.4   Feed

In order to evaluate the method of describing a population of broilers, the response of the population to six feeds in a dilution series was compared with that of an individual. These feeds were lysine limiting and formed a dilution series in which dietary energy and all non-

protein nutrients were held constant. The lysine content of the feed was varied from 4.5 to 15.9 g/kg by producing a summit (HP) and dilution (LP) feed (Table 2.2) in which all amino acids were kept in the same ratio with lysine thereby maintaining the same amino acid balance throughout the series. The four intermediate feeds were 'produced' by blending the two basal feeds in appropriate proportions. The digestible protein and lipid contents of the feeds were used by the model to calculate the effective energy content of the six feeds. In the period 0 – 7d the broiler chicks were 'fed' a starter feed (220g protein/kg, 11.5g lysine/kg and 13MJ ME/kg).

This lysine response series was used for the evaluation of the average individual in a population and for the mean of the population. The shape of the response curve is a more useful way of comparing treatments than making use of just one dietary treatment.

Table 2.2   *Composition (g/kg) of the two basal feeds used in the simulation. Amino acids contents are given as digestible*

Nutrient	LP	HP
Protein	8.67	26.42
Fat	13.34	14.55
AME_n	13.0	13.0
Ash	4.66	7.30
Lysine	0.40	1.4
Methionine	0.17	0.47
Threonine	0.33	0.99
Trptophan	0.08	0.33
Arginine	0.55	2.02
Histidine	0.26	0.7
Isoleucine	0.37	1.25
Leucine	1.01	2.03
Phe+Tyr	0.76	2.16
Valine	0.46	1.35

LP = Low protein; HP = High protein

2.5   Simulation design and analysis

2.5.1   Individual verses population response

A factorial design was used in the simulation, with two sexes and six dietary lysine contents. The response of the mean individual in the population was simulated using the mean values of each of the parameters that described the population (Table 2.1). For the population response, 100 individuals were generated, as described previously, and the response of these same individuals to the six lysine-limiting feeds was simulated. The mean response to each feed was determined by averaging the responses of all 100 individuals.

Simulation was conducted for the 14-d period from 8 – 21 days of age. A total of 1212 simulations was conducted over the period to compare the two responses in the two sexes. The output was transferred to an Excel spreadsheet, rearranged and descriptive statistics were obtained using Genstat (2002).

2.5.2   Sensitivity analysis

The technique proposed by Morris (1991) of varying one factor at a time was used to determine to what extent variation in each of the six parameters that describe the genotype would influence the production parameters, such as growth, food intake and FCE. Each of the genetic parameters, in turn, was reduced by 5, 10, 15 and 20 percent, and then increased by the same percentages. The exercise was conducted at 8.9 and 15.9g lysine/kg respectively. Together with the mean value for the parameter, this analysis resulted in nine responses of a population to the six lysine-liming feeds used in the first exercise. A total of 576 simulations was conducted over the period to determine the change in production parameter values.

2.6   Results

2.6.1   Simulated population

Correlation coefficients, with corresponding P-values, between the values assigned to the six genetic parameters used to describe the population are presented in Table 2.3. The mean and SD of each of the parameter estimates in the population were as designed.

Hence, there was no multicollinearity between these parameters. The highest correlation between any two parameters was 0.385 between B and P_m, with the next highest being only 0.158 between B and LPR_m.

Table 2.3   *Correlations between stochastic parameters, with P-values, of male broilers*

	P_m	B	W_0	LPR_m	MLG
B	0.385				
	0.000				
W_0	0.104	-0.074			
	0.011	0.069			
LPR_m	-0.141	0.158	0.109		
	0.001	0.000	0.007		
MLG	0.108	0.113	0.044	-0.007	
	0.008	0.006	0.280	0.867	
Fr	0.032	-0.166	-0.048	-0.075	-0.038
	0.440	0.000	0.243	0.067	0.359

Mature protein weight (P_m), rate of maturing (B), initial body weight (W_0), maximum lipid in gain (MLG), feathering rate (Fr)

2.6.2   Comparison between individual and population

The results of the comparison between the simulated response of the average individual and the mean of the population to the six different lysine contents are shown in Table 2.4 and Figures 2.1 and 2.2. The EFG Broiler Growth Model (Emmans *et al.*, 2002) simulates daily growth of broiler chickens based on the information supplied as input variables. In each simulation, mean protein gain (PG), weight gain (WG), food intake (FI) and feed conversion efficiency (FCE) were recorded over the 14-d period.

There was no significant difference between the response of the average individual in the population and the population mean in any of the variables measured. The relationships between lysine content and either FI or FCE for the average individual and the mean of the population are shown in Figure 2.1. Weight gain between sexes was similar on low lysine feeds but males grew faster than females at the highest lysine contents (Figure 2.2). All

four measures of performance increased with increasing content of the test ingredient, except that FI decreased above an inclusion of 11.2g lysine/kg feed.

Table 2.4   *A comparison of response in food intake (FI), protein gain (PG), weight gain (WG) and feed conversion efficiency (FCE) to six dietary lysine contents between the average individual (Ind) and the mean of the population (Pop)*

Male	FI (g/d)		PG (g/d)		WG (g/d)		FCE (g gain/kg FI)	
Lysine								
g/kg	Ind	Pop	Ind	Pop	Ind	Pop	Ind	Pop
4.5	37.7	37.6	1.4	1.4	11.5	11.6	305	307
6.7	45.9	45.7	2.7	2.7	19.5	19.5	425	426
8.9	56.6	55.9	4.5	4.6	31.2	30.7	551	548
11.2	64.7	64.4	6.5	6.4	42.7	42.5	660	659
13.6	63.2	63.1	7.1	7.0	44.6	45.0	706	713
15.9	61.3	61.0	7.3	7.2	46.2	46.4	754	761
Female								
4.5	37.4	36.5	1.4	1.3	11.3	11.1	302	304
6.7	46.4	45.0	2.7	2.6	19.7	19.1	425	424
8.9	57.6	55.6	4.5	4.3	31.6	30.7	549	553
11.2	57.8	57.2	5.7	5.6	36.7	36.7	635	642
13.6	56.8	55.9	6.0	5.9	38.1	37.9	671	679
15.9	56.6	55.7	6.0	6.0	39.1	38.9	691	698

2.6.3 Sensitivity

The results of the sensitivity analysis for the low and high lysine diets are presented in Table 2.5 and Figures 2.3 and 2.4. The majority of responses are linear with increases in the genetic parameter value, although some of the parameters have a significant quadratic slope (Table 2.5). The ranking in sensitivity of the stochastic parameters was similar for both sexes. A change in P_m had no effect when using the low lysine feed, on any of the

measures of performance, but had a significant effect when the high lysine feed was used. The effect was the same for both sexes. Changes in this parameter resulted in a significant quadratic slope for weight gain in females at the low lysine level.

The effect of change in B and W_0 on all measures of performance was highly significant at both high and low lysine contents. Feed conversion efficiency was affected only by decreasing value of B in both sexes (Figure 2.3). Maximum lipid in gain had a significant effect on PG, LWT and FI only at low lysine level. In some cases (e.g. B, Fr) there was a 35% change in performance for 20% change in the value of the parameter, whereas in other case the performance changed by only 5% (Figures 2.3 and 24; Table 2.5)
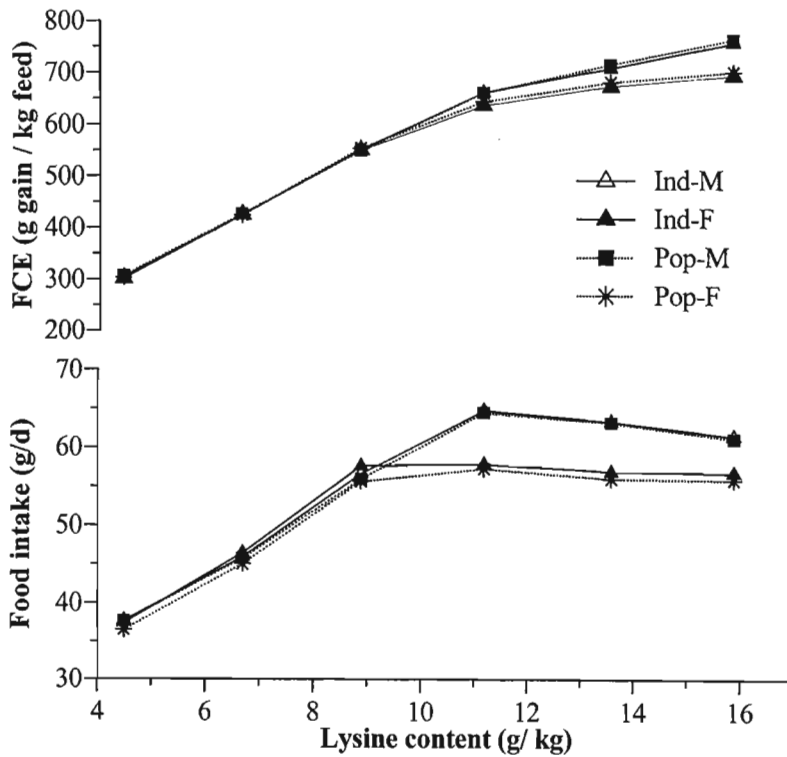
Figure 2.1 *Responses measured for the mean individual and for the mean of the simulated population, in feed conversion efficiency (g gain/ kg feed) (top) and food intake (g/d) (bottom) of male and female broilers from 8 – 21 d of age, to six feeds varying in lysine content.*
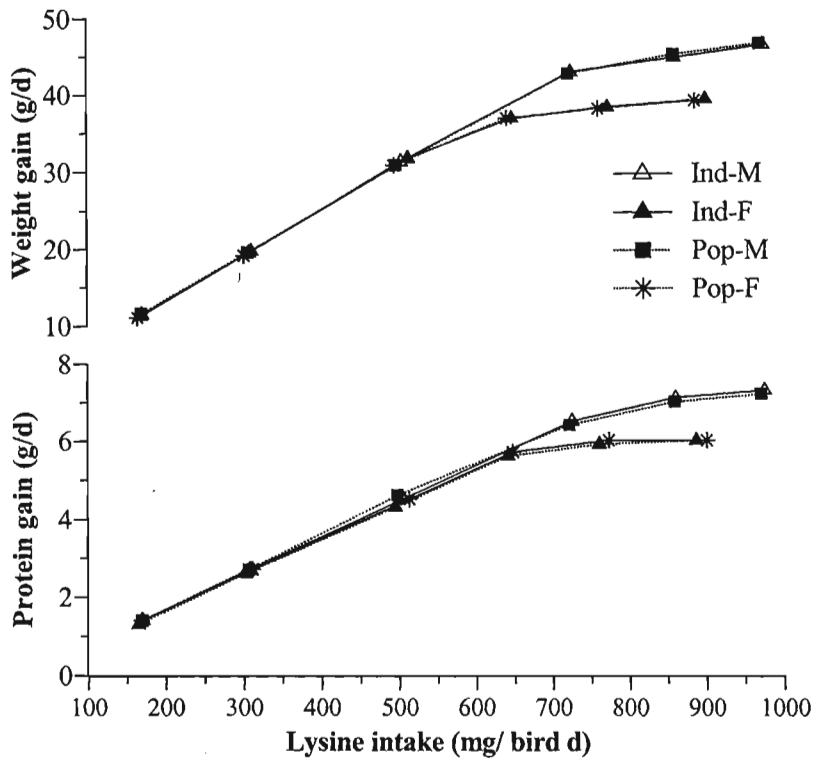
Figure 2.2 *Responses measured for the mean individual and for the mean of the simulated population, in weight gain (g/d) (top) and protein gain (g/d) (bottom) of male and female broilers from 8 – 21 d of age, to lysine intake.*
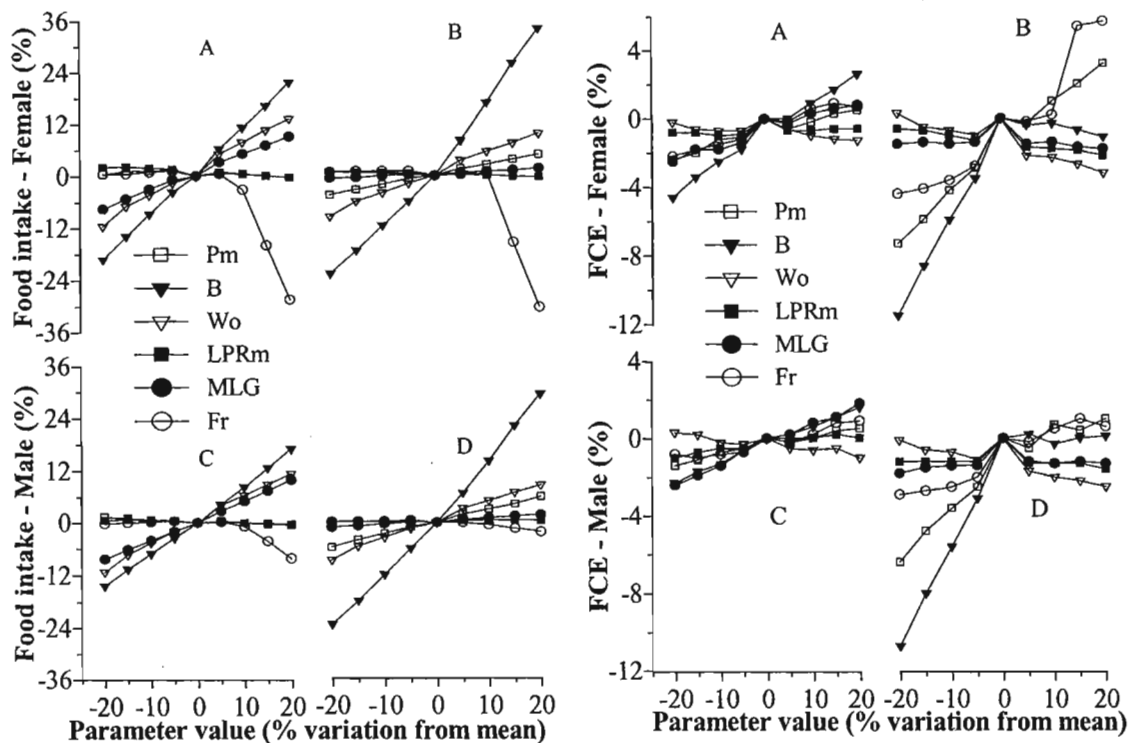
Figure 2.3   *The relative effect on food intake (left) and feed conversion efficiency, FCE, (right) in male and female broilers from 8 to 21 d of age, fed a lysine–limiting feed containing 4.5g lysine/kg, A and C, and 15.9g lysine/kg, B and D, when the means of each of six genetic parameters were increased or decreased by 5, 10, 15 or 20 percent whilst holding the five other genetic parameters constant.*
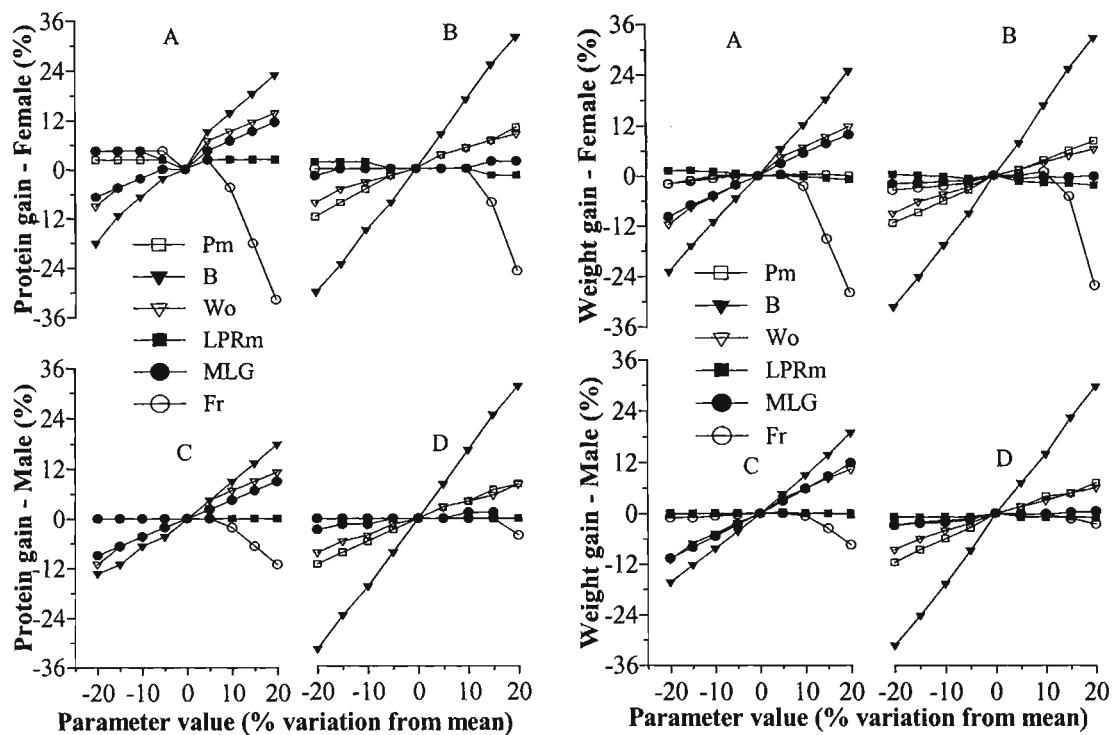
Figure 2.4   *The relative effect on protein gain (left) and weight gain (right) in male and broilers female from 8 to 21 d of age, fed a lysine–limiting feed containing 4.5g lysine/kg, A and C, and 15.9 g lysine/kg, B and D, when the means of each of six genetic parameters were increased or decreased by 5, 10, 15 or 20 percent whilst holding the five other genetic parameters constant.*

Table 2.5   *Regression coefficients indicating the change in the value of the four production parameters of male and female broilers from 8 to 21 d of age, at 8.9 (Low) and 15.9g lysine/kg (High), as each of six genetic parameters were decreased and increased by 5, 10, 15 and 20 percent from the base value, whilst holding the remaining five genotype parameters constant*

Parameter	Feed intake				Feed conversion efficiency				Protein gain				Weight gain			
	Male		Female		Male		Female		Male		Female		Male		Female	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Pm	-0.045**	0.284**	-0.031ns	0.229**	0.046**	0.187**	0.070**	0.262**	0.0	0.489**	0.0**	0.523**	0.001ns	0.464**	0.040**	0.487**
						-0.005**				-0.003**		-0.004*		-0.005**	-0.003**	-0.002*
B	0.780**	1.316**	1.011**	1.418**	0.096**	0.272**	0.176**	0.265**	0.793**	1.594**	1.015**	1.572**	0.874**	1.536**	1.179**	1.620**
	0.003**	0.008**		0.013**		-0.011**		-0.013**	0.005**					0.003**	0.002*	
Wo	0.555**	0.426**	0.609**	0.467**	-0.028**	-0.058**	-0.022*	-0.083**	0.548**	0.397**	0.560**	0.410**	0.526**	0.362**	0.581**	0.376**
														-0.003**		-0.003*
LPRm	-0.028**	0.023ns	-0.067**	-0.032**	0.028**	0.006ns	0.007ns	-0.040*	0.0**	0.027ns	-0.066ns	-0.091**	0.0**	0.029ns	-0.060**	-0.07**
														-0.001**		
MLG	0.456**	0.070**	0.412**	0.0517**	0.104**	0.010ns	0.086**	-0.007ns	0.445**	0.101**	0.454**	0.062**	0.559**	0.080**	0.492**	0.044**
	0.002**													0.001**		
Fr	-0.157**	-0.054**	-0.580**	-0.588**	0.049**	0.111**	0.084**	0.265**	-0.230**	-0.055ns	-0.778**	-0.416**	-0.110**	0.112**	-0.497**	-0.355*
	-0.012**	-0.003**	-0.039**	-0.042**					-0.015**	-0.005*	-0.042**	-0.033*	-0.011**		-0.040**	-0.038**

*P< 0.05, **P<0.01 and ns Non significant.

2.7   Discussion

Comparison of responses of the mean individual and the population mean

The only sensible approach to predicting the nutrient requirements of a population using simulation models is to repeat the simulation for a number of individuals representative of the population and then average the results. The approach is discussed in Emmans and Fisher (1986). Differences in response between the average individual and the mean of the population would be expected to occur in that the population response accounts for the different maintenance requirements for the limiting nutrient and different maximum rates of protein deposition of all individuals in the population (Curnow, 1973; Emmans and Fisher, 1986; Ferguson *et al.*, 1997). However, when using the average individual, as described previously, the response is for one animal with one maintenance requirement and one maximum protein deposition rate, even if these values are representative of the population average. It is for these reasons that most researchers suggest that predicting nutrient requirements of a population of animals is more meaningful and is thus preferred to the use of individuals when attempting to optimise the performance of a group of animals (Fisher *et al.*, 1973; Ferguson *et al.*, 1997; Gous, 1998). Using the average individual as a predictor of a population is likely to under-estimate the nutrient requirement of the population because there will be many individuals that will benefit from higher nutrient intakes and this will affect the profitability of the production system.

Among many different methods of generating a population, random sampling was used in this simulation exercise. This method proved to be efficient since the minimum and maximum value of the six parameters were in the range of actual measurements. Gous (1998) used a similar approach to generate a population in order to conduct a simulation exercise. He reported that the response of the average individual in a population was clearly not the same as the mean response of the population. From Table 2.5 it is evident that there were very small differences in all four measures of performance in response to dietary lysine intake between the average individual and the population, especially when lysine content was low since the growth rate of the broiler is constrained below its potential. In the exercise reported by Gous (1998), the difference between the two responses is slightly greater than the results reported in

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this paper. This might be due to: first, the values of CV for the parameters used to generate a population were different. For this particular simulation exercise the coefficients of variation are presented in Table 2.1. In Gous' simulation exercise, a population of 500 males and 500 females was generated using CV for P_m, B, W_0 and LPR_m of 8, 5, 10 and 7% respectively Gous (1998). The CV for P_m used in the two exercises was the same, but the CV for B, W_0 and LPR_m differed: in the present exercise these were 4, 8 and 12% respectively. Whereas the difference in CV for LPR_m is unlikely to have had an effect on the result, changes in the CV of B and W_0 would significantly change the result, as shown by the sensitivity analysis conducted here (Table 2.5). Secondly, there were two additional parameters, MLG and Fr, used here as sources of variation in describing the genotype to increase its descriptive and/or predictive power of the EFG Broiler Growth Model. This may have affected the simulation outputs differently. For instance, a bird with a high MLG would be capable of growing faster, on a poor quality feed, and especially at high temperatures, than would a bird with a low capacity for depositing body lipid. Thirdly, only 100 individuals were used to represent a population in the present simulation exercise. It is possible that the number of individuals representing the population will have an effect on the response, but this has not yet been examined.

Sensitivity analysis

From the results of the sensitivity analysis, P_m has a marked effect at high lysine contents on all four measures of performance for both sexes, but almost no effect at low lysine contents. For instance, for a change of 20% in P_m, weight gain changed by 0.80 and 9.74 g/d for the low and high lysine content, respectively, for females. This might be due to the fact that for low lysine diets the potential protein growth is restricted by the diets. Moreover, at a high lysine content it is the potential growth rate that constrains growth. Although there was a linear relationship between P_m and the model outputs, the increment was not the same, increasing at a decreasing rate, with increasing change of percentage values of P_m. The effect of P_m on PG is in agreement with Emmans (1989) equation, $P = P_m \exp(-\exp(-B(t - t^*)))$. That is, P_m is directly proportional to P, where P is protein retention. Thus, by increasing the potential growth rate (P_m) the performance can be increased further.

Rate of maturing, B, is one of the most important parameters describing the genotype and influencing the daily FI, PG and LWT regardless of sex and lysine contents in all simulations (Table 2.5). A small change in this variable resulted in significant changes in the model outputs due to the double exponential relationship with the outputs rather than linear relationship as with the other stochastic parameters. The effect of increasing or decreasing the value of B is different on high and low lysine diets. A change of 10% increase or decrease in the parameter affected weight gain in males by 15.36 and 9.04g/d on the high and low lysine diet, respectively. The slope is steeper at high lysine contents than at low lysine contents. This might be due to a combined effect of P_m at high lysine content, but not examined yet, and when lysine is limiting the growth rate of the broiler is constrained below its potential, but at high lysine contents it is the potential growth rate that constrains growth. The pattern of effect, for the two sexes, was similar especially for the high lysine diet. Although high PG and WG were observed for males because they grow faster than female, the effect of changing B was very sensitive in females, with the result that the slope is greater for females than for males (Table 2.5). This might be due to higher value of B used in the simulation exercise for females, making the value of percentage change of parameter even higher. Therefore, all measures of performance are more sensitive to changes in this parameter compared with other stochastic parameters considered at individual level.

The lipid-to-protein ratio at maturity, LPR_m, is a useful measure when comparing genotypes (Hancock et al., 1995) and may vary over at least a ten-fold range and needs to be seen as a genetic variable (Emmans, 1988). From Table 2.5 it is evident that this variable had no effect at high lysine level, especially for males, since at high lysine contents birds have no need to over-consume energy, which would otherwise cause them to be fat. In the case of the low lysine levels, LPR_m has an effect, and a higher slope for females relative to males, since females contain about twice the amount of lipid than the males, this being a characteristic of most genotypes (Hancock et al., 1995; Gous et al., 1999). At a low lysine level broilers tend to consume excess energy, which must either be stored as lipid or lost as heat. Compared to the other stochastic parameters this variable was far less sensitive. Except for a slight effect on FCE on the high lysine diet due to increased LPR_m, there were few differences resulting from a change in the value of this parameter. This might be due to the simulation period (8-21d)

being too early to influence the responses, and also birds would need to consume excess energy to express the change. The effect of this variable will be clarified in the next chapter.

According to Figures 2.3 and 2.4 and Table 2.5, W_0 had a significant effect on the model outputs, almost to the same extent as the effect brought about by B. It is known that a given kind of bird will be capable of growing at different rates depending on its weight at the time. For a change of 15% in W_0, weight gain changed by 8.72g/d at low lysine levels in females. However, on the high lysine diet the effect was only 4.97g/d. Thus, the effect of W_0 was high on low lysine diets, for both sexes, on the measures of performance due to a high food intake to satisfy the nutrient requirement. The levels of effect when increasing or decreasing the parameter were similar; the slopes are almost the same (Table 2.5). Even though the same initial body weight was used for both sexes, male live weight at the specified period was greater than females due to high food intake and growth rate. But the effect of percentage change was the same for both sexes. Initial body weight was positively related to all the variables measured except FCE. Although the effect was small, FCE decreased as W_0 increased due to the increasing maintenance requirement. This was highly sensitive in the case of females.

Variation in maximum lipid gain, MLG, has only recently been introduced in the growth model as a source of variation between individuals. The effect of MLG was observed at low lysine contents, for both sexes, on all measures of performance (Figures 2.3 and 2.4) but had almost no effect at the high dietary lysine content. For a change of 20% decrease or increase in MLG, the weight gain was affected by 11.58g/d on the low lysine diet and by only1.6g/d on the high lysine diet, in males. This is in accordance with Emmans (1981b) who reported that, when a bird is exposed to a poor quality feed, it attempts to consume sufficient of that feed to meet the requirement for the limiting nutrient. As a result, as described previously, it consumes excess energy that either has to be lost as heat or stored as fat. The higher the value of MLG, the more lipid that may be deposited, and the less heat that needs to be lost from the body. On high lysine diets there is no need to over-consume energy to satisfy the requirement for lysine. The effects of increasing or decreasing MLG were similar; the slopes were almost the same (Table 2.5).

There was no effect on performance when feathering rate was decreased although FCE was marginally affected. However, there was a significant effect when this parameter was increased (Table 2.5). The effect differed between the sexes. For instance, at +20% change of the parameter, for females, PG decreased by 32.36g/d from the original (mean) value whereas for males the decrease was only 10.6g/d. The same situation occurred with food intake and weight gain. Since females have a greater feather cover than males, the amount of heat that may be lost is less, with better feed conversion efficiency. Thus, in order to balance their heat exchange with the environment the broilers were forced to decrease their food intake, which resulted in lower protein retention and weight gain. Moreover, there is competition for some of the amino acids between body protein and feather protein growth. This is in agreement with Gous (1986) who reported that the difference in the rate of feather development during different stages of growth as well as between sexes which could contribute to a change in the response of amino acids and efficiency of utilisation will appear to be enhanced with increased feather growth. In the case of FCE, there was a positive relationship with the change of this parameter because of high insulation for heat loss. Thus, Fr is very sensitive at high lysine levels (Figures 2.3 and 2.4 and Table 2.5).

Generally, the difference between the average individual and the population mean depends on the CV applied to each parameter, to the diet and period of simulation. It is likely that the performances of broilers on either side of the mean will balance out for parameters such as P_m, B and LPR_m, but this is less likely with Fr because of differences in response above and below the mean, and with MLG since its effect is different on low and high lysine diets.

CHAPTER THREE

Comparison between the average individual and the mean of the population, together with sensitivity of the genetic parameters, in broilers between 22 and 35d of age.

3.1 Introduction

In the previous chapter the response of the average individual in a population and the mean of the population were compared in the period 8 to 21d of age. In this chapter the comparison is made with broilers between 22 and 35d of age. However, the sensitivity analysis was conducted at 6.7 and 11.2g lysine /kg to investigate the relative effects of the genetic parameters used in the simulation exercise as a source of variation in the performance of broilers. This is because of the lower concentration requirements of amino acids due to high food intakes in this period of simulation. The objective, materials and methods, including the stochastic parameters, number of individuals and simulations and experimental design were the same as in an earlier exercise (see Chapter Two), except that the period under investigation was that between 22 and 35d and feed composition. Birds were 'fed' a starter feed (220g protein/kg, 11.5g lysine/kg and 13 MJ ME/kg) to 21d of age.

3.2.1 Results

3.2.1 Comparison between individual and population

The responses of the average individual and the mean of the simulated population to the six feeds differing in lysine content are shown in Table 3.1 and Figures 3.1 and 3.2. The most significant differences between the mean individual and the population mean was in food intake in the females, where the mean individual consumed on average 10g more food than the mean of the population, this difference being lowest at a lysine content of 8.9g/kg and largest at 15.9g/kg. This resulted in lower gains in body weight (1.4g/d in males and 3.9g/d in females, on average) and protein weight (0.1g/d in males and 0.3g/d in females) by the population than by the mean individual. Feed conversion efficiency was almost the same for the individual and population mean in both sexes.

The effects were similar in the males: the differences were not as great as in food intake or growth. The smallest difference in food intake between the individual and the population was at 11.2g lysine/kg as opposed to the 8.9g/kg for females.

There was a more rounded curvature in protein gain for the population than for the individual in response to lysine intake (Figure 3.2).

3.2.2 Sensitivity analysis

The results of the sensitivity analysis are shown in Figures 3.3 and 3.4. The largest changes in food intake for both males and females were brought about by changes in B and Fr. In all except Fr, the responses appeared to be linear, or close to linear, and symmetrical about the mean, but the response to a change in Fr was far from symmetrical, the effect on food intake and growth rate being considerably more severe as the value was increased. The coefficients indicating the rate of change with a change in the parameter value are given in Table 3.2. These coefficients are for the linear effect except where a quadratic effect was significant ($P<0.05$), in which case the linear and quadratic terms are included in Table 3.2. The ranking in sensitivity of the parameters was similar for both sexes. B, P_m and Fr had the most influence among the stochastic parameters on all measures of performance at both levels of lysine, for both sexes, whereas W_0, LPR_m and MLG had very little effect on the simulation outputs.

Table 3.1 *A comparison of response in food intake (FI), protein gain (PG), weight gain (WG) and feed conversion efficiency (FCE) to six dietary lysine contents between the average individual (Ind) and the mean of the population (Pop)*

Male	FI (g/d)		PG (g/d)		WG (g/d)		FCE (g gain/kg FI)	
Lysine g/kg	Ind	Pop	Ind	Pop	Ind	Pop	Ind	Pop
4.5	171.3	167.9	6.2	6.0	51.7	50.7	302	302
6.7	198.7	194.0	11.3	11.0	80.0	78.2	403	403
8.9	195.1	192.1	15.0	14.8	97.1	94.9	498	494
11.2	168.5	167.2	15.1	15.1	90.5	90.3	537	540
13.6	168.6	165.0	15.1	15.1	90.5	89.4	537	542
15.9	169.5	164.2	15.1	15.1	92.1	90.3	543	550
Mean	178.6	175.1	13.0	12.9	83.7	82.3	469	472
Female								
4.5	178.8	171.5	6.4	6.2	59.2	57.0	331	333
6.7	189.5	178.0	10.6	9.9	79.2	73.7	417	414
8.9	156.6	152.7	11.0	10.7	72.9	70.5	465	462
11.2	157.7	148.2	11.0	10.8	73.3	69.8	464	471
13.6	159.4	146.6	11.0	10.8	73.4	69.0	460	471
15.9	161.3	145.8	11.0	10.8	74.9	69.7	464	478
Mean	167.2	157.1	10.2	9.9	72.2	68.3	434	438
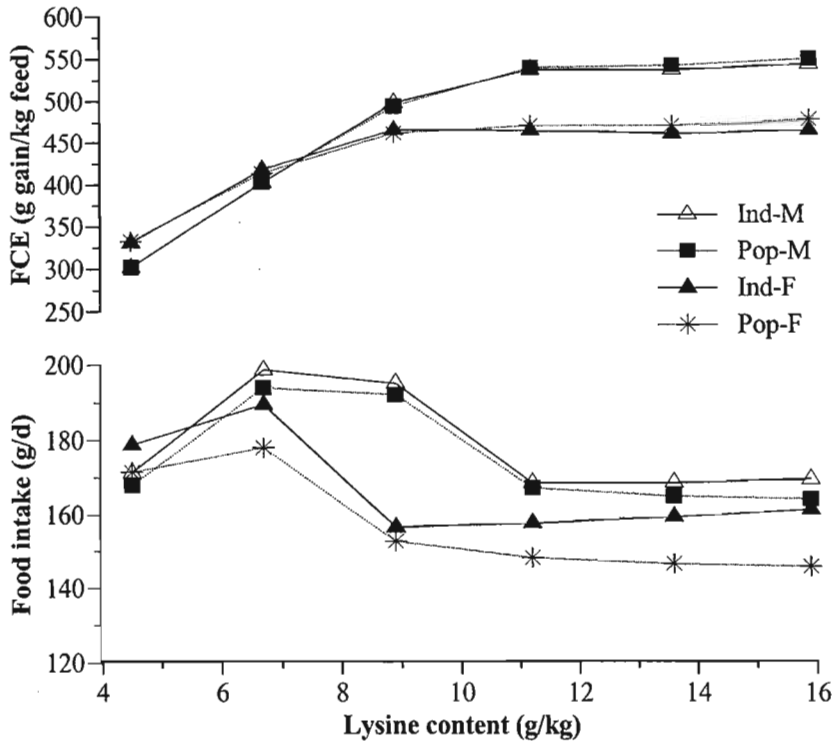
Figure 3.1 *Responses measured for the mean individual and for the mean of the simulated population, in feed conversion efficiency, FCE, (g gain/ kg feed) (top) and food intake (g/d) (bottom) in male and female broilers from 22 – 35 d of age, to six feeds varying in lysine content.*
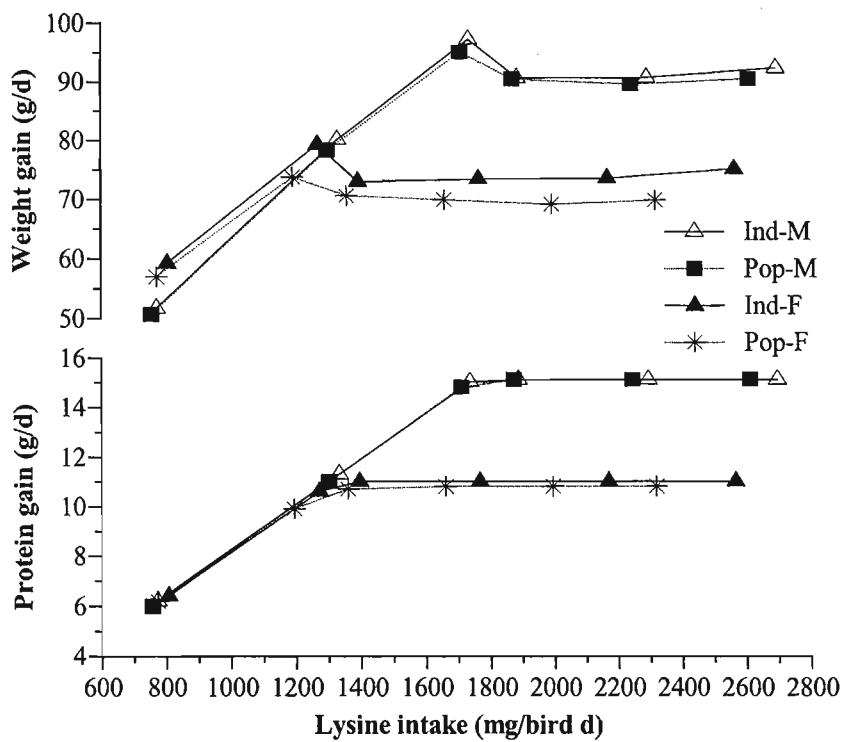
Figure 3.2   *Responses measured for the mean individual and for the mean of the simulated population, in weight gain (g/d) (top) and protein gain (g/d) (bottom) in male and female broilers from 22 – 35 d of age, to lysine intake*
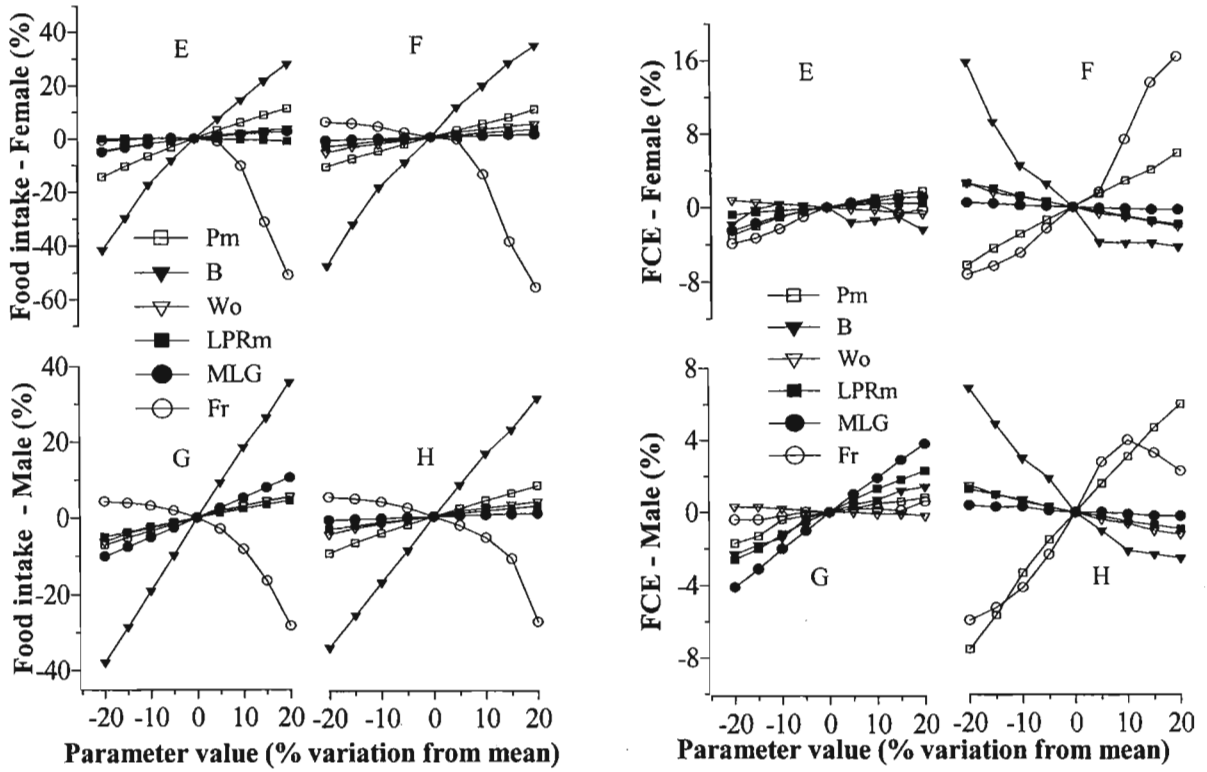
Figure 3.3 *The relative effect on food intake (left) and feed conversion efficiency, FCE, (right) in male and female broilers from 22 to 35 d of age, fed a lysine–limiting feed containing 6.7g lysine/kg, E and G, and 11.2g lysine/kg, F and H, when the means of each of six genetic parameters were increased or decreased by 5, 10, 15 or 20 percent whilst holding the five other genetic parameters constant.*

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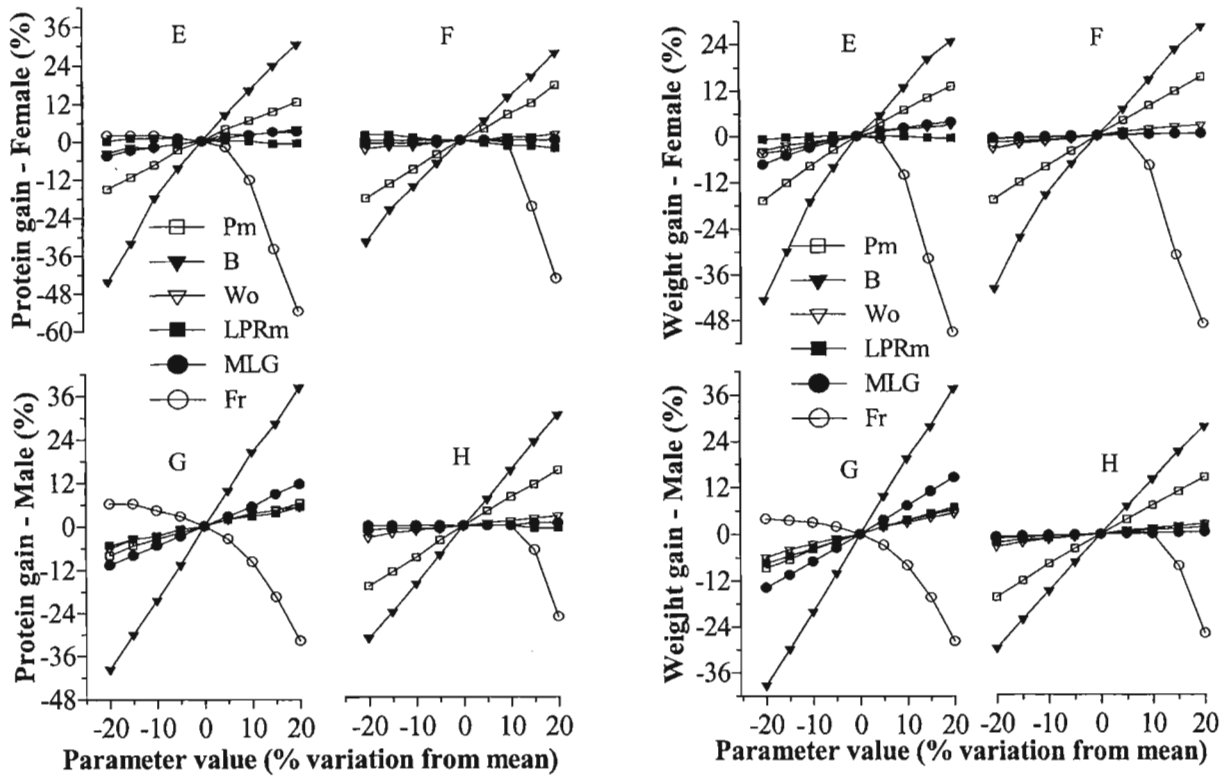
Figure 3.4 *The relative effect on protein gain (left) and weight gain (right) in male and female broilers from 22 to 35 d of age, fed a lysine–limiting feed containing 6.7g lysine/kg, E and G, and 11.2g lysine/kg, F and H, when the means of each of six genetic parameters were increased or decreased by 5, 10, 15 or 20 percent whilst holding the five other genetic parameters constant.*

Table 3.2 *Regression coefficients indicating the change in the value of the four production parameters of male and female broilers from 22 to 35 d of age, at 6.7 (Low) and 11.2g lysine/kg (High), as each of six genetic parameters were decreased and increased by 5, 10, 15 and 20 percent from the base value, whilst holding the remaining five genotype parameters constant*

Parameter	Feed intake				Feed conversion efficiency				Protein gain				Weight gain			
	Male		Female		Male		Female		Male		Female		Male		Female	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Pm	0.316**	0.434**	0.637**	0.883**	0.060**	0.336**	0.114**	0.291**	0.345**	0.800**	0.688**	0.870**	0.377**	0.765**	0.744**	0.793**
	-0.002**	-0.002**	-0.004**		-0.001**	-0.002**	-0.002**		-0.003**	-0.002**	-0.004**		-0.003**	-0.002**	-0.005**	-0.002**
B	1.844**	1.600**	1.701**	2.016**	0.096**	-0.241**	-0.040ns	-0.477**	1.962**	1.549**	1.833**	1.439**	1.934**	1.437**	1.643**	1.642**
	-0.003*	-0.004**	-0.018**	-0.020**	-0.001*	0.005**	-0.004*	0.016**			-0.019**	-0.005*		-0.002**	-0.022**	-0.014**
Wo	0.293**	0.209**	0.203**	0.262**	-0.013**	-0.067**	-0.038**	-0.114**	0.283**	0.141**	0.183**	0.108**	0.280**	0.142**	0.167**	0.148**
	-0.001**	-0.001*	-0.002**	-0.001*		0.001*		0.001*		-0.001*			-0.001**	-0.001	-0.002**	-0.001*
LPRm	0.237**	0.150**	-0.029**	0.154**	0.124**	-0.055**	0.031**	-0.113**	0.256**	-0.016**	-0.039**	-0.117**	0.361**	0.097**	0.004ns	0.038**
	-0.001**	-0.001**	-0.002**	-0.001**	-0.001**	0.001**	-0.001**	0.001**		-0.001*			-0.001**		-0.002**	
MLG	0.516**	0.043**	0.186**	0.049**	0.198**	-0.016**	0.089**	-0.021**	0.551**	0.048**	0.187**	0.030**	0.713**	0.028**	0.272**	0.026**
	0.001**		-0.003**		-0.001**		-0.002**	0.001*	0.001**		-0.002**		0.001**		-0.005**	
Fr	-0.728**	-0.670**	-1.054**	-1.403**	0.025**	0.265**	0.098**	0.606**	-0.880**	-0.402*	-1.206**	-0.796**	-0.710**	-0.397**	-0.953**	-0.969**
	-0.030**	-0.028**	-0.068**	-0.068**			-0.005**	0.013**	-0.033**	-0.033*	-0.068**	-0.059**	-0.031**	-0.035**	-0.073**	-0.068**

*$P< 0.05$, **$P<0.01$ and ns Non significant.

3.3   Discussion

Comparison of responses of the mean individual and the population mean

Differences between the average individual and the population mean were greater in this period than in the period from 8 to 21d (Chapter 2). The requirement for lysine in this period is lower than in the earlier period, so at least two of the highest lysine diets are in excess of the requirement and would not normally be used in practice. But it is interesting to note that differences in food intake on these high lysine feeds widened as the lysine content increased, especially among the females, with the mean individual consuming more food than the population mean. Food intake is expected to fall as the protein supply is increased, and this was observed with the population mean, but not with the average individual. As the protein supply is increased above the requirement, the energy:protein ratio (E:P) falls below a critical point, after which the efficiency of utilisation of protein is compromised, resulting in the need to consume more feed to meet the requirement for the limiting nutrient. In a population, where half the birds have a higher lysine requirement than the mean individual, this lowering of the utilisation efficiency, with a resultant need to increase food intake, would not be observed. The difference is greater with the females than with the males because their requirement is met at a lower dietary protein content than with the males, therefore the excess protein supply would start from a lower protein content than in the case of the males.

Protein gain would not be reduced by the lower intake of food at the high protein contents, unless the birds were unable to consume sufficient of these feeds, e.g. if the environmental temperature were too high, but because the energy supply is limiting (additional energy is required to deaminate the excess protein consumed) birds fed these high protein feeds would be expected to be very lean, resulting in a lower body weight gain than would be expected from the population mean, as was observed here. Individuals within the population with feathering rates above the mean would be unable to increase food intake on these higher protein feeds because they would be incapable of losing as much heat to the environment as would the average individual.

As the protein supply dropped below the required amount, food intake of the population increased substantially compared with that of the mean individual, resulting in higher gains in protein and body weight at marginally deficient levels of lysine than were achieved by the mean individual. The lipid content in the body weight gains would have been substantial on these marginally deficient feeds, as the birds would have consumed considerably more energy than would be necessary for incorporation into body protein. On the lowest lysine diet, intakes were more similar between the two means, with body and protein gains being very similar within both sexes.

Sensitivity analysis

Where a change in the value of a genetic parameter has an almost equal and opposite linear effect on a given performance indicator, as in the case of a change in food intake as a result of a change in the rate of maturing (B), the responses of the average individual and that of the population would be expected to be virtually the same, with those individuals with B values below the mean cancelling out those with higher B values, Figure 3.3. Even though the changes in performance brought about by changes in B could be considerable, these changes do not result in differences between the performances of the individual and the population.

Equal and opposite changes in the performance variables resulted from changes in P_m, B, W_0, and LPR_m in most instances, irrespective of the composition of the feed offered, suggesting that these genetic parameters do not contribute substantially to variation in the performance of a population. For instance, a change of 20% above or below the mean in P_m had an effect of 17.66g feed/d. However, increases in Fr resulted in totally different responses in food intake, body and protein gains to those when Fr was reduced in value Figures 3.3, 3.4 and Table 3.2. It is therefore essential to include Fr as a stochastic parameter when simulating a population of broilers.

Whereas equal and opposite changes in the performance variables resulted from changes in MLG on the high lysine feed, the composition of the feed offered made a substantial difference to the response to these changes. For a change of 20% in males on low lysine diets the weight gain was affected by 14.66g/d whereas at high lysine diets it was only by 0.56g/d

when MLG value was decreased or increased about the mean. It is therefore important to include MLG as a stochastic parameter even though, for a given feed, the differences brought about by changes in MLG are minimal.

Generally, the difference between the average individual within a population and population mean were not affected by the parameters that had a similar effect in two directions (increasing and decreasing). Although no further growth is possible when the average individual in the population reaches its genetic potential, even when more nutrients are included in the feed, the maximum growth rate in a population can be increased beyond this point because half of the individuals will have a potential growth rate higher than the average individual. It is surprising, therefore, that the maximum response in weight gain to an increase in lysine intake, was higher for individuals than for the population mean (Fig. 3.2).

CHAPTER FOUR

The effect of variation in feathering rate on the response
of a population of broilers to dietary lysine

4.1 Introduction

Based on the results of the sensitivity analysis conducted in the previous chapters it appears that variation in feathering rate (Fr) has a non-linear effect on growth and food intake, unlike the effect of variation in most of the other parameters describing the genotype of a broiler. It is well known that high temperatures within a broiler house will severely impact food intake and weight gain, the depression in these measures of performance increasing as the feather cover of the bird is increased, so the non-linear response to variation in feather cover can be explained on this basis. Of interest is the extent to which the response of the mean individual varies from that of the mean of the population for increasing variation in Fr over a range of environmental temperatures, given that non-linear responses would be expected to produce larger differences between individual and population means than would linear responses.

Thus, the purpose of the simulation exercise reported in this chapter was to determine the effect of variation in feathering rate on the measures of performance in a population of broilers when air temperature is varied.

4.2 Materials and methods

4.2.1 Creation of a hypothetical population

In order to minimise the number of simulations needed to describe the population response, whilst ensuring that the required variation within the population is maintained, a second method of generating a population was developed and used in this exercise. The mean and CV of the genetic parameters that are to be made stochastic are defined, as before, but in this case simulations are conducted for all combinations of (user-) defined variations from the

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mean only (e.g. -2, -1, 0, +1 and +2 SD from the mean). The results of the simulations for the defined values of the genetic parameters are weighted according to their expected frequency in the population, thereby defining the population mean.

A theoretical population of 75 broilers was generated using this sampling method. Apart from using the mean value for each of the parameters, -2, -1, +1 and +2 SD were used for Fr and values of -2, and +2 SD were applied to B and MLG in order to generate a realistic population. The average individual in the population was described using the results obtained from different experiments and publications in terms of six genetic parameters (Table 4.1). However, the variation of individuals in live weight at the start of the trial (21d) is given in Table 4.2. This helps to identify whether the variation is increasing with age and to establish the real effect of Fr.

Table 4.1 *Mean values and coefficient of variation (CV) of the genotype parameters used in defining the population*

Parameters	Mean	CV%
Initial body weight, (Wo), g	45.0	8
Mature protein weight (Pm), kg	1.100	8
Scaled maturing parameter (B*), /d	0.042	4
Lipid: Protein ratio at maturity (LPR$_m$), g/g	1.200	12
Maximum lipid gain (MLG), g/g	1.800	10
Feathering rate (Fr), /d	0.052	10

$B^* = B \, P_m^{0.27}$

The effect of variation in Fr was evaluated at three environmental temperatures (21, 25 and 29°C), the lowest temperature being within the comfort temperature of a broiler between 22 and 35d, and the highest being below the panting threshold (31°C or above). A stocking density of 15 birds/m^2 was used with no mortality occurring over the period of simulation.

In this exercise growth and food intake were simulated to 35d of age, but the period from 22 – 35d was used when comparing the results. This period of simulation was chosen because the resultant variation could be compared with variation that is measured in commercial practice, at 35d and greater variation was observed in this period than in the earlier period (Chapter 3).

The simulation model used in this exercise was designed to allow changes to be made to the coefficients of variation of each genotype parameter as well as to the parameters themselves (Table 4.1).

Table 4.2   *Variation at the start of the trial (21d of age)*

C.V.[1]	Mean Liveweight, g		S.D.		Minimum[2]		Maximum[2]		C.V. at 21d	
	M	F	M	F	M	F	M	F	M	F
0	852	738								
0.05	834	660	45	69	743	522	925	798	5	10
0.1	788	648	116	148	556	352	1020	944	15	23
0.15	692	605	163	202	366	201	1018	1009	24	33

[1]Coefficient of variation at day old; [2]mimimum and maximum live weights were calculated using -2 and +2 SD, respectively.

4.2.2   Feed

To evaluate the response of a population to the defined inputs, two basal feeds were formulated using WinFeed 2.0 (EFG Software[1]). The feeds were lysine limiting and were blended to form a dilution series over the range 4.0 to 14.0 g digestible lysine per kg feed. Dietary energy (13 MJ/kg) and other nutrients remained the same in all formulated feeds.

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[1] Emmans, G. C., Fisher, C. and Gous, R. M. (2003) EFG Model. University of KwaZulu-Natal, Discipline of Animal and Poultry Sciences,25 Fairfield Ave, Pietermaritzburg 3201, South Africa, e-mail: gous@ukzn.ac.za

These feeds were transferred to the EFG Model and used in defining the feeding programme (Table 4.3). In the period 0 – 21d the broilers were 'fed' a starter feed (220g protein/kg, 11.5g digestible lysine/kg and 12.0 MJ ME/kg).

Table 4.3   *Composition (g/kg) of the two basal feeds used in the simulation. Amino acids contents are given as digestible*

Nutrient	LP	HP
Protein	12.30	31.25
Fat	4.49	7.97
AME_n	13.00	13.00
Water	1.08	1.17
Ash	5.78	6.53
Lysine	0.40	1.40
Methionine	0.21	0.59
Threonine	0.36	0.99
Trptophan	0.10	0.25
Arginine	0.69	1.79
Histidine	0.45	0.82
Isoleucine	0.35	1.14
Leucine	1.16	2.69
Phe+Tyr	0.81	2.21
Valine	0.35	1.14

LP = Low protein; HP = High protein

4.2.3 Simulation design and analysis

Six dietary lysine levels, four CV of Fr (0 to 0.15), three temperatures (21, 25 and 29°C) and two sexes were used in the factorial experiment. A total of 144 simulations was conducted on broilers between the ages of 22 and 35 d. In each simulation FI (g/d), protein gain (g/d), weight gain (g/d) and lipid gain (%) were recorded over the two-week period (22 to 35d). Lysine intake and FCE were calculated from these data. The output was transferred to an Excel spreadsheet, the data were rearranged and descriptive statistics were generated using Genstat (2002).

4.3 Results

The results of the effect of changing the CV of feathering rate, Fr, on the measures of performance at three environmental temperatures for both sexes are presented in Figures 4.1, 4.2, 4.3, 4.4 and 4.5. The mean individual in the population (no variation) had the highest food intake regardless of the environmental temperature and sex. The highest food intake was also observed where lysine was included at 8.9 and 6.9g/kg feed at the lowest environmental temperature, in males and females, respectively. As the variation in Fr increased, the FI decreased in the same pattern for all environmental temperatures, while the highest difference in food intake was observed at the lowest temperature in both sexes. Variation in food intake as a result of an increase in the CV of Fr was greatest at low lysine contents in females, reducing to almost no variation at the highest lysine contents. However, this variation was maintained over all lysine contents in the males (Figure 4.1).

There was no significant effect of variation in Fr on FCE in either sex as influenced by temperature: FCE increased slightly as the lysine content increased. Weight gains at low lysine contents were the same irrespective of the amount of variation in Fr, but the maximum gains achieved on the highest lysine feeds differed considerably (Figure 4.4). The mean individual in the population always achieved the highest gains, with lower maximum gains resulting from each increment in variation in Fr. The greatest difference between different degrees of variation occurred at the lowest temperature to which the birds were subjected. The linear-plateau responses of gains gradually changed to curvilinear as the temperature increased.
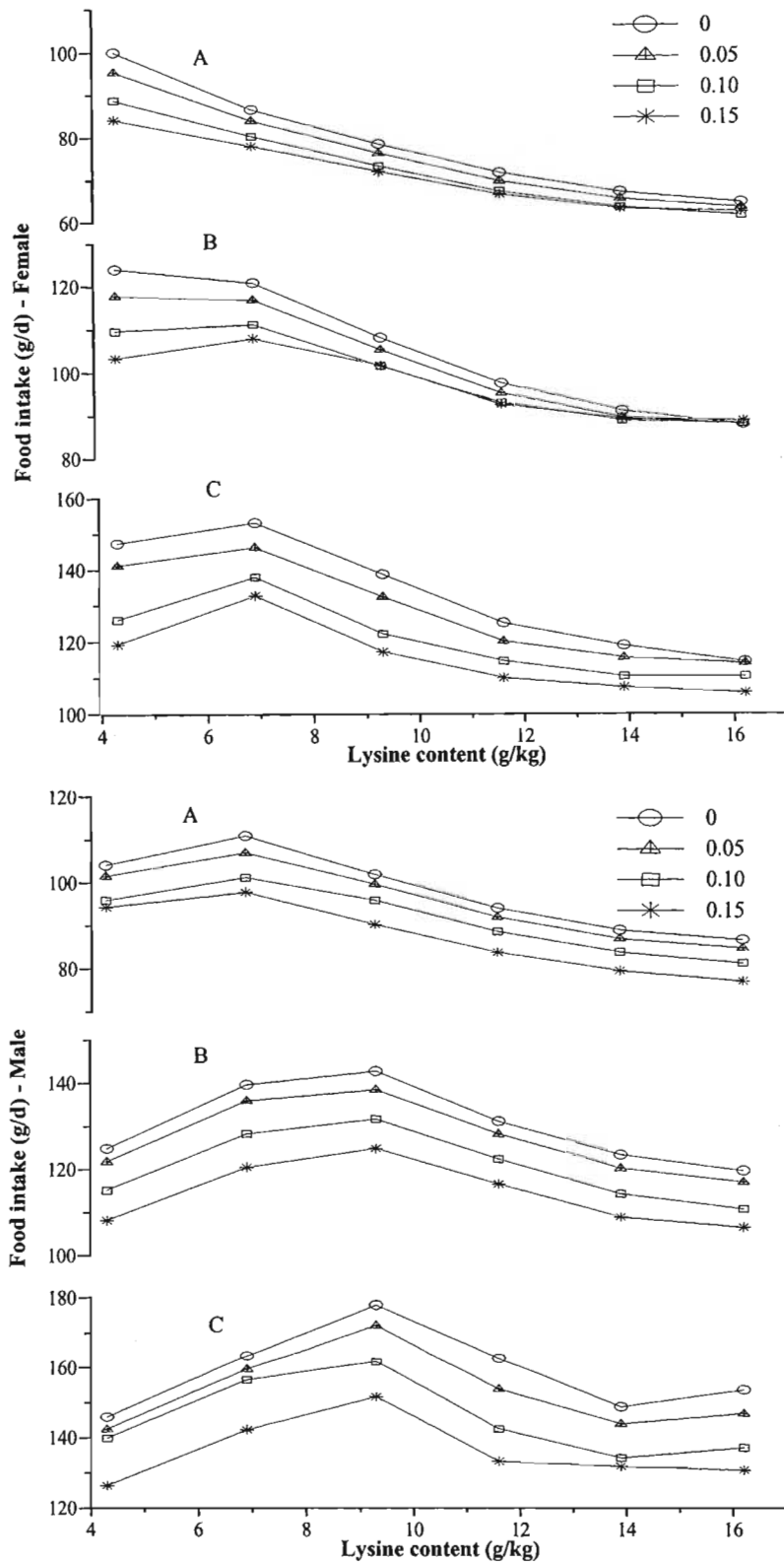
Figure 4.1 *The effect of variation in feathering rate (Fr) on food intake (g/d) of female (top) and male (bottom) broilers from 22 to 35 d of age, fed lysine-limiting feeds at environmental temperatures of 29°C (A), 25°C (B) and 21°C (C).*
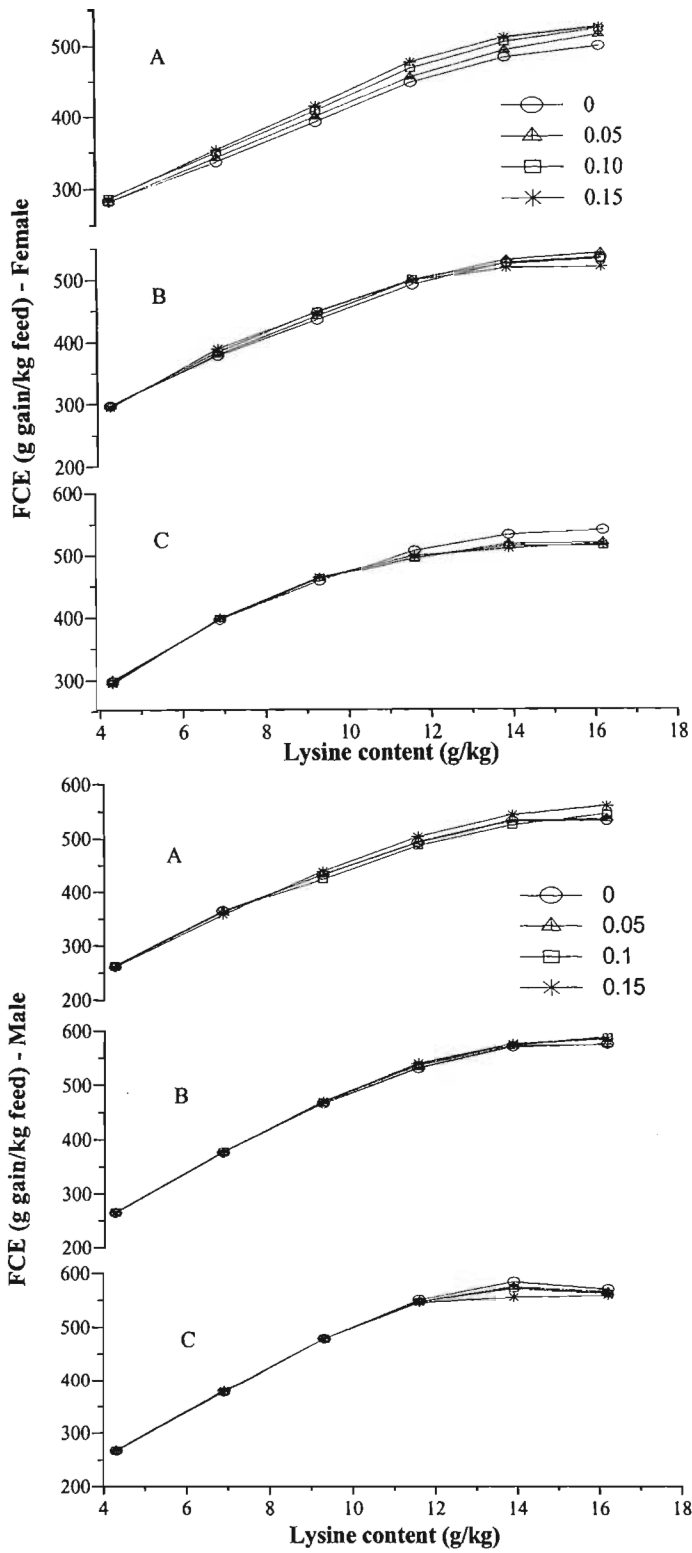
Figure 4.2 *The effect of variation in feathering rate (Fr) on feed conversion efficiency (FCE) (g gain/kg feed) of female (top) and male (bottom) broilers from 22 to 35 d of age, fed lysine-limiting feeds at environmental temperatures of 29°C (A), 25°C (B) and 21°C (C).*
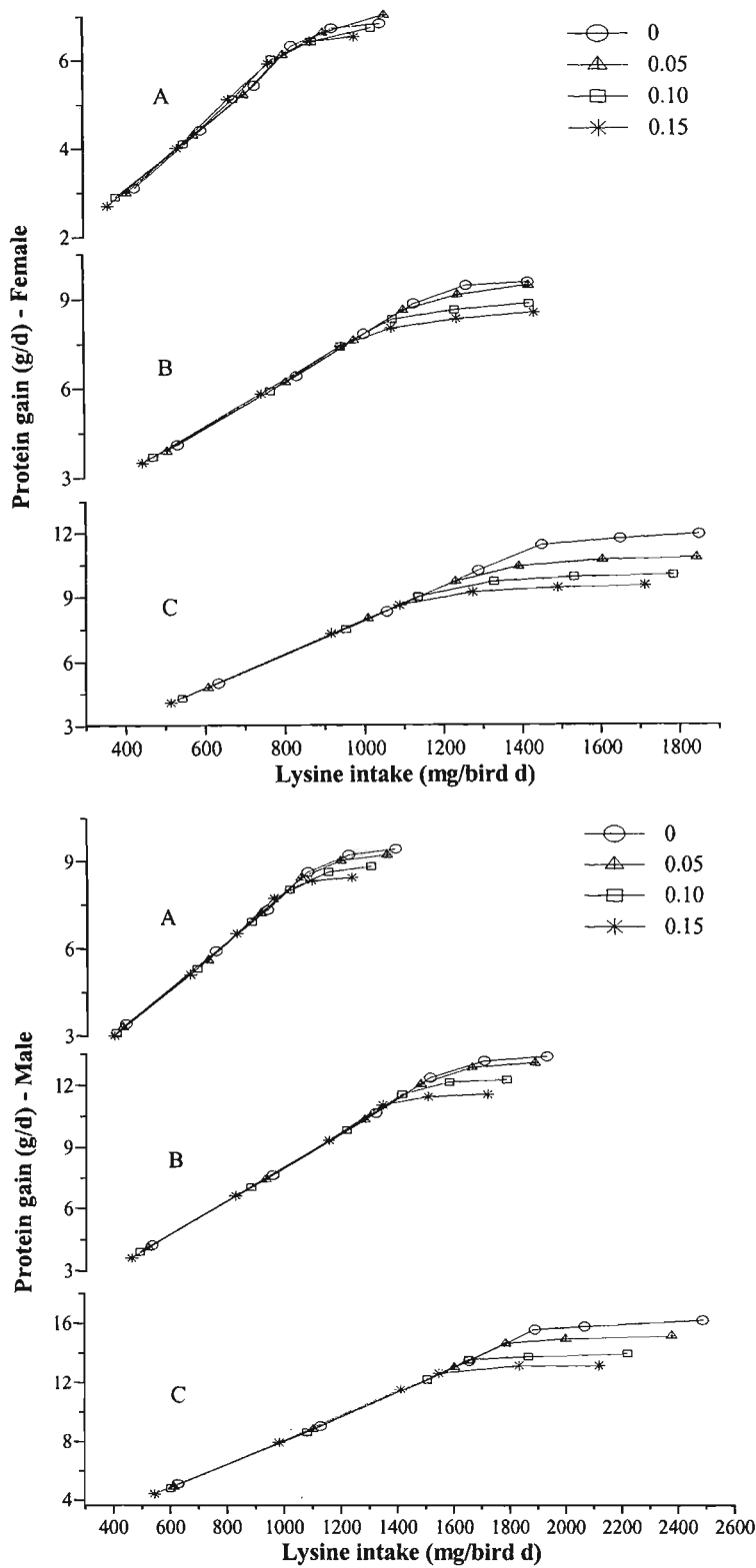
Figure 4.3 *The effect of variation in feathering rate (Fr) on protein gain (g/d) of female (top) and male (bottom) broilers from 22 to 35 d of age, fed lysine-limiting feeds at environmental temperatures of 29°C (A), 25°C (B) and 21°C (C).*
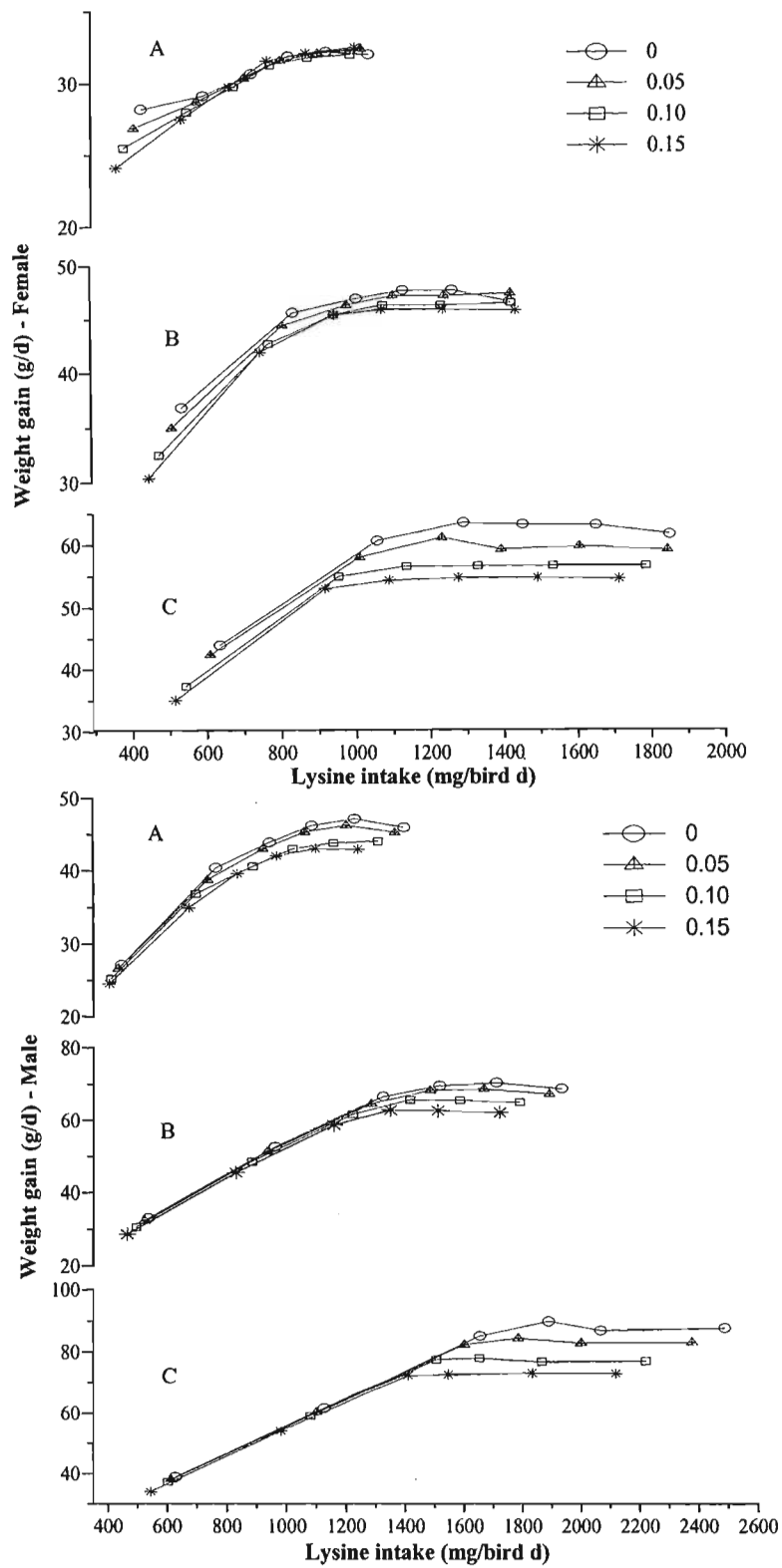
Figure 4.4 *The effect of variation in feathering rate (Fr) on weight gain (g/d) of female (top) and male (bottom) broilers from 22 to 35 d of age, fed lysine-limiting feeds at environmental temperatures of 29°C (A), 25°C (B) and 21°C (C).*

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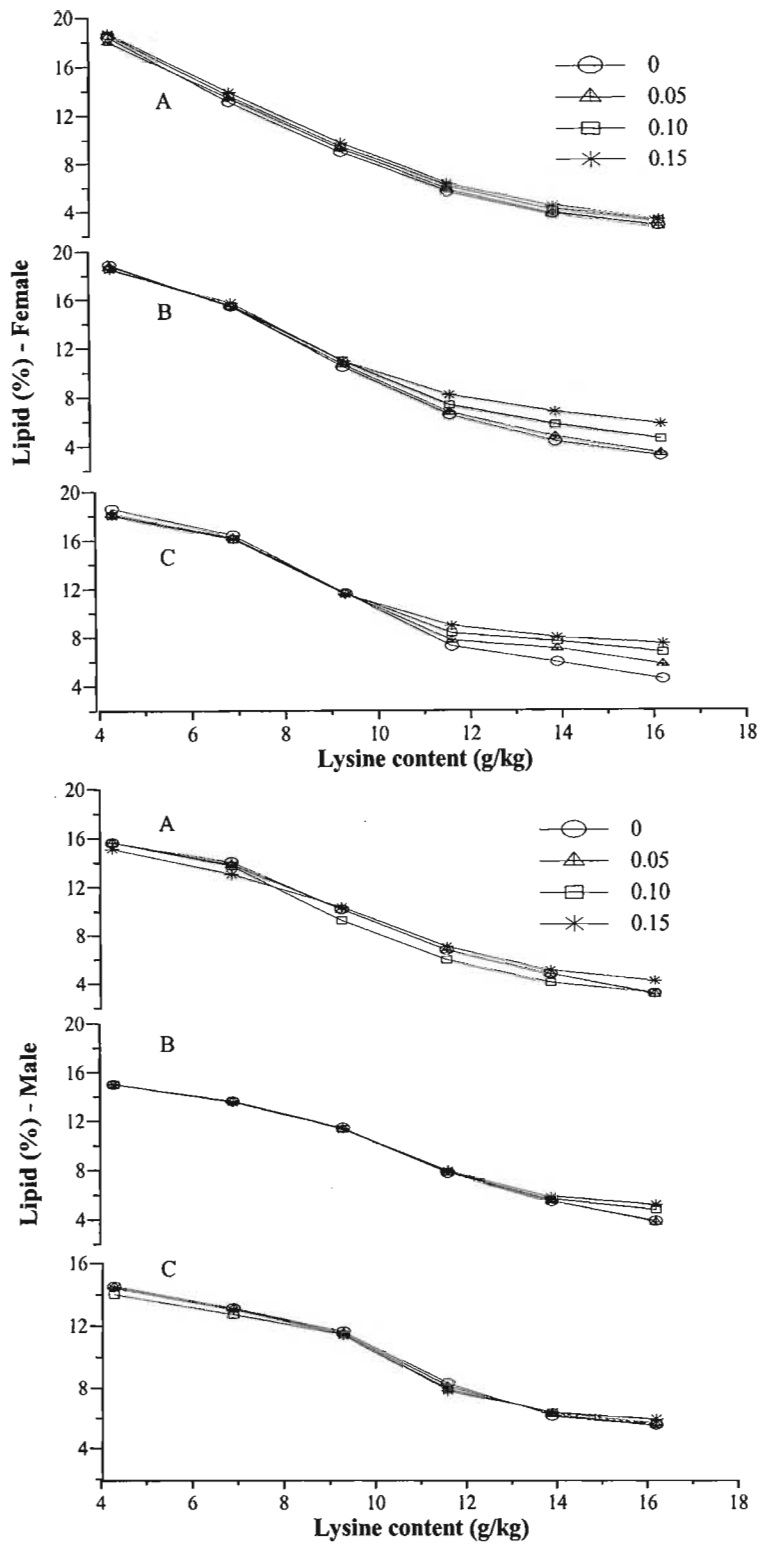
Figure 4.5 *The effect of variation in feathering rate (Fr) on lipid percentage (%) of female (top) and male (bottom) broilers from 22 to 35 d of age, fed lysine-limiting feeds at environmental temperatures of 29°C (A), 25°C (B) and 21°C (C).*

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4.4 Discussion

The performance of a broiler population depends largely on the inherited genotype of an individual bird in a population and the extent to which the genotype varies between individuals (Emmans and Fisher, 1986; Knap, 1995). Feathering rate is one of the genetic parameters that affect the above variables in terms of insulation and heat dissipation (Yahav *et al.*, 1996) and it also has a significant impact on the ideal protein ratio (Fisher, 1993, as cited by Fisher and Gous, 2000). Furthermore, whether a particular feed is balanced or not in a given environment depends on the feathering characteristics of the bird (Emmans, 1987b). Also, heat loss of the bird varies in some way with the temperature of the environment (Emmans and Fisher, 1986; Gous, 1998). Thus, an accurate prediction of growth and amino acid requirements depends, among many others, on the variation that could be expected in the rate of feathering of individuals in a population of broilers.

The sensitivity analysis reported in the previous chapter showed that the model output in terms of FI, PG, WG and FCE was strongly sensitive and non-linear to changes in Fr. Because of the non-linear nature of the response to changes in Fr, where the variation in Fr between individuals is high, a wider distribution in the performance of a population is expected.

The response in FI due to variation in Fr varied between sexes. Food intake first increased and then decreased in both sexes as the dietary lysine and temperature increased from 4 to 16g digestible lysine/kg which was to be expected. In females, over the range of Fr used, the difference in FI was about 25g/d on the lowest lysine feed at 21°C, and 15g/d at 29°C, but this difference decreased as the lysine content increased, and almost disappeared (10g/d at 21°C and 4g/d at 29°C). However, in males, the difference in food intake resulting from differences in Fr (20 and 10g/d on the low lysine feed at 21 and 29 °C respectively) was maintained throughout the range of lysine contents used. This is partly due to the lower requirement for lysine in females than in males. Hence, at high lysine contents, nutrient requirements were met in the females at a lower food intake relative to that in males. Conversely, when feeds low in lysine are fed to broilers, food intake is generally increased in an attempt by each bird to consume sufficient lysine to meet its requirement, 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). Feather cover is an effective barrier preventing heat from being lost by the bird, so the food intake of fast-feathering strains will be constrained before that of poorly feathered birds, especially on low lysine feeds and at high temperatures. In the above exercise, those broilers that had a fast feathering rate reduced FI more than did those with a slower Fr at low lysine contents and at high temperatures. The variation in FI at low and high lysine contents among males and females resulted in different trends in protein and weight gains.

Although protein gains were the same, within a sex, for low lysine intakes at the three temperatures used in the simulations, lower maximum protein gains were observed when the temperature was increased, regardless of the CV of Fr or lysine content. Even though food intakes on the low lysine feeds varied considerably as a result of variation in Fr, protein gains were unaffected by this variation when plotted against lysine intake. However, even on high lysine feeds, where the differences in food intakes were maintained (in males), protein gains varied considerably because the maximum growth rates were increasingly constrained by the inability to lose heat to the environment. Separation of the protein response curves occurred in females at lysine intakes of 1100, 1000 and 900mg/d at 21, 25 and 29 °C respectively, and for males, at 1600, 1400 and 1100mg lysine/d, the difference in maximum protein gain being greater at 21°C (3g/d) than at 29°C (less than 1g/d) in both males and females.

Pomar *et al.* (2003) simulated a population of pigs using a similar technique as to this study to deal with variations between individuals. They reported that maximum protein deposition occurred when there was no variation in a population of pigs and that the degree of curvature of the transition zone increased with the population variability. The findings in this study are in agreement with those of Pomar *et al.* (2003): less protein was deposited and there was a greater degree of curvature in the response in more variable populations.

It is clear that as the content of the limiting nutrient in the feed was reduced, birds consumed more food to meet their body requirements, leading to increasing intakes of energy which must either be deposited as fat or lost to the environment in the form of heat. That is why the lipid deposition was high at low lysine and decreased with increasing lysine intakes and also increased as the temperature increased. Variation in the ratio of E:P will have significant effects on the overall performance of broilers as well as in the composition of live weight gain. Carcass composition is dependent on environmental temperature: fat and energy in the carcass increase as the temperature increased (Leenstra and Cahaner, 1991). Increasing the variation in Fr resulted in a difference in lipid content at high lysine intakes, with more lipids being deposited when the variation in Fr was 0.15 than when there was no variation in the population. The decrease in feather cover allows a greater heat loss, which reduces the amount of fat in the carcass. Considering the feather coverage in females, less energy was dissipated to the environment. Moreover, females have higher lipid deposition potentials than males (Gous et al., 1990). Hence, differences in the proportion of lipid in the gain will affect the response in gain between sexes, resulting from differences in feathering rate.

The response in weight gain to feeds containing increasing concentrations of lysine is similar to the model proposed by Fisher et al. (1973). Hence, weight gain increased as lysine intake increased until it reached a maximum and became constant at high lysine intakes.

Feed conversion efficiency increased with increasing lysine content due to reduced FI for a given gain in weight. No observable difference occurred in FCE as variation in Fr increased, although there was a slight difference at the highest environmental temperature. Thus, a reduction in feather cover does not necessarily penalise efficiency.

In general, it can be concluded that variation in Fr had a significant effect on all measures of performance of a broiler population, the response of the population differing from that of an individual bird. Variation in feathering rate and the temperature of the environment affected the population response differently as lysine supply increased. One cannot expect high performance from a flock with a low uniformity. Substantial deviations from the potential performance of broilers resulted from an increase in environmental temperature to 29°C, and

when the feed protein content was reduced. However, all the results presented in this study were derived from simulations in which only Fr was varied, while variation in the five other genetic parameters was held constant. Some of these parameters might have an effect when the feed type or environmental temperature changed. For instance, lipid to protein ratio is the most likely to be influenced by exogenous factors such as temperature and feed type (Hruby *et al.*, 1995). In addition, MLG might contribute an effect to the population at low lysine and high temperature although by a small amount. Therefore, it is important to determine the effect of changing two or three parameters in addition to one factor at a time in producing the model results.

CHAPTER FIVE

Accounting for variation between individuals when optimising the feeding of a broiler flock

5.1 Introduction

Broilers have been produced commercially since the early 1940's and research has been conducted for years to improve production efficiency. Much research has been directed towards finding the optimum feeding programme for a population of broilers. On the other hand, little research has been conducted to determine the effect of variation among broilers of the same strain when defining the nutrient requirements.

Both the generation interval of about one year and varied selection programmes have helped create a large number of distinct breeds, strains and lines of broilers. Different selection criteria are used by the major breeding companies, leading to widely different genotypes being available to the broiler industry (Gous, 1998). Each bird has its own characteristic values of the inherited parameters that describe its potential. Emmans (1987b) outlined two possible sources of variation in genotype. The first is what they are like when mature, i.e. how big is the bird at maturity and its composition at maturity. The second is the path of development that they take to get to maturity.

Of greater importance to the broiler producer, once a strain has been selected, is the variation that occurs in growth rate and carcass composition within each batch of broilers. The variation between males and females is obvious and many companies now rear these two sexes separately, thereby taking advantage of the reduced variation to make decisions about feeding and environmental management. But even where one sex is reared on its own, variation in final body weight, carcass yield, feed efficiency and other production parameters of importance makes it difficult to produce a uniform product, which the consumer demands.

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Variation in processing yields within a flock of broilers at a time and over time is another area which requires further research in order to maximize profit, where parts of chicken are sold separately. For example, the way in which the yield of breast meat changes as a bird grows and variations among individuals are of considerable importance in deciding the optimal weight for slaughter (Gous *et al.*, 1999).

The trial reported here was directed towards measuring the amount of variation among broilers of the same strain, subjected to the same feed and a similar environment, with the aim of determining more accurately the coefficients of variation in genotype parameters, and simulating a population with the same amount of variation as measured in this trial. Once an accurate estimate of genetic variation in a population is known, it would be possible to determine the consequences of such variation when defining the nutrient requirements of commercial broilers when subjected to the same environment and feed type. Thus, the objective of the experiment was to determine the extent to which individuals within a genotype vary in terms of growth rate and carcass yield.

5.2   Materials and methods

A total of 240 day-old Ross broilers, 120 males and 120 females were used in the experiment. Upon arrival at Ukulinga Research Farm the 1-d-old chicks were weighed individually. Birds were randomly assigned to one of four floor pens of the same dimensions (1.5m x 2m) and containing the same number and distribution of feeders (2 per pen) and drinkers (nipples). Each pen housed 60 broilers, 20 at birds/m^2. Each of the birds was wing banded at 6 days of age. Wood shavings were used as bedding. A continuous lighting regime was used. Gas heating was used, with canopy brooders. A mini-pelleted starter feed was fed to 14 d of age; from 15 to 32 d the birds were fed grower feed; and for the last two days they were fed pelleted finisher feed. Feed and water were offered *ad libitum* throughout the trial. The broilers were under the same treatment throughout the trials.

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To supplement the data collected in this trial, data were made available from two previous trials, in which eight genotypes had been evaluated. Carcass data from a total of 96 birds of the same genotype as was used in the present trial were available from the two previous trials.

Measurements

The live weight data were collected only from the present experiment, but the eviscerated data from all three trials were included. The body weight of each surviving bird was recorded weekly. At the end of the experiment (35d) the broilers were weighed and the feed was removed from the pen at 10:00 pm to decrease the amount of feed remaining in the crop and proventriculus. Birds were processed from 8:00am the following morning, each bird being weighed immediately prior to slaughter. Birds were killed by exsanguination, after which they were scalded, plucked and eviscerated. The birds were weighed after exsanguination and again after plucking to determine the weights of blood and feathers. The eviscerated birds were placed in a cold room overnight. The next day birds were reweighed (chilled carcass weight) and dissected according to the standard procedure to determine the yield of different portions of the carcass; the weight of these portions was recorded.

Statistical analysis

Once the weights of all individuals were inserted in an Excel spreadsheet, the data were rearranged according to sex and analysed using analysis of variance procedures of Genstat (2002). The means and coefficients of variation (CV) were calculated for both sexes. The percentages of abdominal fat pad and giblets were calculated based on the weight at slaughter. The data from two additional experiments, conducted at Ukulinga at a different time, were used and analysed separately. In all three trials, birds were slaughtered at 35 days of age, with a total of 301 birds being evaluated.

5.3   Results

The mean live weight, the range in live weight and variation amongst males and females for each week are shown in Table 5.1. Although there was no difference in mean live weight at 1 day old between the two sexes, there were significant differences (P<0.05) at the end of the

4th and 5th weeks of the trial. The CV between individuals of the two sexes was almost the same throughout the trial. Moreover, the pattern of CV was the same for both sexes. The average daily gain throughout the experiment was 59.5 ± 5.4 and 63.9 ± 5.1 g/d for females and males, respectively.

The mean weight, SE and CV of the different carcass portions for females and males in the three experiments are given in Tables 5.2a and 5.2b. Because males were heavier at 35d than females all carcass portions were heavier, while the average abdominal fat pad was larger (18.1g/kg live weight). However, there was less variation in the weights of carcass components in females than in males (16.9g/kg live weight). The CV of the mean abdominal fat pad weight for both sexes was much larger than for the mean live and mean carcass weights. The average giblets yield was 6.5 and 6.2% of the average live weight of females and males, respectively. The highest variation was observed in drumstick skin and abdominal fat pad weights for females and males, respectively, whereas the lowest was in live weight in both sexes. The dispersion of body weight was highest at the age of 5 weeks (Figure 5.1). The correlation coefficients (r) for carcass portion weights from Experiment 3 are presented in Tables 5.3a and 5.3b, for females and males respectively. Correlations between each of the heavier parts (breasts, thighs, and drumsticks) and live or eviscerated weight were over 0.7. The correlations among the portions were almost similar in both sexes. However, the correlations for abdominal fat pad and heart with live or eviscerated weight were significantly higher in males than in females (P<0.05).

Table 5.1   *Mean, range in live weight (g) and CV of females and males to 5 weeks of age*

| Week | Female | | | | Male | | | |
---	Mean	Range	SE[1]	CV%	Mean	Range	SE[1]	CV%
0	43.5	34.2 - 53.4	0.3	8.5	43.5	33.1 - 51.8	0.4	8.8
1	127	95.9 - 161	1.4	11.0	114	68.2 - 146	1.3	11.8
2	349	251 - 444	4.2	12.0	345	229 - 425	3.9	11.8
3	717	587 - 881	6.8	9.4	761	568 - 910	6.7	9.0
4	1248	927 - 1537	11.2	8.9	1291	1004 -1589	10.7	8.6
5	1792	1450 - 2220	15.7	8.7	1905	1550 -2240	14.3	7.7

[1]Standard error of mean.
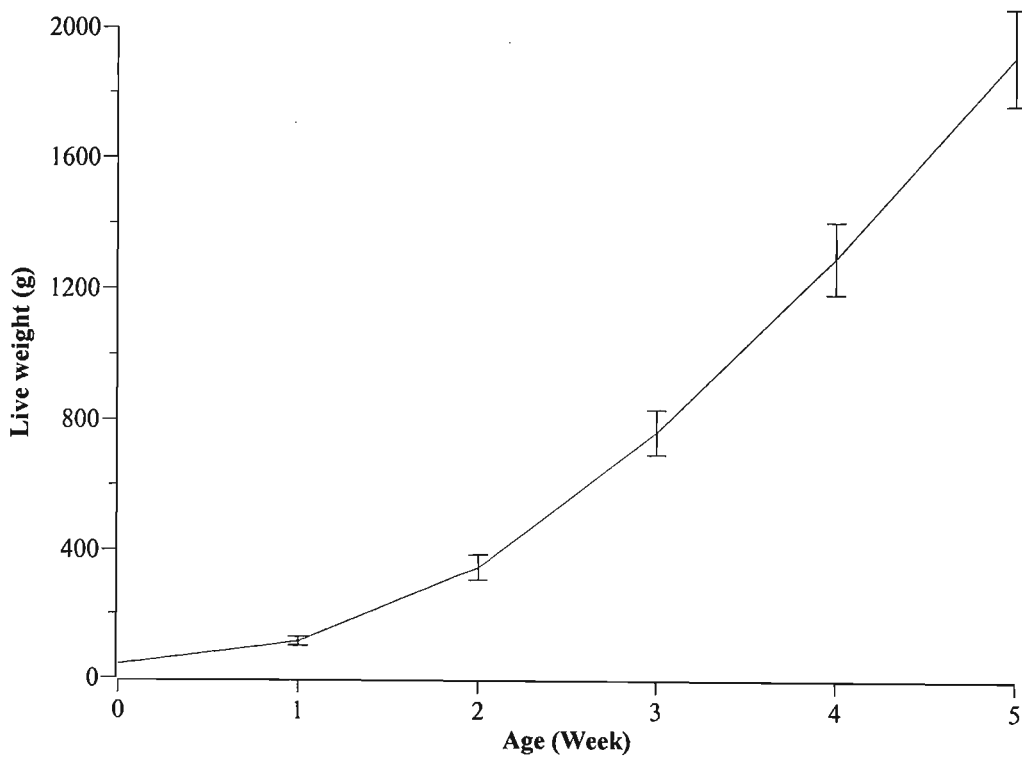
Figure 5.1   *Mean live weight of males for each week with confidence interval of SD. Since the variation between sexes was very similar, only one sex was displayed in the graph.*

Table 5.2a   *Mean weights, with SE and CV of carcass portions of female broilers at 35 days of age in three experiments*

Carcass	Mean				SE				CV (%)			
	Experiments				Experiments				Experiments			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
Live wt	1906	1865	1747	1840	30.4	36.3	14.0	26.9	7.8	9.5	8.0	8.4
Back	117	51.4	50.9	73.2	4.9	1.8	1.0	2.6	20.4	17.2	19.2	18.9
Blood	56.3	67.3	62.1	61.9	2.5	1.4	1.2	1.7	21.6	9.9	18.4	16.6
Fillet	41.4	43.9	40.5	41.9	1.3	1.4	0.7	1.1	15.8	15.5	16.2	15.8
Br-Wt	228	233	202	221	5.5	7.2	2.6	5.1	11.8	15.2	12.6	13.2
Br-skin	31.2	48.7	44.7	41.5	1.3	2.5	1.1	1.6	20.4	25.2	25.1	23.6
Chi -Wt	-	1340	1244	1292	-	32.1	11.2	21.7	-	11.7	8.8	10.3
Dr-Wt	168	173	160	167	3.4	3.6	2.6	3.2	9.9	10.2	17.8	12.6
Dr-skin	20.6	17.8	14.2	17.5	1.5	1.6	0.4	1.2	34.9	43.4	29.0	35.8
Evi -wt	1334	1444	1298	1359	23.0	37.4	11.5	24	8.4	12.7	8.7	9.9
Fat-pad	46.7	20.2	33.1	33.3	2.4	1.8	0.8	1.7	24.7	43.1	22.2	30.0
Feather wt	69	74.8	67.5	70.4	2.1	2.3	1.2	1.9	14.5	15.2	17.2	15.6
Feet	75.3	71.5	71.9	72.9	2.5	1.6	1.0	1.7	16.1	10.7	14	13.6
Giblets	129	118	112	120	2.2	5.2	1.8	3.1	8.5	18.7	9.8	12.3
Gizzard	28.5	38.3	27.8	31.5	1.0	2.3	0.4	1.2	16.6	29.4	15.5	20.5
Head	52.6	42.9	43.5	46.3	1.6	1.3	0.6	1.2	14.4	14.8	13.5	14.2
Heart	11.1	9.5	10.3	10.3	0.6	0.4	0.2	0.4	24.7	19.7	20.7	21.7
Liver	54.0	38.6	35.4	42.7	1.8	1.7	0.4	1.3	16.3	21.7	12.0	16.7
Neck	35.1	39.8	38	37.6	0.6	2.6	0.4	1.2	8.5	28.2	11.3	16
Neck-skin	35.7	33.5	36.8	35.3	2.1	3.0	1.1	2.1	27.4	42.3	29.7	33.1
Pars-nose	14.3	21.2	19.5	18.3	0.5	1.0	0.5	0.7	18.7	23.7	24.8	22.4
Thigh meat	288	271	269	276	4.8	6.6	2.6	4.7	8.2	12.0	9.7	10.0
Thigh skin	41.7	24.5	28.6	31.6	3.9	1.1	0.6	1.9	45.1	22.8	19.1	29.0
Wing drum	74.2	74.4	75.7	74.8	2.5	2.4	0.9	1.9	16.4	15.6	11.1	14.4
Wing-thigh	55.2	57.2	53.9	55.4	1.1	1.3	0.6	1.0	9.8	10.9	11.3	10.7
Wing-tip	20	17.5	18.4	18.6	0.7	0.4	0.3	0.5	16.8	11.2	17.8	15.3

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Table 5.2b *Mean weights, with SE and CV of carcass portions of male broilers at 35 days of age in three experiments*

Carcass	Mean				SE				CV (%)			
	Experiments				Experiments				Experiments			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
Live wt	1967	2105	1861	1978	27.0	41.0	14.0	27.3	7.0	10.0	8.0	8.3
Blood	60.3	77.0	70.6	69.3	1.7	2.3	0.9	1.6	13.6	14.4	13.7	13.9
Back	114	58.0	33.9	68.8	4.7	1.9	0.7	2.4	20.0	16.3	21.0	19.1
Fillet	40.7	47.5	40.0	42.7	1.5	1.6	0.7	1.3	18.0	16.5	18.2	17.6
Br-Wt	217	248	217	228	5.0	7.2	2.4	4.9	11.2	14.2	11.4	12.3
Br-skin	33.2	58.9	46.0	46.0	1.8	2.9	1.0	1.9	25.3	23.9	22.3	23.8
Chi -Wt	-	1502	1333	1418	-	29.8	10.8	20.3	-	9.7	8.4	9.1
Dr-Wt	180	207	180	189	4.8	4.4	1.8	3.7	13.1	10.5	10.3	11.3
Dr-skin	19.3	17.0	14.8	17.0	1.2	1.2	0.3	0.9	30.7	34.1	21.8	28.9
Evi- wt	1369	1575	1389	1444	22.3	27.1	11.6	20.3	8.0	8.4	8.6	8.3
Fat-pad	44	26.3	29.8	33.4	2.2	2.5	0.8	1.8	24.0	47.2	26.7	32.6
Feather wt	70.9	76.5	68.4	71.9	4.6	3.1	1.5	3.1	32.0	20.0	22.7	24.9
Feet	84.6	94.0	86.7	88.4	2.1	2.9	0.8	1.9	12.1	14.5	9.5	12.0
Giblets	126	125	115	122	2.6	2.4	1.2	2.1	10.2	9.4	10.3	10.0
Gizzard	28.4	35.0	28.9	30.8	1.0	1.6	0.5	1.0	17.1	21.7	17.8	18.9
Head	55.1	46.9	48.1	50.0	1.4	0.9	0.4	0.9	12.5	9.2	9.4	10.4
Heart	11.1	10.6	10.6	10.8	0.5	0.4	0.2	0.4	22.2	20.5	17.9	20.2
Liver	51	41.2	36.4	42.9	2.3	1.1	0.5	1.3	21.6	12.5	13.2	15.8
Neck	35.1	37.9	39.1	37.4	1.3	1.2	0.7	1.1	17.5	15.9	18.2	17.2
Neck-skin	40.0	41.8	33.9	38.6	1.9	3.5	0.7	2.0	23.3	40.8	21.0	28.4
Pars-nose	14.6	22.0	19.9	18.8	0.7	1.3	0.5	0.8	21.5	28.3	23.7	24.5
Thigh meat	292	318	296	302	5.5	8.5	2.8	5.6	9.3	13.1	9.9	10.8
Thigh skin	36.3	27.5	29.8	31.2	1.9	0.9	0.5	1.1	25.6	15.4	17.1	19.4
Wing drum	75.4	83.2	77.5	78.7	1.9	2.6	0.9	1.8	12.3	15.3	12.5	13.4
Wing thigh	58.2	63.3	57.1	59.5	1.1	1.5	0.5	1.0	9.3	11.9	9.5	10.2
Wing tip	21.2	20.6	20.1	20.6	0.7	0.6	0.2	0.5	16.6	13.6	11.0	13.7

Table 5.3a   *Correlation coefficients among different carcass components at 35 days of age for the Experiment 3 (female)*

	Back	Blood	Br-Meat	Chi-Wt	Dr-Wt	Evi-Wht	Fat-Pad	Fr-Wt	Feet	Fillet	Giblets	Giz	Head	Heart	Live	Liver	Neck	Thigh	Wg-Drum	Wg-Thigh
Blood	0.27																			
Br-Meat	0.32	0.29																		
Chi-Wt	0.46	0.46	0.76																	
Dr-Wt	0.35	0.44	0.51	0.81																
Evi-Wht	0.46	0.45	0.73	0.99	0.79															
Fat Pad	0.12	0.01	0.01	0.11	0.02	0.11														
Feather	0.10	0.17	0.18	0.25	0.18	0.24	0.06													
Feet	0.27	0.53	0.47	0.75	0.84	0.74	-0.07	0.12												
Fillet	0.21	0.27	0.45	0.43	0.31	0.40	0.10	0.02	0.25											
Giblets	0.18	0.34	0.17	0.42	0.45	0.42	0.10	0.18	0.39	0.15										
Gizzard	-0.00	0.14	-0.15	-0.01	0.04	0.01	0.13	0.02	0.09	-0.05	0.62									
Head	0.25	0.32	0.46	0.52	0.58	0.50	-0.06	0.23	0.63	0.13	0.36	0.06								
Heart	0.09	0.32	0.16	0.22	0.32	0.19	0.05	0.08	0.22	0.00	0.51	0.06	0.19							
Live	0.45	0.54	0.72	0.98	0.82	0.97	0.15	0.30	0.78	0.43	0.51	0.05	0.55	0.28						
Liver	0.15	0.23	0.26	0.49	0.39	0.47	0.17	0.16	0.29	0.26	0.65	0.11	0.36	0.23	0.54					
Neck	0.22	0.25	0.20	0.37	0.43	0.39	-0.10	0.19	0.39	0.14	0.75	0.25	0.30	0.37	0.44	0.27				
Thigh	0.26	0.36	0.53	0.81	0.56	0.82	-0.00	0.25	0.62	0.31	0.36	0.01	0.28	0.14	0.80	0.39	0.34			
Wg-Drum	0.27	0.33	0.15	0.43	0.34	0.46	-0.12	-0.00	0.32	0.13	0.19	-0.01	0.19	0.08	0.42	0.21	0.19	0.46		
Wg-Thigh	0.45	0.43	0.56	0.77	0.72	0.77	-0.18	0.27	0.66	0.35	0.30	-0.11	0.46	0.30	0.76	0.29	0.36	0.66	0.55	
Wg-Tip	0.34	0.21	0.19	0.39	0.40	0.41	-0.28	0.08	0.39	0.16	0.18	0.01	0.21	0.07	0.37	0.15	0.22	0.45	0.60	0.73

Br = Breast, Chi = Chilled, Dr = Drumstick, Evi = Eviscerated, Fr = Feather, Giz = Gizzard, Wg = Wing, Wt = Weight.

Table 5.3b   *Correlation coefficients among different carcass components at 35 days of age for the Experiment 3 (male)*

	Back	Blood	Br-Meat	Chi-Wt	Dr-Wt	Evi-Wht	Fat-Pad	Fr-Wt	Feet	Fillet	Giblets	Giz	Head	Heart	Live	Liver	Neck	Thigh	Wg-Drum	Wg-Thigh
Blood	0.16																			
Br-Meat	0.49	0.20																		
Chi-Wt	0.64	0.33	0.76																	
Dr-Meat	0.43	0.29	0.48	0.73																
Evi-Wht	0.64	0.31	0.76	0.99	0.71															
Fat-Pad	0.11	0.09	0.21	0.30	0.25	0.27														
Feather	0.19	-0.13	0.31	0.28	0.27	0.28	0.05													
Feet	0.32	0.12	0.20	0.36	0.30	0.38	0.12	0.06												
Fillet	0.37	0.21	0.52	0.45	0.40	0.45	0.23	0.14	0.23											
Giblets	0.14	0.36	0.26	0.36	0.31	0.36	0.26	0.03	0.33	0.15										
Gizzard	0.10	0.06	0.09	0.17	0.12	0.17	0.16	0.05	0.18	0.16	0.62									
Head	0.26	0.15	0.32	0.52	0.47	0.50	0.17	0.14	0.28	0.15	0.40	0.18								
Heart	0.03	0.10	0.22	0.17	0.16	0.16	0.09	0.03	0.14	0.09	0.41	0.06	0.26							
Live	0.61	0.39	0.74	0.98	0.73	0.96	0.39	0.31	0.38	0.45	0.45	0.22	0.56	0.19						
Liver	0.26	0.19	0.36	0.47	0.31	0.45	0.34	0.15	0.24	0.12	0.60	0.27	0.38	0.23	0.51					
Neck	-0.02	0.41	0.06	0.12	0.18	0.13	0.07	-0.10	0.22	0.03	0.71	0.11	0.21	0.21	0.20	0.06				
Thigh	0.47	0.23	0.50	0.81	0.53	0.79	0.31	0.14	0.28	0.26	0.34	0.23	0.50	0.10	0.81	0.35	0.13			
Wg-drum	0.15	0.21	0.29	0.40	0.38	0.38	0.09	0.13	0.15	0.09	0.19	0.04	0.20	0.10	0.41	0.19	0.13	0.31		
Wg-thigh	0.37	0.13	0.38	0.51	0.44	0.51	0.21	0.33	0.59	0.30	0.34	0.21	0.33	0.07	0.53	0.28	0.21	0.43	0.31	
Wg-tip	0.14	0.18	0.23	0.35	0.46	0.33	0.16	0.13	0.14	0.22	0.35	0.17	0.36	0.15	0.38	0.22	0.27	0.37	0.33	0.44

5.4 Discussion

The experiment was designed to provide feeding and environmental conditions to ensure maximum comfort for birds throughout the growing period of 5 weeks. Weighing the birds individually on farm or automatically in the processing factory, and calculating the average weight and CV can measure uniformity within a flock of broilers. Therefore, in order to determine the variation between individuals and sexes, CV for mean live weights per week were calculated and the different carcass portions at 35 days of age were measured. A large amount of variation between individuals reared in the same environment can indicate genetic variation (Leenstra, 1984).

Females had significantly (P<0.01) lower carcass yield than males, as observed in their greater final body weight in males. The range of CV of the variables between sexes was similar. That is, the CV was low (< 15%) for live weight, breast, drumstick and thigh meat, eviscerated weight, feet, giblets, head, wing drum and thigh for both sexes. On the other hand, neck skin, fat pad and drumstick skin had higher CV (> 25%). In addition, thigh skin had a higher CV in case of females. The variation in neck and drum skin and fat pad is unlikely to be due predominantly to genetic causes: this variation results, to a large degree, from differences within and between eviscerators when separating these parts from the eviscerated carcasses. The genetically determined CV for all parts, with the possible exception of fat pad weight, is likely to be less than 15% given the difficulty in eviscerating each carcass in exactly the same way.

Lipid deposition in the abdominal fat pad varied between sexes, this being more variable in males than in females, and with several males having no observable fat. The results reported in this study are in agreement with those obtained by Becker et al. (1979) and Leenstra (1984) whose studies in the same environment found that abdominal fat weight was the most variable trait with CV of between 24 to 47% and that the body weight had CV between 6 and 12%. Thus, the lowest variation between individuals was in live weight and the highest in carcass portions.

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A major difficulty is that the amount of abdominal fat has not yet been measured accurately on the live bird (Leenstra *et al.*, 1986). To determine whether the source of variation is due to the bird or the eviscerator, the correlation between components and live weight can be advantageous. For instance, the correlation between liver weight and live weight was high since it is easy to remove the liver. However, correlation between neck skin and live weight (not shown in the table) was negligible.

The difference in the growth response between males and females suggests that birds of different sexes have different nutritional requirements. By separating the sexes and rearing them in different broiler houses, the nutritionist would be able to apply a feeding programme that suits each sex more accurately, thereby improving the efficiency of utilization of the nutrients supplied to the birds. Males could be fed a higher protein feed throughout their lives and benefit from this. On the other hand, the protein content of feeds offered to the females could be reduced more rapidly over time than would be the case if they were reared together with the males, thus reducing feed cost, imposing less nutritional stress on the females and thus increasing the profitability of the enterprise. However, from the results presented here, there is still considerable variation within the population of each sex, which makes it difficult to optimise the feeding of a population of females or males. The key to prediction as to whether different broiler strains have different amino acid requirements lies in body composition (Peisker, 1999). This would help nutritionists to formulate different diets according to market demands as the nutrient requirements for different carcass portions vary considerably. Many broiler producers are not aware of the implications of variation in body weight and carcass traits in broilers.

It is not practicable to separate a population into further categories with respect to the different individuals at a time and/or within individuals over time due to the cost as well as the changes that take place in the genotype itself. It is a fact that an optimum feeding programme for broilers is that which results in maximum profitability for the enterprise. It is not easy to consider the factors using experimental results due to the requirements for complex and repetitive experiments. Furthermore, there are many factors that have to be integrated before the optimum decision can be implemented. These prompt the use of simulation models to make some economic decisions rapidly and accurately. Using simulation models, it is possible

to determine the main effects of variables and their interaction, which is not possible through experimentation due to complexity and cost. Thus, it is only with the use of simulation models that it is possible to gain a better understanding of the process involved in broiler growth and be able to take all these interacting factors into account (Gous, 1998) and to investigate the effect of variations between individuals in a defined environment (Gous, 2002) when optimizing a feeding programme for broilers.

Generally, the differences in the CV between sexes were less than 5% and females were more variable in the parameters measured than males. However, the weights of the abdominal fat pad, back, neck and parson nose were more variable in males. Individual variations were higher in carcass components than in live weights. Considering the variation between individuals, it is difficult to establish a single set of requirements that is appropriate for all individuals since poultry production is carried out using a population of birds. Although eviscerators may cause variation between birds, there are other environmental factors that would have some effect on this aspect. One needs to separate out the variation caused by genetic and non-genetic (i.e. environmental) factors, thereby comparing these sources of variation on the measures of performance. However, these other non-genetic sources of variation are difficult to simulate mechanistically in a proper way and have been avoided in this and previous stochastic models (Ferguson *et al.*, 1997; Pomar *et al.*, 2003).

GENERAL DISCUSSION

Broiler growth models have been developed and improved over time to simulate the growth and food intake of a bird. These models require accurate information if the simulations are to be realistic. Therefore, a clear description of the genotype is a prerequisite to predict a realistic response. In the exercise conducted in this thesis the response of a population of broilers was compared with that of the mean individual in the flock, which required that each parameter describing the broiler should be defined in terms of its mean and the standard deviation of the mean.

In the EFG broiler growth model used in this exercise, the Gompertz growth curve is used to describe the growth of a broiler, the parameters being the initial weight (W_0), the final (mature) protein weight (P_m) and the rate of maturing (B). In addition to these three parameters, three others are used, which account for the rate of feathering of the bird (Fr), the maximum amount of lipid that can be deposited in relation to the amount of body protein being deposited (MLG), and the lipid: protein ratio at maturity (LPR_m). In this thesis, each of these six parameters was considered to be stochastic, when generating data to be used for comparing the mean of a population of broilers with the average individual in the population.

The way in which these comparisons were made was to simulate the response of a population of individuals to increasing dietary lysine contents over two periods of growth and then to compare the simulated responses with that of the mean individual in the population. There was a difference in the response between the average individual within a population and the population mean in many of the measures of performance. Therefore, it is inappropriate to believe that the deterministically simulated response of an individual is representative of the population mean (Ferguson *et al.*, 1997; Gous, 1998).

Three exercises were conducted in this study: in the first, the six parameters describing a genotype were made stochastic by applying appropriate coefficients of variation (CV) to each of the parameters, and measuring the responses to six levels of lysine in a dilution series. In the second, a sensitivity analysis was used to evaluate the effects of variation in each of the parameters, in turn, on the response to the six lysine levels. In the third exercise,

measurements were taken of the variation in growth and carcass components in a sample population of broilers, so that this measured variation could be compared with the simulated variation obtained in the first exercise conducted.

In the first exercise, the response of the simulated population differed from the single bird, or population mean, response; the response in most cases being more curvilinear in shape. For instance, increasing variation between individuals had a significant effect on population food intake in both magnitude and shape; as a result, protein and weight gain curves were changed. This is in agreement with Curnow (1973), Fisher et $al.$ (1973) and Pomar et $al.$ (2003). A population model is likely to be more accurate and realistic than a single-bird model. However, it is interesting to note that the response of an individual to increasing contents of dietary lysine is curvilinear, not a broken stick as would be expected when measuring the response of an individual on a day. This is because a feed that is initially unable to meet the requirements of the bird becomes adequate as the bird grows and as the capacity of the bird to consume sufficient of that feed increases. The extent to which the curvature brought about by the population response alters the curvature already displayed by an individual over a period of time was not resolved in this exercise.

In the second exercise, the parameters W_0, P_m, and LPR_m had equal but opposite effects when values above and below the mean were used, so the effect on the population mean was minimal. Both MLG and Fr caused deviations to occur from the mean individual in the population when values above and below the mean were used: values of MLG below the mean caused significant depression in food intake and hence growth rate especially on low lysine feeds, this being the result of the inability of birds with a low MLG to overconsume energy in their attempt to consume sufficient lysine to grow at their potential. This problem did not arise for birds with high values of MLG, which were less-severely affected by the low lysine feeds, or for any of the birds when the dietary lysine content was high. Conversely, the value for Fr had little effect on the response of broilers at low lysine contents, but at high lysine contents those birds with high values of Fr were unable to lose heat to the environment, so their response to increasing lysine contents was for food intake and growth rate to decrease, with very little effect for low values of Fr. Hence these two genetic parameters can significantly influence the population response to a range of feeds varying in lysine content,

and it is of importance therefore to obtain reasonably accurate estimates of their CV if a realistic simulation of a population is expected.

A comparison of the CV between actual experiments and population simulation responses, conducted as the third exercise in this thesis, shows that the CV obtained in the trials were similar to the results of the population model at the level of 5% CV for Fr, the difference increasing as the CV of Fr increased. This suggested that 5% of CV in Fr is a practical variation in the real population of broilers, although further investigation is required to confirm the results obtained in this exercise.

The simulation response in this study addresses only the genetic aspect of variation between individuals within a population. However, variation in environmental conditions within the broiler house, variation observed during and after feed mixing, and feed accessibility would all be sources of variation that would influence the population response in such a model, and would be fruitful for further research. In addition, the effect of variation in genotype was not tested at different nutrient densities, temperatures, energy: protein ratios or combinations of these variables. Thus, the response of the average individual within a population and the population mean need to be simulated using the above factors in the EFG broiler growth Model to increase the strength of predicting precise values of the model.

Implications for industry

Poor uniformity reduces revenue and increases waste, and therefore optimisation programs should account for all factors that may influence uniformity. This study addressed only the effect of one small, though important, part of the genetic variation that occurs between individuals within a population. In addition to genetic variation, account should also be taken of variation brought about by feed composition and in the environmental temperature and humidity to which the broilers are subjected. When optimising the feeding of a population of broilers, accounting for such variation is particularly important if realistic feeds and feeding programmes are to be expected. Strain differences in down-grading and mortality, in response to marginally deficient feeds, may not be easy to simulate mechanistically, but if hard evidence is available of such differences, these should be incorporated into optimisation programs. Productivity in the Poultry Industry will benefit from such an exercise.

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