Allometric description of ostrich (*Struthio camelus* var. *domesticus*) growth and development

by

Werné Jacobus Kritzinger

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Agriculture (Animal Science)

at

Stellenbosch University

Department of Animal Sciences

Faculty of AgriScience

Supervisor: Prof. T.S. Brand

Co-supervisor: Prof. L.C. Hoffman

Prof. F.D. Mellett

Date: *March* 2011

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: February 2011

Part of this thesis was presented at:

1. **SASAS 43rd Congress,** Alpine Heath, Durban, July 2009 in the form of one poster.

Poster

Kritzinger, W. J., Brand, T. S., Hoffman, L. C., and Mellett, F. D., 2009. A description of body composition change in ostriches (*Struthio camelus*) under optimal feeding conditions.

2. **World Poultry Science Association Conference (WPSA),** CSIR, Pretoria, October 2010 in the form of one poster.

Poster

Kritzinger, W. J., Brand, T. S., Hoffman, L. C., and Mellett, F. D., 2009. A description of body composition change in ostriches (*Struthio camelus*) under optimal feeding conditions.

Publication

1. Kritzinger, W. J., Brand, T. S., Gous, R. M., Hoffman, L. C., Mellett, F. D., 2010. Preliminary results on the description of body composition change in ostriches (*Struthio camelus*) under optimal feeding conditions. South African Journal of Animal Science, In press

Acknowledgements

This research was carried out under the auspices of the Western Cape Department of Agriculture at the Institute for Animal Production: Elsenburg. Permission to use results from the project: Development of a mathematical optimization model for ostriches (project leader – Prof. T. S. Brand), for a postgraduate study, is hereby acknowledged and is greatly appreciated.

It is with gratitude and love that I thank the following people and institutions.

The Western Cape Agricultural Research Trust (the bank): for assisting my campaign to escape from prison with financial support.

Institute of Animal Production – Elsenburg (police): for keeping me on the path when I wanted to stray.

Prof. Tertius Brand (the boss): your upbeat, optimistic and never back down approach to science is truly inspiring. Thanks for making sure I learned the lessons necessary for success in life. I shall remember.

Prof. Louw Hoffman (the mediator): you know that I know that you know that I know that you know what I'm thankful for. You made headway in teaching me your art of negotiation and laid-back approach to life. I am truthfully thankful.

Prof. Francois Mellett (the purist): your unwavering and constant strive for perfect science is a rare quality that I emphatically enjoyed. Thank you for teaching me the rules, laws and principles to conduct pure science. Keep it up.

Prof. Rob Gous (the mentalist): your relaxed and zen-like approach to science is an example to all. Thank you for making your ideas reality and inspiring others to do the same.

Mnr Bennie Aucamp and Mrs Annelie Kruger (enforcers): without data, no study is possible.

Mrs Gail Jordaan (the helping hand): you really are the bomb. You blew me away with your patience and persistence and I blew your computer with my stacks of data. Words cannot describe the gratitude I feel towards you. Keep your light shining.

Coleen Leygonie, Danie Bekker, Dr. Francois van de Vyver and Theodore Olivier ("baggage" removal assistants): Thank you for keeping me semi-sane, half of the time. I know the ears are burning, but thanks for listening. Love.

Michael Litch, Jan Fortuin, Pieter Adams and Sameul Adams (guardians): thanks for keeping my birds alive up to their time of departure.

Me S. Booysen (separator): thank you for dissecting my birds into experimental pieces.

To our Greater Power: Thanks for creating the game of life I so enjoy playing. Help me to spread the love.

Table of Content

Abstract

Title:	**Modelling ostrich (*Struthio camelus* var. *domesticus*) growth and development**
Candidate:	**Werné Jacobus Kritzinger**
Supervisor:	**Prof. T. S. Brand**
Co-supervisors:	**Prof. L. C. Hoffman**
	Prof. F. D. Mellett
Department:	**Animal Sciences**
Faculty:	**Agricultural and Forestry Sciences**
University:	**Stellenbosch**
Degree:	**M. Sc. Agric**

The ostrich industry has overcome many challenges since it originated. However, it is still vulnerable to sudden changes in customer preferences and economic cycles. As feed costs are the greatest expense in ostrich production, optimising feed formulations is vital. This will be possible if the growth and development of the ostrich can be simulated by modelling software. Various studies were conducted to describe ostrich growth in the form of equations that can be used in modelling software to increase the accuracy of predictions.

In the first study, birds were given the choice of four diets with varying energy (8.5 or 13.5 MJ ME/kg feed) and protein (180 or 120 g/kg feed) levels. The birds preferred the high density diet (high energy and protein) in each growth phase. A growth curve of assumed optimal growth was constructed. The chemical fractions of the body were shown to increase non-linearly with advancing age and equations were established to predict the change of the body composition over time.

In the second trial, birds received a formulated growth diet and were fed according to their nutrient requirements. Growth data was collected on the separate body components of maturing birds. Feather and skin nodule growth was defined for birds hatched in the summer. Allometric equations were set up to determine, predict and model the ostrich skin size and skin weight, some bones, some organs and the commercially valuable muscles through the growth cycle.

The final trial was conducted to determine the effect of diet density (energy and amino acid level) on the growth of ostrich body components. A four-stage, 3 x 5 (energy x protein) factorial design was developed with varying energy and protein feeding regimes. Protein (amino acid) level had no influence on body component growth. Energy level had no effect on feather growth, skin nodule

growth, bone and organ growth and muscle growth. Increased levels of dietary energy increased the skin size and skin weight. Increasing the dietary energy level also had a significant effect on the total body fat of the birds. Allometric equations were set up for each variable to predict the effect of diet on ostrich growth.

Results in this study provide a framework for simulation modelling. Predicting ostrich growth and development is paramount to accurate diet formulations and lower feeding costs.

Uittreksel

Die volstruisindustrie het reeds vele struikelblokke oorkom, maar bly steeds kwesbaar vir skielike veranderinge in die ekonomiese klimaat asook in die voorkeure van die verbruiker. Een van die belangrikste insetkostes in volstruisproduksie is voer en daarom is dit noodsaaklik om voerformulerings te optimiseer. Die doel van hierdie tesis was om by te dra tot die ontwikkeling van modellering sagteware wat die groei en ontwikkeling van die volstruis naboots. Die spesifieke doel was om volstruisgroei te bestudeer en te bespreek deur middel van vergelykings wat gebruik kan word om die akkuraatheid van die simulasiemodelle te verhoog.

Tydens die eerste studie is die voëls die keuse van vier diëte gegee waarvan die energie- (8.5 of 13.5 MJ ME/kg voer) en proteïen- (180 of 120 g/kg voer) vlakke verskil het. Die voëls het in die hoë-digtheid voer (hoog in energie en proteïen) in elke groeifase gekies. Uit hierdie data, wat aanvaar is om optimale groei te verteenwoordig, is ‘n groeikurwe gekonstrueer wat getoon het dat die chemise komponente van die liggaam nie-linieêr toegeneem het oor tyd. Vergelykings is hieruit afgelei wat die verandering in die liggaamsamestelling oor tyd kan voorspel.

In die tweede studie het die voëls ’n vier-fase geformuleerde groeidieët ontvang en is na gelang van hulle voedings behoeftes gevoer. Groeidata is ingesamel van die individuele liggaams-komponente van die groeiende volstruise. Veer- en velgroei is gedefinieer vir die voëls wat in die somer uitgebroei het. Allometriese vergelykings is opgestel om te bepaal hoe die volstruis se velgrootte, velgewig, sekere bene en organe, asook die kommersiële belangrike spiere gedurende die groei-siklus verander.

Die finale studie is uitgevoer om die effek van voedingsvlak (energie- en aminosuurvlak) op die groei van die volstruis se liggaamskomponente te bepaal. ’n Vier-fase, 3 x 5 (energie x proteïen) faktoriale ontwerp is gebruik met veranderende energie- en proteïenvlakke. Proteïen- (aminosuur) vlakke het geen invloed op die groei van die liggaamskomponente gehad nie. Energievlak het geen effek op die veer-, vel-, velknoppie-, been-, organe- en spiergroei gehad nie. Toenemende vlakke van energie het wel gelei tot ’n toename in die velgrootte en massa. Die toename in voedingsengergie-vlakke het ook ’n betekenisvolle effek op die totale liggaamsvet van die voëls gehad. Allometriese vergelykings is opgestel vir elk van die veranderlikes om die effek van dieët op elke komponent van die volstruis te bepaal.

Die resultate van hierdie studies verskaf ‘n raamwerk vir die simulering en modellering van die groei en ontwikkeling van die volstruis. Akkurate voorspellings van die groei en ontwikkeling van die volstruis is noodsaaklik vir akkurate dieëtformulering en verlaagde voedingskostes.

General Introduction

Ostrich farming is well established in Southern Africa and contributes greatly to the economy of the Western Cape. However, the industry is vulnerable to sudden changes in economic conditions and consumer preferences with regards to leather products, feathers and meat.

The cost of feed is the largest expense in an intensive ostrich production system. This creates the need to optimise ostrich production by maximising growth and reducing feeding costs. Creating a model that simulates the growth and performance of ostriches reared under various conditions will increase the flexibility of ostrich farming and reduce production costs. When growth is simulated, the nutrient requirements of the birds can be modelled as it changes throughout the growth cycle.

A fundamental step toward the prediction and modelling of ostrich production as a system is to have an in depth knowledge on the theory of the particular system. Biological responses to changing circumstances need to be defined scientifically.

This research was therefore conducted to provide some insight into ostrich growth.

Chapter 1
Literature review

To enable the prediction of the nutrient requirements of any animal, knowledge of how the animal grows is required. As biological tissue grows in a similar way, mathematical equations can be fitted to growth data to enable the simulation of animal growth as it advances in age.

1.1 Introduction to modelling

Models are a simplified representation of reality. It provides the creators with an ordered way to understand how things work and enables the prediction of different courses of action (Gous *et al.,* 2006). Models provide the means to define and compare results and encourage the interaction between hypotheses and observed data. This enables progress in science (Thornley & France, 2006). The application and implementation of mathematical models is relatively difficult to the non-mathematician. However, the hypotheses and ideas provided by biology and mathematics provide the tools to compare the real world with quantitative predictions (Aggrey, 2002; Ricklefs, 1967; Thornley & France, 2006).

The science of biology is made up of different organisational levels. Each of these levels can be seen as a system that is built on underlying systems (Gous *et al.,* 2006). These underlying systems combine to create the next level in the hierarchy. Subsequently any organisational level can be viewed at any time as an underlying system of a level higher up in the ladder. Gous *et al.* (2006) assigned certain properties to this organisational theory, namely that each level has a unique notion and that the understanding of a sublevel can lead to an instrument providing clarity in the next level. Finally, it is necessary for the sublevels of a system to work for it to function properly (Gous *et al.,* 2006). Three model categories can now be described.

1.1.1 Teleonomic modelling

Teleonomic models attempt to describe higher levels in the organisational hierarchy and are goal orientated. It is a sub-model within a larger model that provides a simple component of value (Gous *et al.,* 2006 and Thornley & France, 2006). A teleonomical model has four requirements namely the existence of a goal, evolutionary forces in the direction of the goal, present accessible mechanisms to fulfil the goal through adaptation and enough time for the required adaptations to take effect (Thornley & France, 2006). It should be remembered that teleonomic models are useful tools with limited validity and should be based on observed data rather than on speculation. Teleonomic models have the potential to expand its role and application in biology.

1.1.2 Empirical modelling

Empirical models portray data by accounting for intrinsic variation in the data. Empirical models aim to describe system responses by using equations of mathematical or statistical basis. The description is not based on any predetermined biological assumption and these models are generally used to describe single level responses of a system in a directorial manner (Haefner, 1996). As the usual concern of this type of modelling is prediction, biological mechanisms cannot be included in the equation parameters. If an equation, however, fits the data well, it can become a powerful tool even though it will be specific to the particular experimental conditions (Gous *et al.,* 2006; Haefner, 1996; Thornley & France, 2006).

1.1.3 Mechanistic modelling

Mechanistic models consider certain processes at a level relative to sublevels. These models are based on processes and ideas. The ideas help to construct the model through its essential components and analysis of system behaviour (Gous *et al.,* 2006). An acute understanding of a system is the aim, and for this, at least two levels of the system that is modelled need to be described. A mechanistic model is always incomplete in one way or another, but objectives should be carefully formulated to ensure that the model can be expanded with little restrictions. This will help to determine the scope of the model (Thornley & France, 2006). A well put together mechanistic model offers more possibilities than other models and can be modified and expanded (Thornley & France, 2006). It is important to apply models correctly. Wrongly, applied models can be misleading and as the output of quantitative models is usually numbers, finding the source of errors will be difficult.

1.2 Growth functions

Certain equations can be applied to growth data. All of these functions show sigmoid behaviour, exhibit minor differences in shape and are primarily rate changing functions. They can be said to fall under mechanistic and/or empirical models if certain parameter assumptions are made (Thornley & France, 2006). Mathematics, in the form of growth functions have long been used by scientists for information on the growth of various organisms and/or their underlying tissues or organs. These growth functions or analytical functions usually connect dry weight (W) to time (t) and can be written as a single equation. The application of some growth functions are made purely on an educated guess, but it makes more sense to construct or choose a function that has biological meaning with parameters that is relevant to the subject (Thornley & France, 2006). Although certain equations have little biological backing, they proved through the years that accurate predictions can be obtained

when applied to the growth of certain species (Ricklefs, 1967; Buchanan *et al.*, 1997; Zullinger *et al.,* 1984).

1.2.1 Logistic equation

The logistic equation was proposed and published by Pierre François Verhulst in 1938 as:

$$\frac{dN}{dt} = rN\ (1 - \frac{N}{K}) \qquad (1)$$

With the solution (2) upon exact integration:

$$N\,(t)\ = \frac{KN_{\ 0}}{(K - N_{\ 0}\ )e^{-rt} + N_{\ 0}} \qquad (2)$$

Where *N(t)* = number of individuals at time *(t)*, *r* represents the growth rate and *K* is the system carrying capacity. There are three key features of logistic growth namely: a carrying capacity will be reached when *t* strives to infinity and *N(t)* = *K*. As the population size increases, the relative growth rate is in a linear decline, until the zero minimum where *N* = *K.* The size of the population at the inflection point is exactly half of the total carrying capacity thus: $N_{inf} = K/2$ (Tsoularis & Wallace 2002). Thornley & France (2006) recognised the same features and made the assumption of proportionality between the quantity of growth machinery and dry matter. Consequently, growth occurs proportional to the available amount of substrate and this growth is irreversible. From this, maximum growth occurs at $(dN/dt)_{max} = rK/4$.

The logistic equation gives a smooth continuous sigmoid curve ($r > 0$) with a long initial exponential growth period (Zullinger *et al*, 1984; Tsoularis & Wallace, 2002). From equation (2) it is clear that if $r = 0$, there is no growth rate and it is for this reason that biologists and ecologists are interested in the case where $r > 0$. The logistic equation has been modified in several ways by various authors for application to plant (Parsons *et al*., 2001; Hernandez-Llamas & Ratkowsky, 2004) and fish growth respectively (Tsoularis & Wallace, 2002; Winsor, 1932).

1.2.2 Gompertz equation

When using the Gompertz equation the assumption is made that dry weight and growth are in proportion to each other and that substrate is not a limiting factor (Thornley & France, 2006). Winsor (1932) reviewed an article by Benjamin Gompertz (1825) in which Gompertz stated: “if the average exhaustions of a man’s power to avoid death were such that at the end of equal infinity small intervals

of time, he lost equal portions of his remaining power to oppose destruction," this will cause the number of survivors at age *x* to be given by:

$$L_x = kg^{c^x} \tag{3}$$

Previously only actuaries showed interest in the Gompertz curve, but since 1932, various authors used the curve to describe biological growth and economic phenomena. Winsor (1932) took equation (3) and purposed a more convenient form for which *k* and *b* are both greater than zero.

$$y = ke^{-e^{a-bx}} \tag{4}$$

From equation (4) it is clear that as *x* becomes more negative, approaching infinity, *y* will approach zero. Similarly, *y* will approach *k* if *x* becomes more positive and approaches infinity. Winsor (1932) now took (4) and by differentiation found:

$$\frac{dy}{dx} = kbe^{a-bx}e^{-e^{-a-bx}} = bye^{a-bx} \tag{5}$$

Sigmoid curves are essentially made up out of two parts: the first part is convex increasing and the second part is concave decreasing. The crossover point between the two parts is the inflection point and the point of maximum growth rate. This is determined by maximizing the first derivative function by equating the second derivative to zero (Mellett, 1992). Consequently, there will always be a positive slope for finite *x* values and the slope approaches zero for infinite values of *x*. Finding the second derivative Winsor (1932) quantified the points of inflection by giving the second derivative as:

$$\frac{d^2y}{dx^2} = b^2ye^{a-bx}(e^{a-bx} - 1) \tag{6}$$

Thereby showing that there is a point of inflection when:

$$x = \frac{a}{b} \tag{7}$$

The ordinate at the point of inflection is then given as:

$$y = \frac{k}{e} \tag{8}$$

The point of inflection is shown by Winsor (1932) to be at about 37 per cent when final growth has been reached. It is then logical to say that the Gompertz growth curve could be fitted to data that is expected to have a point of inflection during the first 35-40 per cent of the growth cycle (Hernandez-Llamas & Ratkowsky, 2004).

1.2.3 Von Bertalanffy equation

Karl Ludwig von Bertalanffy proposed his individual growth model in 1934. The simplest version of the equation has the form:

$$L't = r_B(L_\infty - L(t)) \quad (9)$$

Here it is expressed as a length (*L*) over time (*t*) equation where r_B is equal to the growth rate proposed by von Bertalanffy and L_∞ is the length of the individual. Von Bertalanffy introduced the equation to model the growth of fish. Tsoularis & Wallace (2002) reported that physiological reasoning was used to modify the Verhulst logistic curve in order to incorporate and accommodate different crude metabolic types. This led to the formation of:

$$\frac{dN}{dt} = rN^{\frac{2}{3}}(1 - (\frac{N_0}{K})^{\frac{1}{3}}) \quad (10)$$

With the solution:

$$N(t) = K[1 - [1 - (\frac{N_0}{K})^{\frac{1}{3}}]e^{-(rt/3K^{1/3})}]^3 \quad (11)$$

Where *N(t)* = number of individuals at time *(t)*, *r* represents the growth rate and *K* is the carrying capacity. From (11) Tsoularis & Wallace (2002) gave the inflection point on the curve as

$$N_{inf} = \frac{8}{27}K. \quad (12)$$

The curve has a variable point of inflection that occurs at about 30 per cent of the adult mass (Zullinger *et al*, 1984). The assumptions under which this curve is used include: the growth experienced is the difference between anabolism and catabolism; the substrate is non-limiting; anabolism and dry weight is related in an allometric way and catabolism and dry weight is linearly related (Thornley & France, 2006).

1.2.4 Richards' equation

Richards developed the curve constructed by Von Bertalanffy further to apply it in the plant sciences. He suggested the following equation (Tsoularis & Wallace, 2002):

$$\frac{dN}{dt} = rN\ [1 - (\frac{N}{K})^{\beta}\ ] \tag{13}$$

With the solution:

$$N\ (t) = \frac{N_0 K}{[\ N_0^{\beta} + (\ K^{\beta} - N_0^{\beta})\ e^{-\beta rt}\ ]^{1/3}} \tag{14}$$

Where *N(t)* = number of individuals at time *(t)*, *r* represents the growth rate and *K* is the carrying capacity. Tsoularis & Wallace (2002) showed the inflection point to be at:

$$N_{inf} = (\frac{1}{1+\beta})^{1/\beta} K \tag{15}$$

The Richards function is often referred to as the generalised logistic curve as it can be manipulated into the Verhulst equation form. This function can be difficult to use, as it is not as susceptible to biological interpretation. Instabilities that may arise with the power functions will also increase the difficulty when trying to fit the function to data (Thornley & Johnson, 2000 as cited by Thornley & France, 2006). However, Brisbin *et al.* (1987) suggested that the model has a greater likeliness to change because of environmental changes than from the growth rate or asymptotic weight. Subsequently, the function may be used to study the effects of environmental stress on growth. With this reasoning Brisbin *et al.* (1987) implied that contributions from growth functions with a fixed shape may be negligible when environmental, dietary and similar factors are investigated.

1.2.5 Smith's equation

Smith (1963) concluded that the Verhulst logistic equation did not fit growth data to satisfaction, due to time lag problems. Time lags are responsible for the distortion of the shape of the curve. Smith's greatest concern with the fitting of the logistic equation to growth data lies in the fact that the portion of the unutilised limiting factor needs accurate portrayal. He argued that the term 1 – (N/K) from the logistic should be replaced with a term that represents the currently unutilised proportion of the rate of food supply to the population. The following equation was derived:

$$\frac{1}{N}\frac{dN}{dt} = r(1 - \frac{F}{T}) \tag{16}$$

Where *F* is the rate of food consumption from the population size and *N* and *T* are described as the rate of growth at saturation level. For (16) to be valid, *F/T* must be greater than *N/K* as food will be utilised faster in a growing population than in a saturated population (Smith, 1963; Tsoularis &

Wallace, 2002). Consequently, *F* must be dependent on *N* and *dN/dt*. Tsoularis & Wallace (2002) states that a linear relationship will be the simplest form where:

$$F = aN + b\frac{dN}{dt} \tag{17}$$

For $a > 0$, $b > 0$

Now $F = T$, $N = K$, $dN/dt = 0$ at saturation and this makes $T = aK$. The modified growth function will now be:

$$\frac{dN}{dt} = rN\left(\frac{1-\frac{N}{K}}{1+c\frac{N}{K}}\right) \tag{18}$$

Where $c = rb/a$. Equation (16) is now the logistic growth, scaled by factor $(1 + c(N/K))^{-1}$ which accounts for the delaying of growth as the substrate starts to become limiting. Tsoularis & Wallace (2002) take this further and reported an analytical solution for *t* as a function of *N*.

$$t = \frac{1}{r}\ln\left[\frac{(K - N_0)^{1+c}}{N_0}\right] + \frac{1}{r}\ln\left[\frac{N}{(K - N)^{1+c}}\right] \tag{19}$$

For which *N(t)* = number of individuals at time *(t)*, *r* is the growth rate and *K* is the carrying capacity. The inflection point is shown to be:

$$N_{inf} = \frac{K}{1 + \sqrt{1 + c}} \tag{20}$$

From this it can be seen that Smith's equation is reduced to the logistic form if c = 0. Where the inflection $N_{inf} = K/2$. If $c > 0$, the inflection point will be below 50 per cent of the curve when final growth is achieved ($N_{inf} < K/2$), and for $c < 0$, $N_{inf} > K/2$ the inflection will be in the section higher than 50 per cent on the curve when final growth is achieved.

1.2.6 Blumberg's equation

From the previous discussions, it can be seen that most of the curves used to describe biological growth come from a modification of the Verhulst logistic equation. Blumberg (1968) also modified the Verhulst logistic growth equation to model the evolution of organ size or population dynamics. He pinpointed the inflexibility of the inflection point of the logistic as its greatest limitation. He then observed that treating the constant intrinsic growth rate term, *r,* as a polynomial dependent on time in an attempt to counteract this limitation, will lead to the underestimation of the future values (Blumberg, 1968; Tsoularis & Wallace, 2002).

Blumberg called his equation the hyperlogistic function and introduced it in the following form:

$$\frac{dN}{dt} = rN^{\alpha}(1 - \frac{N}{K})^{\gamma} \quad (21)$$

Analytic expressions of the growth function *N(t)* for different values of the parameters α and y were catalogued. Subsequently, Tsoularis & Wallace (2002) show the inflection point to be at:

$$N_{\inf} = \frac{\alpha}{\alpha + \gamma} K \quad (22)$$

When α = y, the inflection point is the same as the Verhulst logistic curve's inflection. Also, for values where α >> y, the inflection will occur very near to the carrying capacity of the population, and for α << y, the inflection point is approaching zero (Tsoularis & Wallace, 2002).

1.2.7 Application of models

The concern with all these equations is to fit them to growth data to make predictions of the growth response of animals over time. Many equations used for application to growth data spread from manipulations made to Verhulst's logistic equation that enables the modeller to apply it to data with specific criteria. Case (1978) and Millar (1977) were concerned with relating evolutionary and ecological factors to growth in mammals. The growth rate was taken as the average gaining rate over time where growth was assumed linear. Zullinger *et al.* (1984) found that a loss of information occurs when the growth rate is estimated from restricted data and that growth is non-linear. The result is that the estimates may be biased when an inappropriate model is fitted to the data.

The reason so many different equations are applied to different growth data may spread from the fact that each one fits data with specific criteria better. This can be seen when comparing the Gompertz, logistic and the Von Bertalanffy equations. Each curve has an inflection point at a different time and the result of this is that each equation will fit the data of different species better than the other two. In 1932, Winsor compared the Gompertz and the logistic growth curve. He calculated that there appears to be no apparent advantages of the curves over one another when comparing the phenomena range it will fit. Later, Ricklefs (1967) compared the Gompertz, the logistic and the Von Bertalanffy, and concluded that the Gompertz and the Von Bertalanffy differ from the logistic model. There is a marked slowing in the prediction of growth rate when the former curves are applied to data (Ricklefs, 1967). Zullinger *et al*. (1984) found that the inflection points of the Gompertz model, the Von Bertalanffy model and the logistic model occur at 37, 30 and 50 percent of adult mass. The estimated age at the inflection point will thus be the greatest with the logistic and the least with the Von Bertalanffy equations. Zullinger *et al*. (1984) and Ricklefs (1967) fitted these three models to the same data and found that the differences result from the characteristic shapes of each function. Some of these differences include that the Von Bertalanffy always predicts the highest asymptotic

mass and the logistic always renders the lowest. The logistic always predicts the highest maximum growth rate with the Gompertz and the Von Bertalanffy to follow.

Zullinger *et al*. (1984) chose the Gompertz as the best general equation to fit to growth data as it consistently performed between the logistic and the Von Bertalanffy and has been shown to be the best compromise between those two models. It was found, however, that the Gompertz model forces an asymptote on the curve and this caused the weights of the older individuals to be underestimated.

1.3 Predicting and modelling growth and nutrient requirements

To predict the nutrient requirements of an animal, it is necessary to know something of the growth, feed intake and genetic makeup of that animal. It is also important to predict the effects that different feeding programs and environmental conditions will have on the performance of the animal under investigation (Gous *et al*., 1999). Nutritionists and modellers have shown the need to predict growth responses to dietary nutrients (Gous, 2007). An adequate description of potential growth, the partitioning of the chemical body components and feed intake would assist in the modelling of nutrient requirements (Gous & Brand, 2008). Emmans & Fisher (1986) recognised that an important element in setting up a theoretical method of prediction was to be able to predict the potential performance of an animal. The description of how an animal grows and interacts with its environment is very important to any model that attempts to predict growth and feed intake (Ferguson, 2006). Wilson (1977) reported on the usefulness of growth curves for the description of differences between animals. Emmans & Fisher (1986) made the assumption that each animal has a potential growth curve that can be measured under optimal, non-limiting conditions. This is thought to be the first step toward the prediction of nutrient requirements and growth under limiting conditions.

The body changes in a systematic way during growth, especially regarding the size and chemical composition. An adequate description of growth potential is required to deal with this subsequent change in composition. Potential growth of the animal will depend on a combination of factors such as genotype, environmental conditions and state of the animal. The rate of maturing, mature body protein weight, the protein:lipid ratio at maturity and the quantifying of the relationships between the four chemical components of the body at maturity is important to describe the genotype of the animal (Ferguson, 2006). Differences in genotypes regarding mature size, composition and maturation rates of body chemical components may be found. The nutritional requirements necessary to attain maximum growth and the daily feed intake will be influenced by these variables (Emmans & Fisher, 1986; Gous *et al*., 1999).

The existing allometric relationships for body components need to be defined, as constant relationships exist between chemical body components (protein, water and ash) across animal genotypes (Hancock, *et al*., 1995). However, some variability for the water function between certain genotypes was indicated by Emmans (1989). Hancock *et al*. (1995) suggest two required

assumptions when defining the chemical composition of animals. The first is that each body component has a potential growth rate that is an exponential function of time and the second is that body protein, body ash, body water and body lipid has the same rate of growth parameter for a particular genotype (Hancock, *et al*., 1995). An analysis throughout the growth period of birds representing a particular genotype is required to compute relative growth rates for each body component (Hancock, *et al*., 1995). From this, body compositional changes can be described and the weights of the carcass components will be predictable (Gous & Brand, 2008).

To complete the accurate description of a genotype, the potential rate of body composition change needs to be defined. With this information, all the tissues and components that are allometrically related to body protein growth can be described in relation to body protein weight (Ferguson, 2006). This will lead to the quantification of the growth of the body as a whole or in its individual components. Accurate predictions will now be possible for animals from their protein weights as predicted by an exponential growth curve. This is possible due to the allometric relationship that exists between most, but not all body components (Emmans, 1989; Ferguson, 2006; Gous and Brand, 2008). The necessary predictions can be done by fitting the exponential function, described by Gompertz (1825), to growth data. Wellock *et al*. (2004) examined numerous functions and concluded that the Gompertz growth curve is an appropriate descriptor of potential growth as it is accurate and easy to apply. Reasons for selecting this function include the fact that there are only three variables that need to be known, all with biological meaning. This function is less complex and fits the data just as well as other growth functions that do not have any of the above properties (Zullinger *et al*., 1984). The growth rate parameter in this function can now be used to determine and define allometric relationships between various components of the body (Hancock *et al*., 1995).

When examining the growth of birds, it is necessary to separate the growth of feathers from the growth of the rest of the body. Feather protein differs from body protein in that the maturation rate is different for feathers than for total body protein weight (Emmans and Fisher, 1986; Emmans, 1989). This is significant as feathers are not allometrically related to total body protein and predictions for feather growth cannot be made from body protein growth. Feathers are responsible for a substantial proportion of total body protein. The proportion of feather protein in relation to the total protein gain will change as the bird matures. It is therefore necessary to define feather protein and body protein separately (Emmans, 1989). An adequate description of feather growth is required to be able to predict potential feather growth. This is necessary as feather protein differ from body protein in amino acid composition. Emmans (1989) showed that the feathers have considerable amounts of cystine (70 g/kg protein) and low levels of lysine (18 g/kg protein) where the rest of the body is shown to have low levels of cystine (11 g/kg protein) and much higher levels of lysine (75 g/kg protein). The value of the rate of maturing parameter for feathers needs to be known. It is also necessary to give some kind of report on mature feathering. Emmans (1989) related the weight of the mature body protein to the weight of the mature feather protein of turkeys. He named this relationship the “feathering factor”. If it is determined that this factor is constant between different species and/or genotypes, then the mature

body protein weight could be used to predict the mature feathering weight. Gous *et al*. (1999) showed that this “feathering factor” for broilers was similar to the value that Emmans (1989) proposed for turkeys. A similar comparison to the feathers of the ostrich has not been performed to date.

1.4 Historical position of the ostrich

During the late nineteenth and early twentieth century, the class *Aves* consisted of three subclasses. These were *Saururae* (lizard-tailed birds), *Ratitae* (flat breastbone) and *Carinatae* (birds with a keel on the breastbone) (Mellett, 1985). The ostrich is primitive and flightless and belongs to the subclass *Ratitae,* order *Struthiones,* under the family *Struthionidae* and genus *Struthio*. It has been established that there is only one species, *S. camelus* (Mellett, 1985; Swart, 1988).

The ostrich is without a keel on the sternum (Mellett, 1985; 1992), which explains their relatively small wings and underdeveloped breast muscles. Their long and powerful legs aid movement and they can run at speeds as high as 70 kilometres per hour. The feet present only the third and the fourth toes, the larger displaying a claw or nail used in aggressive displays (Mellett, 1985). The feathers of the male ostrich are black with white plumes on the wings and tail, and that of the female ostrich is brown displaying a pale edging. Ostriches have no stiff contour feathers and no oil gland so the feathers are not waterproof (Swart, 1988).

The ostrich industry is a growing one. Consumers have displayed interest in ostrich meat because of its healthy image. When compared to beef, ostrich meat reveals a favourable fatty acid profile and a low fat and cholesterol content (Hoffman *et al*., 2005; Sales, 1999). As consumers become more aware of the health effects and nutritional quality of foods, another boom for the industry is looking likely (Hoffman *et al*., 2005; Lanza *et al*., 2004; Shanawany, 1995). Ostrich research in improved efficiency and product quality is particularly important to ensure the continued economic well-being of the industry. The intensive production and finishing of slaughter birds on high concentrate diets contains immense potential for the industry. Further research to improve the efficiency and profitability of this practice is however necessary.

1.5 Anatomy of the ostrich muscles

A description of the anatomy of the various ostrich muscles and their individual names are necessary, as ostrich muscles are sold as a whole for commercial purposes (Mellett, 1992).

Sales (1999) deemed the biggest proportion of useable meat in an ostrich carcass to be situated on the legs, whereas a lesser proportion is located in the neck and muscles from the back. Ten major muscles (*M. gastrocnemius, M. femorotibialis, M. iliotibialis cranialis, M. obturatorius medialis, M iliotibialis lateralis, M. iliofibularis, M. iliofemoralis externus, M. fibularis longus, M. iliofemoralis* and *M. flexor cruris lateralis*) combine to yield two thirds of the meat on an ostrich carcass, and the remaining being lean trimmings (Sales, 1999). Mellett (1985) studied ostrich anatomy and ostrich growth (Mellett, 1992). His findings included a detailed description of the vicinity and anatomy of the muscles in the ostrich. Twenty-three muscles make up the entire ostrich carcass.

Table 1.1 includes the anatomical and commercial names where available, and Figures 1.1 to 1.4 illustrate the vicinity of each of the muscles. Muscle numbers in the table correlate with the figure numbers.

Table 1.1 Anatomical names, commercial names and marketing application of ostrich muscles (Mellett, 1992; 1994; 1996a; Brand, 2006).

Muscle name	Commercial name	Application
Pre-acetabular muscles		
1. *M. iliotibialis cranialis*	Top Loin	Whole muscle
2. *M. ambiens*	Tornedo Fillet; Small Fillet	Whole muscle
3. *M. pectineus*		Whole muscle
Acetabular muscles		
4. *M. iliofemoralis externus*	Oyster	Whole muscle
5. *M. iliofemoralis internus*		Processing
6. *M. iliotrochantericus caudalis*		Processing
7. *M. iliotrochantericus cranialis*		Processing
Post-acetabular muscles		
8. *M. iliotibialis lateralis*	Round; Rump Steak	Whole muscle
9. *M. iliofibularis*	Fan Fillet	Whole muscle
10. *M. iliofemoralis*	Inside Strip; Eye Fillet	Whole muscle
11. *M. flexor cruris lateralis*	Outside Strip	Whole muscle
12. *M. flexor cruris medialis*	Small Steak	Whole muscle
13. *M. pubio-ischio-femoralis*	Tender Steak	Whole muscle
14. *M. ischiofemoralis*		Processing only
15. *M. obturatorius medialis*	Tender Loin	Whole muscle
16. *M. obturatorius lateralis*		Carcass meal
Femoral muscles		
17. *M. femorotibialis medius*	Tip Trimmed; Moon Steak	Whole muscle
18. *M. femorotibialis accessorius*	Tip	Whole muscle
19. *M. femorotibialis externus*	Minute Steak	Whole muscle
20. *M. femorotibialis internus*		Whole muscle
Lower leg muscles		
21. *M. gastrocnemius*	Big Drum	Whole muscle
22. *M. fibularis longus*	Mid Leg	Processing
23. Flexor and extensor group		Processing

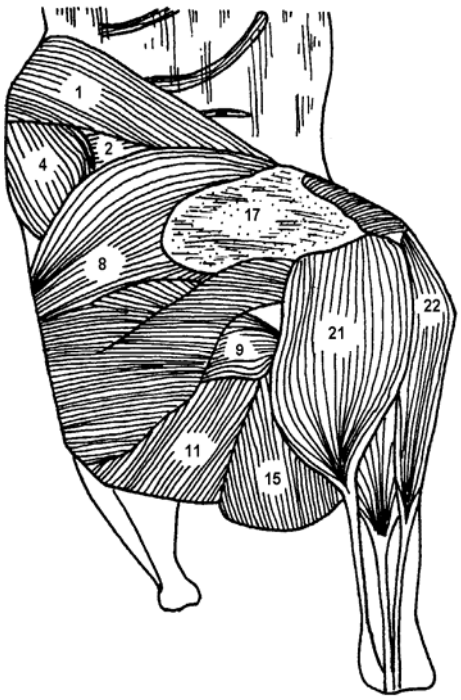

Figure 1.1 Superficial layer of muscles of the pelvic limb (Mellett, 1994; 1996a).

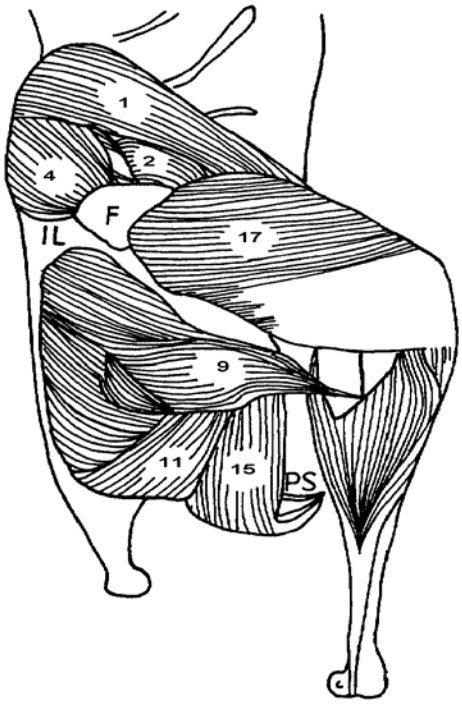

Figure 1.2 The second layer of muscles of the pelvic limb (Mellett, 1994; 1996a).

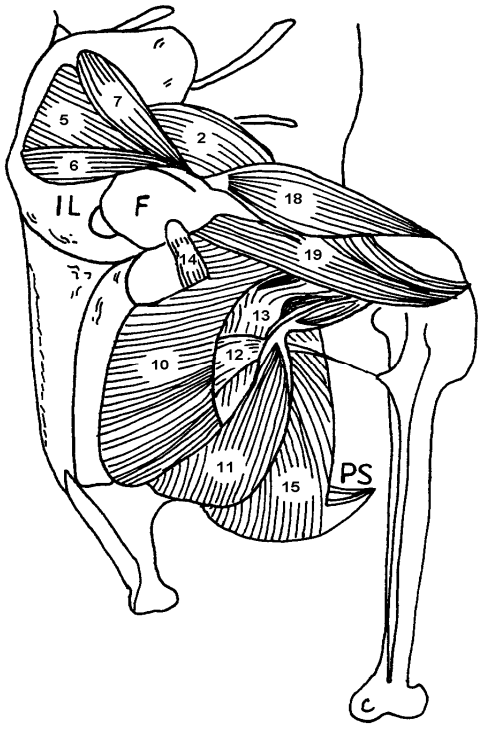

Figure 1.3 Third and fourth layers of muscles of the pelvic limb (Mellett, 1994; 1996a).

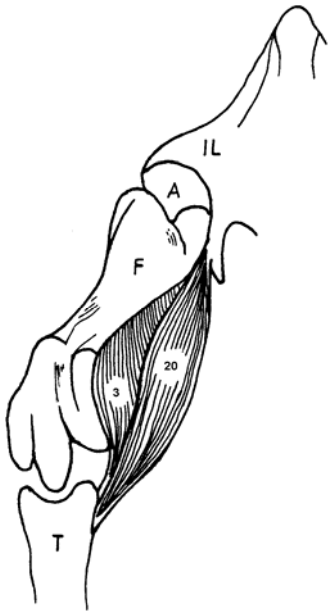

Figure 1.4 Medial muscles of the upper leg (Mellett, 1994; 1996a)

The majority of ostrich meat is marketed as individual muscles although some of the smaller muscles can only be used for processing (Mellett, 1996a). Some of the individual muscles generating the

highest income include the big drum (*M. iliofibularis*), inside strip (*M. iliofemoralis*) and the round (*M. iliotibialis lateralis*) (Mellett, 1992).

1.6 Digestion

Ostriches are monogastric herbivores with a relatively large gastro intestinal tract. The tract consists of a mouth, oesophagus, proventriculis, ventriculis, small intestine, large intestine (includes two large cecums and the proximal-, medial-, and distal colon) and a cloaca (Brand, 2008). A crop is absent and the proventriculis acts as a high volume storage organ (Holtzhauzen & Kotzé, 1990). Hydrochloric acid and enzymes are secreted in the proventriculis and chemical digestion starts here. Mechanical digestion takes place in the ventriculis as strong muscle contractions and ingested objects like stones aid in the digestion process (Holtzhauzen & Kotzé, 1990). The pH in the ventriculis is acidic (pH, 2.2) and this changes as the digesta moves into the small intestine. The different regions in the small intestine are the duodenum, jejunum and the ileum and various enzymes (amylase, lipase, maltase, sucrase and arginase) proceed with chemical digestion (Iji *et al*., 2003). Absorption of digested nutrients starts in the small intestine (McDonald et al., 2002). The large intestine has two seca where digesta undergoes microbial fermentation. This is a critical step in the digestion process as it enables the bird to digest fibre (hemicelluloses and cellulose) which is mostly indigestible for most monogastric animals.

Ostriches are able to utilise about 25% more energy than pigs when fed the same diet (Brand *et al*., 2000c). Swart (1988) showed that ostriches are able to utilise hemicelluloses and cellulose with an efficiency of 66 and 38% respectively. Swart (1988) confirmed this with work, showing that ostriches can derive between 12 and 76% of their energy in the form of volatile fatty acids in comparison with the 10 to 30% for pigs (Eggum *et al*., 1982) and about 8% for chickens (Jozefiak *et al*., 2004).

1.7 Nutritional requirements

The ostrich industry in South Africa has been in existence and flourishing for more than a hundred years (Brand *et al*., 2002). It did, however, hit a slump during the world depression in 1914-1945 (Swart, 1988) and in 1997-1998 (Brand *et al*., 2000). Feeding represents a large portion (70-80%) of the total production costs of the ostrich. Despite and maybe partly due to this high cost, birds are reared on a variety of diets (Iji *et al.* 2003).

Du Preez (1991), Smith *et al.* (1995) and Cilliers *et al*. (1996) determined energy, protein and amino acid requirements for ostriches using carcass analysis techniques. Table 1.2 combines their results to show the energy requirements and expected growth rate for each phase of the growth cycle, while Table 1.3 shows the expected protein and amino acid requirements for the ostrich.

Table 1.2 Expected energy requirements and subsequent growth rates for ostriches calculated from values published by Du Preez (1991), Smith *et al*. (1995) and Cilliers *et al*. (1996) as tabulated by Brand (2008).

Stadium of production	Live mass (kg)	Age (months)	ME (MJ/kg feed)	Expected growth rate (g/bird/day)
Pre-starter	0.85 – 10	0 – 2	14.65	163
Starter	10 – 40	2 – 5	13.58	296
Grower	40 – 60	5 – 7	10.80	387
Finisher	60 – 90	7 – 10	9.83	336
Maintenance	90 – 120	10 – 20	7.00	115
Breeding	110	> 20	11.58	-

Table 1.3 Expected protein and amino acid requirements for ostriches as calculated from values published by Du Preez (1991), Smith et al. (1995) and Cilliers *et al.* (1996) as tabulated by Brand (2008).

Component	Stadium of production					
	Pre-starter	**Starter**	**Grower**	**Finisher**	**Maintenance**	**Breeding**
Live mass (kg)	0.85 – 10	10 – 40	40 – 60	60 – 90	90 – 120	110
Age (months)	0 – 2	2 – 5	5 – 7	7 – 10	0 – 20	24[+]
Protein (%)	22.89	19.72	14.71	12.15	6.92	10.50
Essential amino acids (%)	-	-	-	-	-	-
Lysine	1.10	1.02	0.84	0.79	0.58	0.68
Methionine	0.33	0.33	0.29	0.28	0.24	0.26
Cysteine	0.23	0.22	0.18	0.17	0.14	-
Total (TSSA)[+]	0.56	0.55	0.47	0.45	0.38	-
Threonine	0.63	0.59	0.49	0.47	0.36	0.59
Arginine	0.97	0.93	0.80	0.78	0.63	0.51
Leucine	1.38	1.24	0.99	0.88	0.59	0.90
Isoleucine	0.70	0.65	0.54	0.51	0.38	0.45
Valine	0.74	0.69	0.57	0.53	0.36	0.55
Histidine	0.40	0.43	0.40	0.40	0.37	0.25
Phenylalanine	0.85	0.79	0.65	0.61	0.45	0.47
Tyrosine	0.45	0.44	0.38	0.38	0.31	0.37
Phenylalanine & Tyrosine	1.30	1.23	1.03	0.99	0.76	0.84

[+]Based on a 110 kg breeding bird laying one 1.4 kg egg in two days

[++]Sulphur containing amino acids

Various studies investigate the effect of dietary energy and protein on the production of slaughter and breeding birds.

Swart & Kemm (1985) fed slaughter birds (60-110 kg) diets containing three levels of energy (8.1, 9.5 and 10.7 MJ ME-pigs/kg) and three levels of protein (140, 160 and 180g/kg). Growth (g live weight/day) appeared to increase with an increase in energy for each protein level. An increase in the protein content of the diets did not have an effect on growth, with similar growth values recorded between the different protein levels. Cornetto *et al*. (2003) supplied ostriches with three levels of dietary energy (11.71, 12.90 and 14.09 MJ ME/kg) up to the age of 148 days, and reported improved growth on the higher energy diets. Gandini *et al*. (1986) conducted a study on the growth of young birds and did not find a difference between the growth of birds fed diets formulated on an iso-energy basis (11.5 MJ ME-poultry/kg) with varying protein levels (160, 180 and 200g/kg). Brand *et al*. (2000)

provided ostrich chicks ranging from 13 to 34 kilograms in mass with feeds containing three energy levels (10.5, 12.5 and 14.5 MJ ME/kg) and increasing protein levels (140 to 220g/kg). The birds showed an increase in growth rate as the diets increased in energy. In another study (Brand *et al.*, 2003), diets varying in energy (8.5, 10.5 and 12.5 MJ ME/kg) and protein (115, 135, 155, 175 and 195g/kg) were fed to ostriches. Protein, at levels provided in these studies, proved to have no effect on production in terms of average daily gain, but a drop of up to 15 percent was reported in the average daily gain values between the high and low energy levels.

It seems then that dietary protein, above minimum requirements and as a single entity, does not affect the growth rate of ostriches, but increased dietary energy will have a positive effect on growth rate when expressed as weight increase per time unit, as long as protein is not limiting. The way in which dietary energy and protein interact and affect growth in the ostrich is not clear. Studies attempting to clarify this will aid accurate feed formulation.

1.8 Skin

Ostrich leather is an important source of income for the local industry as it makes a marked contribution (40 – 50 %) toward the total income generated from a slaughter bird. The demand for ostrich meat has increased dramatically during the last few decades. Subsequently the proportional contribution from the leather declined (Van Schalkwyk, 2008).

1.8.1 Structure

Lunam & Weir (2006) reported the presence of a thin keratin covered epidermis made up of two to three cell layers. The keratin assists in the control of water loss, while also acting as a physical barrier to prevent microbial invasion. Underneath the epidermis, the dermis is the main component of ostrich skins and consists of three-dimensional perpendicular orientated arrays of collagen fibers that are predominantly aligned parallel to the skin surface (Lunam & Weir, 2006). Skin strength and flexibility are important features ensuring sufficient strength for the manufacture of leather products (Mellett *et al*., 1996b). Lunam & Weir (2006) argued that the three-dimensional cross-weave arrangement of the collagen fibers equip the ostrich skin with strength and flexibility. The grain layer, relatively thin and composed of compact collagen fibers, is separated from the corium layer by a layer of well-vascularised loose connective tissue. This could account for the susceptibility of the ostrich skin to bruising and skin damage (Lunam & Weir, 2006).

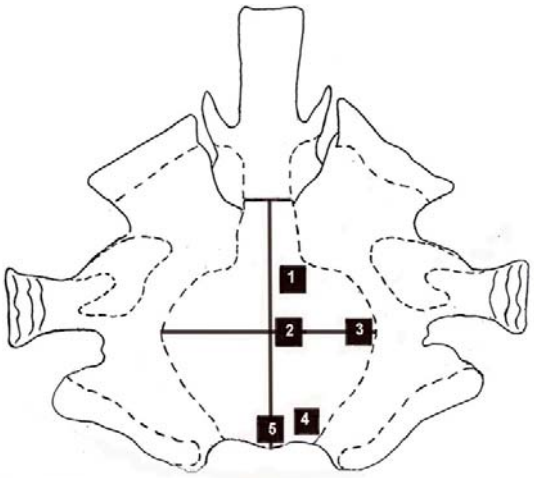

Figure 1.5 An illustration of an ostrich skin (Van Schalkwyk, 2008) that indicates sample sites for the assessment of nodule traits (1. Bottom neck, 2. Median, 3. Upper leg, 4. Flank and 5. Tail).

1.8.2 Characterisation

Feather follicles create the characteristic nodules or quill sockets (Sales, 1999) that make ostrich leather unique (Swart, 1981). Nodule size and shape are important factors when determining the quality and therefore the value of the skin (Mellett *et al*., 1996b; Meyer *et al*., 2004) and knowledge of the factors affecting this will aid producers to maximise bird productivity.

Van Schalkwyk (2008) deemed the lack of uniformity in the nodule appearance and distribution to be an important characteristic of any particular ostrich skin, as nodules are only present on certain parts of the skin. The nodule appearance in the nodulated areas differ visibly on different locations on the skin, which indicates that sampling in certain areas of the skin, may not yield results that represent the whole skin (Van Schalkwyk, 2008). Skin location has a noticeable influence on nodule size and density (Cloete *et al*., 2006a, 2006b; Meyer *et* al., 2004; Van Schalkwyk, 2008), with nodule density generally decreasing towards the ventral part of the ostrich. The highest density of nodules are found on the back line and the nodules on the mid-crown and neck area are smaller than the nodules located toward the sides and back of the ostrich (Cloete *et al*., 2004, 2006a). Nodule density was deemed to decrease with an increase in nodule size. Conversely, the butt region was found to have a high density of large nodules (Cloete *et al*., 2006a).

Swart (1981) reported the number of nodules on an ostrich skin to vary between 1032 and 1762. As the nodules are created by the feather follicles (Sales, 1999) it is thought that the nodule number will stay relatively constant during the life of the ostrich, which will in turn account for the decrease in nodule density with an increase in age and therefore skin size.

1.8.3 Genetic effects

The effect of genotype on ostrich leather quality has not been documented yet (Van Schalkwyk, 2008). South African Black ostriches (*Struthio camelus* var. *domesticus*) are smaller than Zimbabwean Blue ostriches (*Struthio camelus* var. *australis*) and the latter produce larger skins at a given age than the former. Hoffman *et al*. (2007) and Brand *et al*. (2005) confirmed that these genotypes differ significantly in live weight at slaughter. As there is a high correlation between live weight and skin size (Engelbrecht *et al*., 2005) the skin yield is expected to differ notably between these two genotypes.

Cloete *et al*. (1998, 2006b) and Van Schalkwyk *et* al. (1999) reported that body weight and skin yield was influenced by gender. Meyer *et al.* (2002) supported this, when it was indicated that the skins of ostrich males were significantly heavier than the skins from the females. Cloete *et al*. (2006b) and Van Schalkwyk *et al*. (2002) also measured leather thickness within the crown and butt area of the skin, and reported that male skins were consistently thicker than the skins of females. This was supported by the findings of Engelbrecht *et al*. (2005), although the measurements were taken on the non-nodulated flank region of the skin. Nodule traits are also affected by gender with larger and more optimally shaped nodules on male skins (Engelbrecht *et al*., 2005).

1.8.4 Age and weight effects

It was previously alleged that optimal leather quality and nodule size could only be obtained at 14 to 16 months of age (Mellett *et al*., 1996; Swart, 1981), although Mellett (1992) noted that a satisfactory skin size (120 dm^2) was obtainable at 10 months of age. According to Mellett *et al*. (1996) slaughter age and not necessarily slaughter weight is a primary contributor to leather quality, but there is a considerable debate as to the effect of age on leather quality (Angel *et al*., 1997 as cited by Van Schalkwyk, 2008). As the optimal slaughter weight can be achieved at 11-12 months of age due to improved feeding regimes and improved genetic selection, ostriches are now mostly slaughtered at this age (Van Schalkwyk, 2008). Cloete *et al*. (2004) investigated the effect of age on skin quality and size and ruled raw skin yield as well as slaughter weight to be increasing linearly with an increase in slaughter age, as skin yield and slaughter weight were shown to increase by 4.2 ± 0.7 dm^2 and 6.2 ± 0.4 kg respectively for every month of slaughter age increase.

Reports by Mellett *et al*. (1996) and Swart (1981) indicated that nodule shape and size were also age dependent and were shown to increase with an increase in age (Mellett *et al*., 1996), while Swart (1981) reported that ostriches that are slaughtered too young could result in poorly shaped nodules. Mellett *et al*. (1996) also indicated that follicle size and shape did not change after the age of 19 months and that the optimal nodule size could only be achieved at the age of 14-16 months. More recent studies indicated that an adequate nodule size and shape could be obtained at the age of 11 months (Van Schalkwyk, 2008; Van Schalkwyk *et al*., 2005). Van Schalkwyk (2008) also showed that nodule density decreased as age and body weight increased. This can probably be

ascribed to the fact that the amount of nodules on the skin stays constant while the skin area increases as the bird matures.

Van Schalkwyk (2008) pointed out that more current results may not compare well to results from studies conducted in the 1980s and early 1990s, as these results were drawn from birds weighing 75-80 kg at 14 months of age (Jarvis, 1998) while presently, birds are slaughtered at an age of 11-12 months with a weight in excess of 90 kg.

1.8.5 Nutritional effects

Dietary protein and sulphur-containing amino acids have no effect on skin size and measured characteristics, but it was shown that weight and skin size decreased as the dietary energy levels decreased (Van Schalkwyk *et al.,* 2001; Van Schalkwyk 2008). Inadequate nutrition also has a negative effect on nodule development where ostriches graze on oat pastures (Van Schalkwyk *et al*., 2001).

Various authors further investigated the nutritional effect on skin characteristics and quality. Van Schalkwyk (2002) found that skin area is linearly correlated to an increase in dietary energy level, whilst Cloete *et al*. (2006b) found that dietary protein levels ranging between 130 and 170 g/kg feed had no effect on any of the skin measurements. While ostriches consuming lower energy diets (9.0 MJ ME/kg DM) had lower raw skin weights than birds consuming higher energy diets (10.5 and 12.0 MJ ME/kg DM). Brand *et al*. (2000b; 2004; 2005) also investigated the influence of differing nutritional values on ostrich skin quality and found that the skin size of birds on a low energy diet (9.0 MJ ME) were inferior to the skin size of birds fed higher energy levels. Dietary protein, as used in these studies, did not have any effect on the skin yield, but it had a notable affect on skin grading, as higher levels of dietary protein lead to increased skin damage (Brand *et al*., 2000b). The previous results were confirmed as Brand *et al*. (2004; 2005) found that low dietary energy levels (7.5 and 8.5 MJ ME/kg feed) lowered skin yield when compared to higher energy levels (9.5 to 12.5 MJ ME/kg feed) while dietary protein level had no effect on yields.

From the above it is evident that protein has little effects on the measurable skin characteristics concerning quality and yield. The fact that an increase in dietary energy content contributes to an increase in skin yield can most probably be ascribed to the increase in growth rate that accompanies increased energy intake, which leads to an increased skin size and thus yield.

1.9 Conclusions

According to these discussions, it is evident that there is a need for the accurate characterisation of ostrich growth, as a whole and in its individual components to supply the industry with accurate and useful information to maximise ostrich production. Past research, prediction models and mathematical theory will act as tools for the achievement of this goal. The combining, use and

expression of this in simulation modeling will provide a powerful instrument to predict every aspect of ostrich growth and nutritional requirements as it changes over time.

No model is perfect and it is vital for continuous research to be added to improve prediction accuracy. The aim of this study is to analyse factors involved in ostrich growth in an effort to increase the accuracy of feed formulation and the prediction of nutritional requirements and component growth.

1.10 References

Aggrey, S. E., 2002. Comparison of nonlinear and spline regression models for describing chicken growth curves. Poult. Sci. 81, 1782-1788.

Angel, R., Trevino, L., Mantzel, T., Baltmanis, B., Blue-McLendon, A. & Pollok, K. D., 1997. Effect of ostrich age on hide quality. Amer. Ostrich April, 25-26.

Brand, M. M., 2006. Reproduction criteria and meat quality of South African Black (Struthio camelus var. domesticus), Zimbabwean Blue (Struthio camelus var. australis) and South African Black x Zimbabwean Blue ostriches. MSc Thesis, Stellenbosch University, South Africa.

Brand, M. M., Cloete, S. W. P., Hoffman, L. C. & Muller M., 2005. A comparison of live weights, body measurements and reproductive traits in Zimbabwean Blue ostriches (Struthio camelus var. australis) and South African Black ostriches (Struthio camelus var. domesticus). Proceeding of the Third International Ratite Science Symposium, 14-16 October, Madrid, Spain. pp. 73-80.

Brand, T. S., De Brabander, L., van Schalkwyk, S. J., Pfister, B. & Hays, J. P., 2000a. The true metabolisable energy content of canola oilcake meal and full-fat canola seed for ostriches (Struthio camelus). Br. Poult. Sci. 41, 201-203.

Brand, T. S., Nel, C. J., and van Schalkwyk, S. J., 2000b. The effect of dietary energy and protein level on the production of growing ostriches. S. Afr. J. Anim. Sci. 80, 15-16.

Brand, T. S., Salih, M., van der Merwe, J. P. & Brand, Z., 2000c. Comparison of estimates of feed energy obtained from ostriches with estimates obtained from pig, poultry and ruminants. S. Afr. J. Anim. Sci. 30, 13-14.

Brand, T. S., Aucamp, B. B., Kruger, A. C. M. & Sebake, Z., 2003. Ostrich Nutrition. Progress Report 2003. Ostrich Research Unit, Private Bag X1, Elsenburg 7607, pp. 1-19.

Brand, T. S., Gous, R. M., Horbaňczuk, J. O., Kruger, A. C. M., Aucamp, B. B. & Brand, Z., 2004. The effect of dietary energy and protein (amino acid) concentrations on the end products of slaughter ostriches. S. Afr. J. Anim. Sci. 34, 107-109.

Brand, T. S., Gous, R. M., Horbaňczuk, J. O., Kruger, A., Aucamp, B. B. & Brand, Z., 2005. The effect of dietary energy and protein (amino acids) on the carcass and skin characteristics of slaughter ostriches. Proceeding of Third International Ratite Science Symposium & World Ostrich Congress, Ed., Carbajo, E., 14-16 October, Madrid, Spain, p. 261.

Brand, T. S. & Gous, R. M., 2006. Feeding Ostriches. In: Feeding in Domestic Vertebrates, From Stucture to Behaviour. Ed. Bels, V., CAB International, Oxfordshire, pp. 136-155.

Brand, T. S., 2008. Volstruisvoeding: 'n Wetenskaplike Benadering. SUN Print, University of Stellenbosch, Stellenbosch, pp. 6-35.

Brand, Z., Brand, T. S. & Brown, C. R., 2002. The effect of dietary energy and protein levels during a breeding season of ostriches (Struthio camelus var. domesticus) on production the following season. S. Afr. J. Anim. Sci. 32, 4.

Brand, Z., Brand, T. S., & Brown, C. R., 2003. The effect of different combinations of dietary energy and protein on the composition of ostrich eggs. S. Afr. J. Anim. Sci. 33, 3.

Buchanan, R. L., Whiting R. C. & Damert W. C, 1997. When simple is good enough: a comparison of the Gompertz, Baranyi, and three-phase linear models for fitting bacterial growth curves. Food Microbiology, 14, 313-326.

Chwalibog, A., 1991. Energetics in Animal Production. Acta. Agric. Scand. 41, 147-160.

Cilliers, S. C., 1994. Evaluation of feedstuffs and the metabolisable energy and amino acid requirements for maintenance and growth in ostriches (*Struthio camelus*). Ph. D. Thesis, University of Stellenbosch, South Africa.

Cloete, S. W. P., Van Schalkwyk, S. J. &Brand, Z., 1998. Ostrich breeding – progress towards a scientifically based strategy. Proceedings of the Second International Ratite Congress, Oudtshoorn, South Africa, 21-25 September, pp. 133-136.

Cloete, S. W. P., Van Schalkwyk, S. J., Hoffman, L. C. & Meyer, A., 2004. Effect of age on leather and skin traits of slaughter ostriches. S. Afr. J. Anim. Sci. 34, 80-86.

Cloete, S. W. P., Van Schalkwyk, S. J., Brand, T. S., Hoffman, L. C. & Nel, C. J., 2006a. The effects of dietary energy and protein concentration on ostrich skin quality. S. Afr. J. Anim. Sci. 36, 40-44.

Cloete, S. W. P., Van Schalkwyk, S. J., Engelbrecht, A. &Hoffman, L. C., 2006b. Genetic variation in nodule size at different sites on the skins of slaughter ostriches. S. Afr. J. Anim. Sci. 36, 160-164.

Cornetto, T., Angel, R. & Palmer, T., 1994. Influence of stocking density and dietary energy on ostrich performance. Int. J. Poult. Sci. 2, 102-106.

Du Preez, J. J., 1991. Ostrich nutrition and management. In: Recent advances in Animal Nutrition in Australia. Ed: Farrel, D. J., University of New England, Armidale, Australia, pp. 278-291.

Eggum, B. O., Thorbek, G., Beames, R. M., Chwalibog, A. & Henckel, S., 1982. Influence of diet and microbial activity in the digestive tract on digestibility, and energy metabolism in rats and pigs. Br. J. Nutr. 48, 161-175.

Emmans, G. C. & Fisher, C., 1986. Problems in nutritional theory. In Nutrient requirements of poultry and nutritional research (Eds. C. Fisher and K. N. Boorman). Butterworths, London, U.K. pp 9-39.

Emmans, G. C., 1989. The growth of turkeys. In: Recent advances in turkey science. Ed: Nixey, C., and Grey, T. C., Butterworths, London, U.K., pp. 135-166.

Engelbrecht, A., Cloete, S. W. P. & Van Wyk, J. B., 2005. Parameter estimates for ostrich slaughter and skin traits. Proceedings of the Third International Ratite Science Symposium & XII World Ostrich Congress, Madrid, 14-16 October, pp. 121-127.

Ferguson, N. S., 2006. Basic Concepts Describing Animal Growth and Feed Intake. In: Mechanistic Modelling in Pig & Poultry Production. Ed. Gous, R. M., Morris, T. R., and Fisher, C., CAB International, Oxfordshire, pp. 22-54.

Gandini, G. C. M., Burroughs, R. E. J. & Ebedes, H., 1986. Preliminary investigation into the nutrition of ostrich chicks (Struthio camelus) under intensive conditions. J. S. Afri. Vet. Assoc. 57, 39-42.

Gompertz, B., 1825. On the nature of the function expressive of the law of human mortality and on a new method of determining the value of life contingencies. Trans. Roy. Phil. Soc. 115, 513-585.

Gous, R. M., Moran, E. T., JR., Stilborn, H. R., Bradford, G. D. & Emmans, G. C., 1999. Evaluation of the parameters needed to describe the overall growth, the chemical growth, and the growth of feathers and breast muscles of broilers. Poult. Sci.78, 812-821.

Gous, R. M., 2007. Prediction nutrient responses in poultry: future challenges. Anim. Prod. 1, 57-65.

Gous, R. M., Morris, T. R. & Fisher, C, 2006. Mechanistic Modelling in Pig & Poultry Production. CAB International, pp. 1-20 ; 282-292.

Gous, R. M. & Brand, T. S., 2008. Simulation models used for determining food intake and growth of ostriches: an overview. Aust. J. Exp. Agri. 48, 1266-1269.

Haefner, J. W, 1996. Modeling biological systems. Principles and applications. pp. 1-30.

Hancock, C. E., Bradford, G. D., Emmans, G. C. & Gous, R. M., 1995. The evaluation of the growth parameters of six strains of commercial broiler chickens. Br. Poult. Sci. 36, 247-264.

Hernandez-Llamas, A. & Ratkowsky, D. A, 2004. Growth of fish, crustaceans and molluscs: estimation of the von Bertalanffy, Logistic, Gompertz and Richards curves and a new growth model. Mar. Ecol. Prog. Ser. 282, 237-244.

Hoffman, L. C., Joubert, M., Brand, T. S. & Manley, M., 2005. The effect of dietary fish oil rich in n – 3 fatty acids on the organoleptic, fatty acid and physiochemical characteristics of ostrich meat. Meat Sci. 70, 45-53.

Hoffman, L. C., Brand, M., Muller, M. & Cloete S. W. P., 2007. Carcass and muscle yield of ostriches as influenced by genotype. S. Afr. J. Anim. Sci. 37, 256-260.

Holtzhausen, A. & Kotzé, M., 1990. The Ostrich, C. P. Nel museum Oudtshoorn, South Africa, pp. 56.

Iji, P. A., van der Walt, J. G., Brand, T. S., Boomker, E. A. & Booyse, D., 2003. Development of the digestive tract in the ostrich (Struthio camelus). Arch. Anim. Nutr. 57, 217-228.

Jarvis, M. J. F., 1998. Options for growth rates and slaughter ages. Prococeeding of third the International Ratite Congress, Oudsthoorn, South Africa, 21-25 September, pp. 24-27.

Jozefiak, D., Rutkaski, A. & Martin, S. A., 2004. Carbohydrate fermentation in the avian ceca: A review. Anim. Feed Sci. Tech. 113, 1-15.

Lanza, M., Fasone, V., Galofaro, V., Barbagallo, D., Bella, M. & Pennisi, P., 2004. Citrus pulp as an ingredient in ostrich diet: effects on meat quality. Meat Sci. 68, 269-275.

Lunam, C. A. & Weir, K. A., 2006. Storage of Ostrich Skin: Effect of preservation methods on skin structure, physical properties & microbial flora. Publication No. 06/054, Rural Industries Research and Development Corporation, Canberra, Australia.

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. & Morgan, C. A., 2002. Animal Nutrition, 6th ed. Pearson, Prentice Hall.

Mellett, F. D., 1985. The ostrich as meat animal: Anatomical and muscle characteristices. MSc. Thesis, University of Stellenbosch, South Africa.

Mellett, F. D., 1992. Die volstruis as slagdier: aspekte van groei. Ph.D. Thesis, University of Stellenbosch, South Africa.

Mellett, F. D., 1994. A note on the musculature of the proximal part of the pelvic limb of the ostrich (Struthio camelus). S. Afr. Vet. Ass. 65, 5-9.

Mellett, F.D., 1996a. Ostrich mycology, post mortem glycolysis, muscle characteristics and GMP abattoir and processing techniques. In: Studieverlof verslag. University of Stellenbosch, Stellenbosch, South Africa.

Mellett, F. D., Fisher, P. & Böhme, H. M., 1996b. Grading of ostrich skins. Proc. Europ. Ostrich Conf., November, Henglo, The Netherlands, European Ostrich Association, Banbury.

Meyer, A., Cloete, S. W. P., Van Schalkwyk, S. J. & Bunter, K. L., 2002. Genetic parameters for live weight and skin traits in ostriches. Proceeding of the Second World Ostrich Congress, Ed., Horbaňczuk, J. O., 26-29 September, pp. 236-237.

Oldham, J. D., & Emmans, G. C., 1990. Animal performance as the criterion for feed evaluation. In: Feedstuff Evaluation (Eds. J. Wiseman and D. J. A. Cole. Butterworths, London. pp 73-90.

Parsons, A. J., Schwinning, S. & Carrère, P, 2001. Plant growth functions and possible spatial and temporal scaling errors in models of herbivory. Grass Forage Sci 56, 21-34.

Ricklefs, R. E., 1967. A graphical method of fitting equations to growth curves. Ecology 48, No. 6.

Sales, J. (1999). Slaughter and products. In: The Ostrich, biology, production and health. Ed: Deeming, D. C., CABI Publishing, Wallingford, Oxon., pp. 231-274.

Shanawany, M. M., 1995. Recent development in ostrich farming. World Anim. Rev. 83, 3-8.

Smith, W. A., Cilliers, S. C., Mellett, F. D. & van Schalkwyk, S. J., 1995. Nutrient requirements and feedstuff values in ostrich production. Feed Compounder, September 1995, pp. 2-29.

Smith, F. E, 1963. Population dynamics in Daphina Magna and a new model for population growth. Ecology 44, No. 4.

Swart, D., 1981. Die evaluering van die ekonomiese waarde van die vel, vleis en vere op die lewendige slagvolstruis. Ongepubliseerde verslag, Departement van Landbou en Visserye, Suid Afrika.

Swart, D. & Kemm, E. H., 1985. Die invloed van dieëtproteïn- en energiepeil op die groeiprestasie en veerproduksie van slagvolstruise onder voerkraaltoestande. S. Afr. Tydskr. Veek. 15, 146-150.

Swart, D., 1988. Studies on the hatching, growth and energy metabolism of ostrich chicks. Ph.D. Thesis, University of Stellenbosch, South Africa.

Swart, D., Siebrits, F. K. & Hayes, J. P., 1993. Growth, feed intake and body composition of ostriches (*Struthio camelus*) between 10 and 30 kg live mass. S. Afr. J. Anim. Sci. 23, 142-150.

Thornley, J. H. M. & France, J, 2006. Mathematical models in agriculture. Quantitative methods for the plant, animal and ecological sciences. 2nd Edition, pp. 1-54 ; 136-169.

Tsoularis, A. & Wallace, J, 2002. Analysis of logistic growth models. Math Biosci 179, 21-55.

Van Schalkwyk, S. J., 2008. Factors affecting ostrich leather traits. Ph.D. Thesis, University of Stellenbosch, South Africa.

Van Schalkwyk, S. J., Cloete, S. W. P., Brand, T. S. &Hoffman, L. C., 2001. Die implikasie van 'n jonger of ouer slagstadium. Volstruisboeredag, Oudtshoorn Proefplaas, 1 August.

Van Schalkwyk, S. J., Cloete, S. W. P., Hoffman, L. C., Brand, T. S., Meyer, A. &Pfister, A. P., 2002. The effect of dietary energy and protein levels on skin size and physical leather parameters of ostriches. Proceedings of the Second World Ostrich Congress, Ed., Horbaňczuk, 26-29 September, Warsaw, Poland, pp. 216-217.

Van Schalkwyk, S. J., Cloete, S. W. P. & Lambrechts, H., 1999. Interrelationship between body weight, sex and skin measurements of slaughter ostriches in the Little Karoo Region. Proceedings of the Thirty-seventh National Congress of the South African Society of Animal Science, 27-29 July, Pretoria, p. 32.

Wellock, I. J., Emmans, G. C. & Kyriazakis, I., 2004. Describing and predicting potential growth in the pig. Anim. Sci. 78, 379-388.

Wilson, B. J., 1977. Growth curves: Their analysis and use. In: Growth and poultry meat production. Boorman, K. N. and Wilson, B. J., ed. British Poultry Science Ltd., Edinburgh, U.K. pp. 89-115.

Winsor, C. P., 1932. The Gompertz curve as a growth curve, Proceedings of the National Academy of Sciences, 18, 1-8.

Zullinger, E. M., Ricklefs, R. E., Redford, K. H. & Mace, G. M, 1984. Fitting sigmoidal equations to mammalian growth curves. J. Mammal., 65, 607-636.

Chapter 2

A description of body growth and body compositional change in ostriches (*Struthio camelus* var*. domesticus*) under free choice feeding conditions

Abstract

Body composition changes of ostriches over a 285-day growth period are described. Forty-five birds were given a choice of four diets with different protein (180 or 120 g/kg feed) and energy (8.5 or 13.5 MJ ME/kg feed) levels, on the assumption that the birds would select feeds according to their protein and energy requirements and subsequently grow close to potential. Birds were weighed at approximately 10-day intervals and randomly selected birds (9-10) were slaughtered at 1, 54, 120, 162 and 285 days of age respectively. Proximate chemical analyses were done on the complete empty carcasses and the components were expressed as a percentage of live weight at the different slaughter ages. Gompertz growth curves (y = a*(exp(-exp(-b*(age-c)))) (Emmans, 1989) were fitted to the live weights of the birds and to the weights of the individual chemical components. The change in body weight with age as the only independent variable can be considered a good description of growth in ostriches (R^2 = 0.93). Parameters a, b and c (a=maximum predicted weight at maturity, b=growth rate parameter and c=age at which maximum growth occurs) were estimated at 119.4 kg, 0.009 and 156.3 days. Body protein (dry) and moisture concentrations decreased as the birds aged, while the body ash concentration remained relatively constant and body fat concentration increased. Estimated Gompertz parameters for the different chemical components were respectively, a=55.0, b=0.014 and c=116.9 for moisture, a=44.5, b=0.015 and c=113.9 for protein, a=33.6, b=0.013 and c=143.4 for fat, and a=10.3, b=0.016 and c=118.2 for ash. As in other animals, fat was a late maturing tissue and protein a relatively early maturing tissue. These results are important in describing the growth of ostriches subjected to optimum feeding conditions, and this information can be used to model the nutrient requirements of growing birds.

Keywords: ostrich, growth, development, feeding optimisation, proportional changes, Gompertz growth curve.

2.1 Introduction

An increase in animal size and weight is an expression of growth. If growth could be simulated, it could provide various means by which to predict animal performance and the subsequent effects that changes in conditions such as state of the bird, nutritional status and environmental conditions will have on production. An accurate and detailed description of animal growth, environmental effects and the influence of other conditions on growth, is essential to any model that attempts to predict growth and voluntary feed intake (Ferguson, 2006). Growth can usually be illustrated graphically in the form of a sigmoidal curve (Huxley, 1932; McDonald *et al.*, 2002). As the animal matures, its conformation changes (Huxley, 1932; Berg *et al.,* 1978). Tissues differ in their rate of maturing as dictated by survival (Berg & Butterfield, 1976) with the nervous and bone tissues developing first. As the animal matures, the need for muscle increases and growth of this tissue will become a priority. The slowest maturing tissue is fat and its growth rate will be at a maximum at a later stage in the growth cycle (Huxley, 1932; Lawrie, 1998; McDonald *et al.*, 2002). Growth and the subsequent prediction of the chemical components (protein, ash and fat) of the animal are of particular importance to nutritionists, as the nutrient requirements of the animal will be dictated by this (McDonald *et al.*, 2002).

The assumption that an animal will attempt to adjust its daily feed intake according to its energy and protein requirements in order to grow to its genetic potential (Ferguson, 2006) is the principle behind the prediction of voluntary feed intake. Therefore, actual intake will be the quantity of feed that is necessary for the satisfaction of the most limiting nutrient requirement as allowed by limitations in gut volume, environmental stresses and social and health issues (Ferguson, 2006). Ferguson (2006) also described the effect of feed intake on protein and energy requirements with three pathways; when energy is the limiting nutrient, when protein is the limiting nutrient and when intake is inhibited by gut capacity. In the situation where energy is limiting, the animal consumes enough feed to satisfy the energy and protein requirements for protein and lipid deposition. In the case where protein is the limiting factor, excess energy will be consumed and additional fat will be deposited. If the concentration of the limiting amino acid were to be increased in the feed the next day, the animal will try to compensate for the excessive intake of energy and attempt to return to its desired state by depositing less fat. In the case where intake is constrained due to gut capacity, knowledge of the most limiting nutrient becomes very important (Ferguson, 2006; McDonald *et al.,* 2002). As ostriches are hindgut fermenters, adequate knowledge of the fermenting capacity and processes is needed (Swart, 1988). When energy is limiting, energy is initially directed primarily to maintenance functions and finally to protein and lipid growth. Similarly, when protein is the limiting factor, protein will be allocated firstly to maintenance and finally to growth.

To date, feed formulation for ostriches has been based on principles used in the poultry industry (Cilliers, 1998; Iji *et al*. 2003) and very little relevant research has been done to predict food intake. The prediction of food intake for pigs and poultry is based on the physical characteristics of the animal involved and the assumption is made that it will be the same with ostriches. However, very

little research has been done up to now on the changes in body composition of the ostrich (Brand & Gous, 2006). The presence of a large hindgut with substantial fermentative properties (Swart, 1988) complicates the prediction of feed intake. Brand *et al*. (2000) stated that feeding costs constitute 70-80 % of the cost of producing ostriches. This necessitates the need for research on the nutritional requirements of ostriches and the factors that may influence these requirements.

The aim of this study was to define the potential growth of the ostrich using an appropriate growth curve and to investigate and quantify the proportional changes and growth rates of the four main chemical constituents of the body (protein, water, ash and fat).

2.2 Materials and Methods

Forty-five day-old birds were placed in 9 identical pens. Four feeds were formulated with high and low levels of protein and energy (high energy = 13.5, low energy = 8.5 MJ/kg feed; high protein = 180, low protein = 120 g/kg feed) and provided to each pen. The formulated feed ingredients are presented in Table 2.1. The feeds were analysed for protein, amino acids, fat, NDF (neutral detergent fibre), ADF (acid detergent fibre), ash and residual fibre, (Table 2.2) and (Table 2.3) (AOAC, 2002). All four feeds were offered *ad libitum* to every pen and made available simultaneously throughout the trial. Each feed combination was weighed back weekly to determine how much of each was selected (Table 2.4). Water was freely available throughout the trial.

Nine birds (one from each pen) were weighed at approximately ten day intervals throughout the trial. Birds were slaughtered at 1, 54, 120, 162 or 285 days of age. Nine birds were weighed, stunned, exsanguinated and eviscerated. Blood was collected in a separate container for each bird. The intestines of each bird were cleaned with water and all body parts, along with the blood, feathers and clean intestines were frozen in plastic bags until the commencement of mincing. The whole body was minced with an industrial grounder and thoroughly mixed whereafter one randomly selected sample (±150g) was used for protein, moisture, ash and lipid analyses (AOAC, 2002).

An adapted form of the Gompertz growth curve (y = a*(exp(-exp(-b*(age-c)))) (Emmans, 1989), was fitted to the live weight data and the individual weight of each chemical component (calculated from percentage of total body weight) using Statgraphics (2005). The growth parameters a, b and c (a=maximum predicted weight at maturity, b=growth rate parameter and c=age at which maximum growth occurs) were calculated for each chemical component. The accuracy of the fitted model was determined by a goodness of fit test (Mellett, 1992). The given significance level (s. l.) is a value between zero and one with the hypothesis that the model fits the data. Regression lines were fitted to each chemical component expressed as a percentage of total body weight to determine how the chemical composition of the body changes over time. The data was then transformed to the natural logarithmic form and each component was related to body protein growth by means of a linear regression.

Table 2.1 The feed ingredients of the formulated ostrich feeds on an as is basis [high energy (HE) = 13.5 MJ/kg, high protein (HP) = 180 g/kg, low energy (LE) = 8.5 MJ/kg and low protein (LP) = 120 g/kg].

Ingredients (g/kg)	Feed			
	HE, HP	**LE, HP**	**HE, LP**	**LE, LP**
Maize meal	200	-	-	-
Barley grain	400	-	706	100
Oat bran	-	570	0	573
Wheat bran	-	-	54	33
Lucerne meal	143	142	142	142
Soya bean oil-cake meal	80	158	-	114
Full-fat soya meal	50	-	43	-
Fish meal	75	88	-	-
Plant Oil	10	-	20	-
Synthetic Lysine	0.46	0.33	-	-
Synthetic Metionine	0.91	1.3	4	4.3
Mono-calcium phosphate	14	18	-	-
Di-calcium phosphate	-	-	8	9
Limestone	19	14	15	15
Vitamin & Mineral mix	5	5	5	5
Salt	4	4	4	4

Table 2.2 Proximate analysis of feeds formulated for energy and protein levels on an as is basis [high energy (HE) = 13.5 MJ/kg, high protein (HP) = 180 g/kg, low energy (LE) = 8.5 MJ/kg and low protein (LP) = 120 g/kg].

Nutrient	HE, HP	LE, HP	HE, LP	LE, LP
Energy (MJ/kg)	13.5	8.5	13.5	8.5
Crude Protein (g/kg)	216	218	155	161
Fat (g/kg)	41	24	41	24
Ash (g/kg)	96	105	73	78
Fibre (g/kg)	77	204	108	214
ADF (g/kg)	106	254	136	261
NDF (g/kg)	210	403	284	433

Table 2.3 The amino acid composition of the ostrich feeds on an as is basis (g/kg) [high energy (HE) = 13.5 MJ/kg, high protein (HP) = 180 g/kg, low energy (LE) = 8.5 MJ/kg and low protein (LP) = 120 g/kg].

Amino Acids	HE, HP	LE, HP	HE, LP	LE, LP
Lysine	9	9	4	5
Methionine	3	3	4	3
Cysteine	2	2	1	1
Threonine	9	10	6	6
Arginine	9	9	5	5
Isoleucine	6	6	3	4
Leucine	14	13	8	8
Histidine	3	3	2	2
Valine	8	8	5	5
Tyrosine	5	5	3	3
Serine	12	13	7	8
Proline	13	11	10	8
Phenylalanine	6	6	4	4
Glysine	16	17	9	9
Glutamate	28	28	18	18
Alanine	15	15	8	8
Aspartate	12	15	5	8

2.3 Results and discussion

The average daily feed intake (g/bird) for every weighed interval and every feed combination are presented in Table 2.4. A graphical representation of the total intake of the birds is presented in Figure 2.1 while Table 2.5 summarises the different selected feed combinations over the phases pre-starter and starter (0-3 months), grower (3-6 months) and finisher (6-9 months). During each phase the feed with the highest nutrient density in terms of energy and protein was preferred to the rest of the feeding combinations. The average actual nutrient intake (g/bird) along with the nutrient requirements (g/day) are presented in Table 2.6. It may be assumed that the birds attempted to eat to their requirements (energy and limiting amino acids), but preferred to do it from the high density diet. This is possible as it would ease the consumption of the required nutrients without the restriction of gut capacity (Ferguson, 2006).

Table 2.4 The average feed intake per bird of the four diets differing in protein and energy content at each weighed interval [high energy (HE) = 13.5 MJ/kg, high protein (HP) = 180 g/kg, low energy (LE) = 8.5 MJ/kg and low protein (LP) = 120 g/kg].

Age (weeks)	Intake (g/bird/day)				Total intake (g/bird/day)
	HE, HP	HE, LP	LE, HP	LE, LP	
3	27	42	3	1	**73**
4	92	29	36	12	**169**
5	208	171	50	21	**449**
6	126	228	104	47	**504**
7	177	343	143	32	**695**
9	722	480	142	11	**1356**
10	266	322	38	113	**740**
12	633	196	130	149	**1107**
14	896	108	355	0	**1359**
16	779	336	149	9	**1273**
18	351	119	0	0	**470**
20	582	275	2	121	**979**
22	486	661	31	39	**1217**
24	1229	575	30	31	**1865**
27	1053	863	38	69	**2023**
29	1084	868	12	118	**2082**

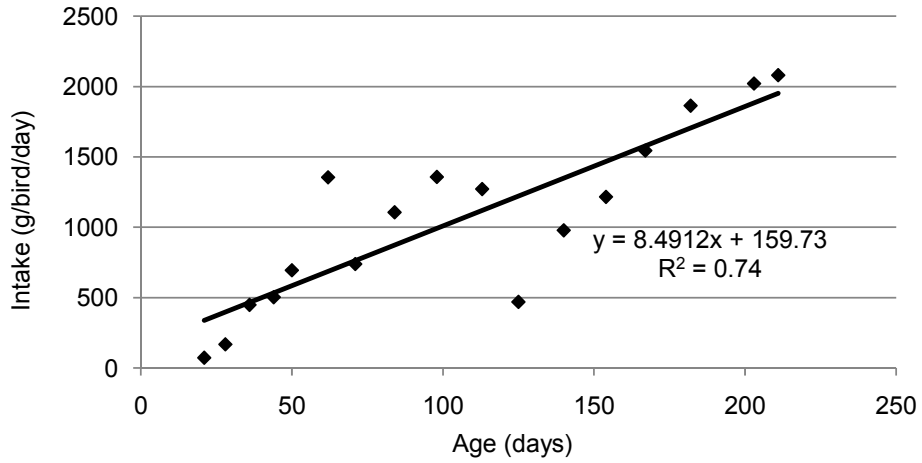

Figure 2.1 Regression line fitted to the total average daily intake (g/bird) of the birds with an age increase

Table 2.5 Feed preference of the slaughter birds when provided with feeds differing in protein and energy in a free choice situation [high energy (HE) = 13.5 MJ/kg, high protein (HP) = 180 g/kg, low energy (LE) = 8.5 MJ/kg and low protein (LP) = 120 g/kg].

Dietary energy (MJ ME/kg feed)	Dietary protein (g/kg feed)	Age group (months)		
		0 – 3 (%)	3 – 6 (%)	6 – 9 (%)
HE	HP	45.5	51.7	67.9
HE	LP	32.0	28.6	21.8
LE	HP	13.9	10.9	6.4
LE	LP	8.6	8.8	3.9

Table 2.6 The actual nutrient intake of the birds in this study along with the corresponding requirements as reported by Du Preez, (1991), Smith *et al.* (1995) and Cilliers *et al.* (1998) during the growth period.

NUTRIENTS	Growth period (months)					
	0 – 3		3 – 6		6 – 9	
	Actual	Req.	**Actual**	Req.	**Actual**	Req.
Metabolisable Energy (MJ/day)	**7.8**	8.9	**20.2**	17.4	**27.8**	21.0
Crude Protein (g/day)	**121.5**	137.8	**310.5**	237.0	**429.5**	260.0
Lysine (g/day)	**4.5**	6.7	**11.5**	13.5	**16.6**	16.9
Methionine (g/day)	**1.9**	2.1	**5.3**	4.7	**6.9**	6.0
Threonine (g/day)	**5.0**	3.9	**12.7**	7.9	**17.8**	10.1
Arginine (g/day)	**4.7**	6.0	**12.0**	12.9	**17.1**	16.7
Cysteine (g/day)	**1.0**	1.4	**2.6**	2.9	**3.7**	3.6
Isoleusine (g/day)	**3.1**	4.3	**7.9**	8.7	**11.3**	10.9
Leucine (g/day)	**7.2**	8.3	**18.6**	16.0	**26.5**	18.8
Histidine (g/day)	**1.6**	2.6	**4.2**	6.4	**5.9**	8.6
Valine (g/day)	**4.3**	4.5	**11.0**	9.2	**15.5**	11.3
Tyrosine (g/day)	**2.7**	2.8	**6.8**	5.3	**9.6**	7.1
Phenylalanine (g/day)	**3.3**	5.2	**8.4**	10.5	**11.7**	13.1
Serine (g/day)	**6.5**	-	**16.5**	-	**23.2**	-
Proline (g/day)	**7.2**	-	**18.4**	-	**25.7**	-
Glysine (g/day)	**8.4**	-	**21.5**	-	**30.5**	-
Glutamate (g/day)	**15.1**	-	**38.8**	-	**54.4**	-
Alanine (g/day)	**7.7**	-	**19.7**	-	**28.3**	-
Aspartate (g/day)	**6.2**	-	**15.8**	-	**22.5**	-
Fat (g/day)	**23.5**	**-**	**60.7**	**-**	**84.0**	**-**
Fibre (g/day)	**73.6**	**-**	**180.4**	**-**	**208.0**	**-**
ADF (g/day)	**94.6**	**-**	**232.7**	**-**	**274.0**	**-**
NDF (g/day)	**176.9**	**-**	**438.9**	**-**	**528.8**	**-**
Ash (g/day)	**55.9**	**-**	**142.2**	**-**	**194.5**	**-**

A Gompertz growth curve was fitted to the data and the predictions (Figure 2.2) provide valuable information as to the potential growth rate of this strain of ostrich. The growth parameters a (maximum weight), b (rate of maturing parameter) and c (age of maximum growth) were estimated at 119.4 kg, 0.009 and 156.3 days respectively. This would prove useful in predicting the growth of ostriches as an accurate description of the potential growth of the body and its components is necessary for the development of an accurate and economic feeding strategy for ostriches (Brand & Gous, 2006).

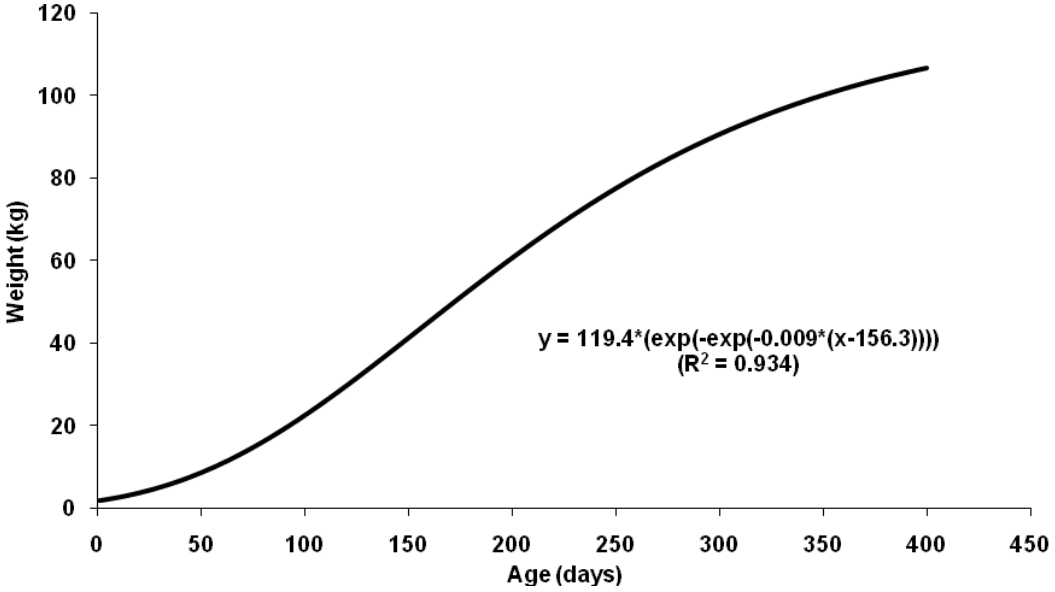

Figure 2.2 Gompertz growth curve for ostriches according to body weight increase over time [a (maximum weight) = 119.4; b (rate of maturing parameter) = 0.009; c (age of maximum growth) = 156.3].

When the four main dried body components were examined, the protein content as a percentage of body weight decreased, body fat increased and the ash content stayed relatively constant with an increase in age (Figure 2.3). The moisture content decreased with an increase in age. The R^2-values are acceptable for protein, moisture and fat (> 0.50), but very low for ash content (R^2 = 0.16). The remainder of other sources of variation (60.0 %) with regards to ash content warrants further investigation.

Swart *et al*. (1993) fed ostriches an experimental diet consisting of higher-than-recommended energy levels and a slightly lower-than-recommended protein level. The trial was terminated at 120 days of age. It was found that for the whole body, the moisture decreased from 74.6% to 66.0%, protein increased from 16.3% to 18.7%, fat increased from 5.32% to 10.9% and the ash increased slightly from 3.74% to 4.46% in the period ranging from 10-30 kg live weight. These values correspond well with values in this trial (Table 2.7) where moisture decreased from 76.9% to 64.1%, protein increased from 15.4% to 20.6%, fat increased from 4.3% to 9.8% and ash increased from 2.3% to 4.4% for the same time interval. Investigating from 120 days up to trial termination, the percentage moisture is decreasing, whilst the percentages of protein and ash are stabilising (have reached a plateau) and fat is ever increasing. Swart *et al*. (1993) concluded that although growth is depended on a necessary protein and water deposition rate, it will at some time be subjected to an increasing rate of fat deposition which seemingly commences at the beginning of growth. From this study the proposed theory that a change in the protein:fat deposition rate will occur at some stage in

the growth cycle and that these changes coincide with a break in the growth curve appears to be valid. The time at which maximum growth would occur is predicted at day 156 (Figure 2.2), which is where the fitted model predicts the break in the growth curve. Scholtz & Roux (1981) reported that the predicted growth inflexion point may correspond to changes in the physiological state of the animal which could be due to the onset of sexual maturity. However, the prediction (156 days) in this study appears too early for the onset of sexual maturity in ostriches. The changes in the physiological state of the bird lead to changes in the efficiency of ME utilisation as the distribution of energy toward protein and fat deposition in the body changes (Swart *et al*., 1993).

Table 2.7 Mean weights (± SD) and percentages of body weight for chemical components (as is) at different slaughter ages.

Age (days)	1	%	54	%	120	%	162	%	285	%
Moisture (kg)	0.66 ±0.06	76.9	4.18 ±1.46	72.1	21.86 ±3.72	64.1	31.78 ±4.70	61.1	50.26 ±4.73	60.1
Body Protein (kg)	0.13 ±0.01	15.4	0.97 ±0.31	16.8	7.02 ±1.50	20.6	10.81 ±1.58	20.8	17.29 ±1.42	20.7
Fat (kg)	0.04 ±0.01	4.3	0.39 ±0.20	6.8	3.35 ±1.55	9.8	6.24 ±1.77	12.0	12.08 ±2.47	14.5
Ash (kg)	0.02 ±0.01	2.3	0.19 ±0.08	3.3	1.50 ±0.38	4.4	2.53 ±0.41	4.9	4.05 ±0.32	4.9

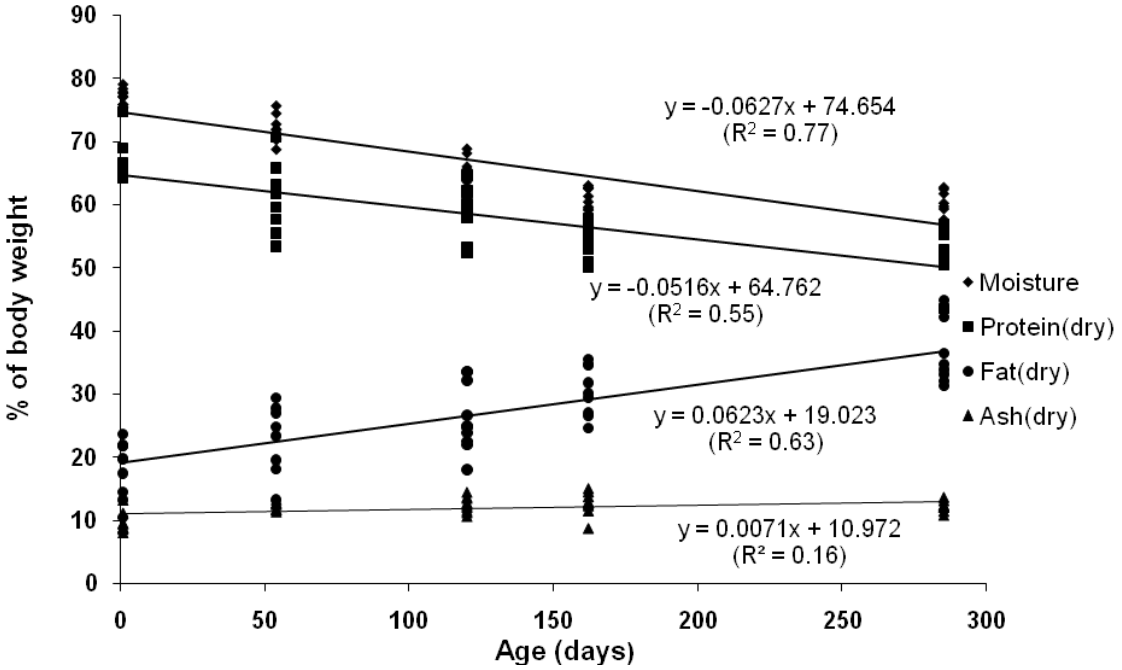

Figure 2.3 Linear regressions fitted to the change in chemical composition (% of body weight) of the body of growing ostriches over time.

Gompertz growth curves, fitted to the weights of each of the chemical components, are illustrated in Figure 2.4, while the parameter predictions that illustrate the differences between the chemical components of the body are set out in Table 2.8. The data in Table 2.8 confirm that growth in the chemical depositioning of ostriches is similar to that in other species (Lawrie, 1998; McDonald *et al*., 2002). Investigating the b-value in Table 2.8, it is noticeable that these values are more or less the same for each tissue. These tissues are allometrically related and it is consequently feasible to relate the growth of the individual components to body protein growth to enable simulation modeling (Table 2.9). All the allometrically related body components (chemical and physical) can be predicted and modeled when related to a single factor such as body protein growth (Ferguson, 2006; Gous & Brand, 2008). Fat did not hve such a good fit (R^2 = 0.57) compared to protein, moisture and ash. This is not uncommon as body fat content is known to be more variable than the rest of the body components (Mellett, 1992) and is largely dependent on the nutritional status of the animal (Ferguson, 2006).

Since animals are slaughtered at intervals, repeated measurements are avoided, eliminating the correlation found in such measurements (Mellett & Randall, 1994).

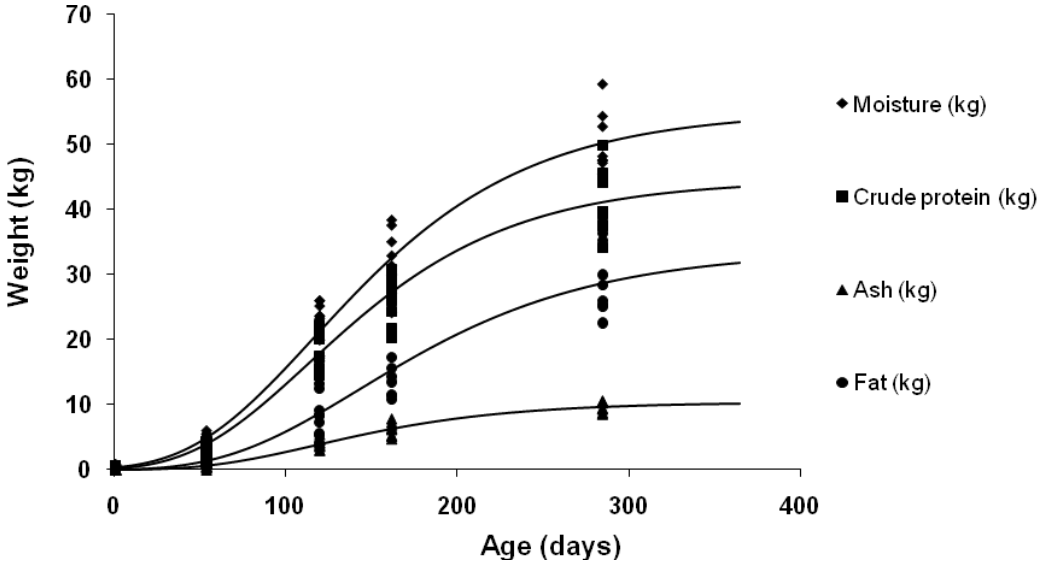

Figure 2.4 Gompertz growth curves fitted to body water, crude protein, fat and ash weights for growing ostriches.

Table 2.8 Growth parameters of the chemical components of the body as expressed by the Gompertz growth curve.

	a	b	c	s. l.
Ash	10.3 ± 0.4	0.016 ± 0.002	118 ± 3.8	0.699
Moisture	55.0 ± 2.3	0.014 ± 0.002	117 ± 4.4	0.321
Body Protein	44.5 ± 1.9	0.015 ± 0.002	114 ± 4.4	0.161
Fat	33.6 ± 3.5	0.013 ± 0.003	143 ± 11.1	0.975

a=maximum predicted weight at maturity, b=rate of growth parameter and c=days at which maximum growth occurs

A free choice feeding system was used on the assumption that the birds would adjust their nutrient intake (McDonald *et al.*, 2002; Van der Merwe & Smith, 1991) so that deficiencies and excesses of protein and energy are avoided, thereby enabling the birds to grow close to their potential without being constrained by the feed offered. The fitted growth curve was then used to determine the potential growth rate of the individual chemical body components where the significant level values derived from the goodness of fit test describe the accuracy of the model predictions. It is important to note that genotypes will probably differ in ways that will affect their potential growth curves, their mature chemical composition and the relative maturing rates of the individual components (Ferguson, 2006).

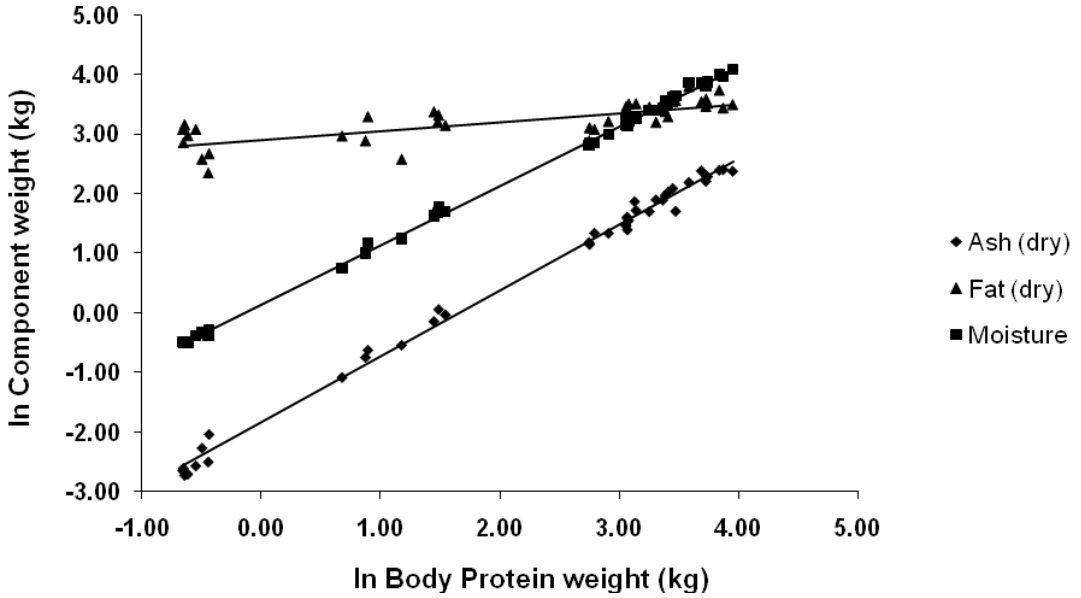

Figure 2.5 The natural logarithm of each body component (kg) expressed against the natural logarithm of the body protein (kg).

Table 2.9 Regression coefficient, constant term and R^2 of the ln of the body components fitted against the ln of the body protein

	Constant Term	Regression Coefficient	R^2
Ash (dry)	-1.8372 ± 0.0340	1.1087 ± 0.0124	0.99
Fat (dry)	2.9099 ± 0.0554	0.1500 ± 0.0204	0.57
Moisture	0.145 ± 0.0151	0.9959 ± 0.0056	0.99

When predicting feed intake, the multiple factors influencing feed intake such as temperature, nutrient density, amino acid content, stress susceptibility and general health should not be overlooked. The rate at which an animal grows is dependent on the current state of the animal, the rate of the maturing parameters (protein, moisture, fat and bone) and on the mature body protein weight (Taylor, 1980). Ferguson (2006) stated that, in pigs, protein will only grow to its full potential if sufficient energy and the essential amino acids are available. Sufficient heat loss must also be allowed by the environment. Similarly, lipid growth is almost solely dependent on the quality and quantity of the consumed diet, the energy:protein ratio, environmental conditions and the state of the animal.

When computing the sum of “a” above, (Table 2.8) it is evident that there was a difference between the mature empty body weight (without intestinal fluid) and the mature live weight (whole body) as predicted by the growth curves, 143.4 kg versus 119.4 kg. This is probably due to the increased accumulation of body fat over time, which would cause the overestimation of body fat by

the Gompertz model. Fat deposition is party dependent on age (Van der Merwe and Smith, 1991; McDonald *et al*., 2002), but mostly on the nutritional status of animals (Ferguson, 2006).

Table 2.10 Comparisons between results in the current study and previous research on ostrich growth curves.

	Gompertz model parameters		
	a	**b**	**c**
This study	119.4	0.0090	156
Du Preez *et al*. (1992)	98.4 – 102.1	0.0090 – 0.0097	163 – 175
*Cilliers (1994)	100.0 – 120.0	0.0090 – 0.0130	-
Sabbioni *et al*. (1999)	109.1	0.0056	256.6

*Another form of the Gompertz model was used and c was susequently not predicted

Table 2.10 compares fitted Gompertz curves from the literature with the results from this study. Similar or better results were observed for birds from this study. This was expected as birds had a selection of four diets with different nutrient densities. It was estimated that maximal growth in this study was achieved by day 156; maximum mature mass was predicted at 119.4 kg and the estimated maturing parameter at 0.009. Results compare relatively well with the study of Du Preez *et al.* (1992), who found that under *ad libitum* feeding, maximum daily weight gain occurred at 92-114 d for Zimbabwean birds, 115-124 d for Namibian birds and 163-175 d for South African birds. The predicted mature weights were found to be 94.2-104.9, 92.6-99.6, 98.4-102.1 kg, and maturing parameters of 0.0138-0.0168, 0.0126-0.0135 and 0.0090-0.0097, respectively. Environmental conditions such as ambient temperature and humidity, as well as feeding regime affect the growth of birds in various ways and this explains some of the differences found between this study and that of Du Preez *et al*. (1992).

2.4 Conclusion

Assuming that ostriches will select feed according to protein and energy requirements and thereby grow close to their potential, without being constrained by the quality of feed supplied to them, the results presented here could be regarded as representing the potential growth rate of this particular strain of ostrich. Growth rates as predicted by the Gompertz growth curve, in this study, exceed values predicted by documented studies. Nutrient intake also exceeds the nutrient requirements (3-6 and 6-9 months) as proposed by earlier studies. It may therefore be concluded that optimum feeding conditions were achieved. Protein was shown to be an early maturing tissue and fat as relatively late maturing. This serves as confirmation that the chemical components of the ostrich increase in similar ways to those in other animal species. Each chemical component was described by a Gompertz growth curve, and the rate of growth parameters deemed the tissues to be allometrically related. This is useful when modeling nutrient requirements of ostriches during the growth period. The partitioning of nutrients toward protein and fat deposition needs to be defined in order to predict voluntary food

intake. This would assist in defining the concentration of nutrients to be specified in a feed formulation program more accurately than at present (Gous & Fisher, 2008). This would then allow the optimisation of feeding regimes for ostriches.

2.5 References

AOAC. (2002) Official methods of analysis: Revision 1 (17th ed.). Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA, pp. 152-169.

Berg, R. T., Andersen, B. B. & Liboriussen, T., 1978. Growth of bovine tissues. Genetic influences on growth patterns of muscle, fat and bone in young bullls. Anim. Prod. 26, 245-258.

Berg, R. T. & Butterfield, R. M., 1976. New Concepts of cattle growth. University of Sydney Press, Sydney.

Berg, R.T., 1967. Genetic and enviromental influences on growth in beef cattle. In: Growth and Development of Mammals, Proceedings of the Fourteenth Eastern School in Agricultural Sciences, University of Nottingham. Ed. Loge, G. A., & Lamming, G. E., Butterworth, London, pp. 429-449.

Brand, T. S. & Gous, R. M., 2006. Feeding Ostriches. In: Feeding in Domestic Vertebrates, From Stucture to Behaviour. Ed. Bels, V., CAB International, Oxfordshire, pp. 136-155.

Brand, T. S., Nell, C. J. & Van Schalkwyk, S. J., 2000. The effect of dietary energy and protein level on the production of growing ostriches. S. Afr. J. Anim. Sci. 30 (Supplement 1).

Cilliers, S. C., 1994. Evaluation of feedstuffs and the ME and amino acid requirements for maintenance and growth in ostriches. Ph.D. Thesis, University of Stellenbosch, South Africa.

Cilliers, S. C., 1998. Feedstuff evaluation, metabolisable energy and amino acid requirements for maintenance and growth in ostriches. Prococeeding of the Second International Ratite Congress, Oudtshoorn, South Africa.

Du Preez, J. J., 1991. Ostrich nutrition and management. In: Recent advances in Animal Nutrition in Australia. D. J. Farrel (Ed)., University of New England, Armidale, Australia, pp. 278-291.

Du Preez, J. J., Jarvis, M. J. F., Capatos, D. & De Kock, J., 1992. A note on the growth curves for the ostrich (*Struthio camelus*). Anim. Prod. 54, 150-152.

Emmans, G. C., 1989. The growth of turkeys. In Recent advances in turkey science. Ed. Nixey, D., and Grey, T. C., Poultry science symposium 21, Butterworths, London, pp.141-145.

Ferguson, N. S., 2006. Basic Concepts Describing Animal Growth and Feed Intake. In: Mechanistic Modelling in Pig & Poultry Production. Ed. Gous, R. M., Morris, T. R., and Fisher, C., CAB International, Oxfordshire, pp. 22-54.

Gous, R. M. & Fisher, C., 2008. Simulation models in poultry production. XXIII World's Poultry Congress, Brisbane, Sydney.

Huxley, J. S., 1932. Problems of Relative Growth. Methuen and Co., Ltd., London.

Iji, P. A., van der Walt, J. G., Brand, T. S., Boomker, E. A. & Booyse, D., 2003. Development of the digestive tract in the ostrich (*Struthio camelus*). Arch. Anim. Nutr. 57, 217-228.

Lawrie, R. A., 1998. Lawrie's Meat Science, 6th edition, Woodhead Publishing Limited, pp.11-30.

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. & Morgan, C. A., 2002. Animal Nutrition, 6th edition. Pearson, Prentice Hall.

Mellett, F. D., 1992. Die volstruis as slagdier: aspekte van groei. Ph.D. Thesis, University of Stellenbosch, South Africa, pp. 54-55.

Mellett, F. D. & Randall, J. H., 1994. A note on the growth of body parts of the ostrich (*Struthio camelus*). Anim. Prod. 58, 291-293.

Sabbioni, A., Superchi, P., Bonomi, A., Summer, A. & Boidi, G., 1999. Growth Curves of intensively reared ostriches (*Struthio camelus*) in Northern Italy. Available from: http://www.unipr.it/arpa/facvet/annali/1999/sabbioni/sabbioni.htm. [Accessed 9 February 2010]

Scholtz, M. M. & Roux, C. Z., 1981. The allometric autoregressive model in genetic studies: Different physiological phases in the rat. S. Afr. J. Anim. Sci. 11, 27.

Smith, W. A., Cilliers, S. C., Mellett, F. D., & Van Schalkwyk, S. J., 1995. Nutrient requirements and feedstuff values in ostrich production. Feed Compounder, Sep. 1995, pp. 2-29.

Statgraphics, 2005. Statgraphics Centurion XV (Statpoint, inc.), www.statgraphics.com.

Swart, D., 1988. Studies on the hatching, growth and energy metabolism of ostrich chicks. Ph.D. Thesis, University of Stellenbosch, South Africa.

Swart, D, Siebrits, F. K. & Hayes, J. P., 1993. Growth, feed intake and body composition of ostriches (*Struthio camelus*) between 10 and 30 kg live mass. S. Afr. J. Anim. Sci. 23, 142-150.

Taylor, St. C. S., 1980. Genetic size-scaling rules in animal growth. Anim. Prod. 30, 161-165.

Van der Merwe, F. J. & Smith, W. A., 1991. Dierevoeding. Anim Sci Pty Ltd, Pinelands, pp. 163-168.

Chapter 3

Feather and skin development of ostriches (*Struthio camelus*)

Abstract

The requirement for accurate and cost-effective predictions and diet formulations are confirmed by the cyclical state of economics. Information on feather and skin growth is important for the development of mathematical optimisation models for ostriches. Overall, 65 birds were subjected to a four-stage formulated growth diet program (pre-starter, starter, grower and finisher), with decreasing protein and energy contents. Approximately nine birds were weighed, stunned, exsanguinated, defeathered and eviscerated at 1, 54, 84, 104, 115, 132 or 287 days of age. Feathers from four regions on the body were plucked and weighed. The nodule sizes from different sites on the skin and the shaft diameters of the wing feathers were measured at each slaughter age. Body components were removed and weighed at each slaughter age. These components were then ground with the remainder of the carcass, excluding gut content, but including blood and feathers. Proximate analyses were performed on the ground samples. Based on the analysis of ostrich feathers and the known mass of the feathers in the current study, the protein mass contribution of the feathers were deducted from the protein accretion of the bird. All the data were transformed to natural logarithms. Regional feather growth was regressed against total feather growth; skin size and skin weight were regressed against the body protein growth (excluding feathers) to set up allometric equations. A predictive model to determine skin nodule size on the live bird is proposed. Results from this study will aid in setting up a mathematical optimisation model for ostriches.

Keywords: growth, development, feeding optimisation, feather growth, nodule development, simulation modelling.

3.1 Introduction

A model is the simulation of a system that enables predictions that are as close to reality as possible. A description of reality is needed to set up an accurate prediction model (Emmans and Fisher, 1986).

A bird will attempt to grow at its absolute genetic potential (Emmans, 1989, 1990; Ferguson, 2006). The achievement of this goal is influenced by environmental conditions, state of the animal, nutritional factors and physical factors like gut capacity and intake regulation (Ferguson, 2006). Growth of the empty body (without gut fill) can be seen as the weight accumulation of protein, ash, water and lipid. Biological tissue growth follows a sigmoid pattern (Huxley, 1932; McDonald, 2002). These tissues and components are allometrically related. Relating all components to a standard factor like the featherless empty body protein weight (EBPW) will provide a way to compare and predict body component growth (Emmans, 1989; Ferguson, 2006).

Feather growth must be separated from body growth, as feather protein differs from body protein in amino acid composition. Emmans (1989) reported that feather protein contains high levels of cystine (70 g/kg protein) and low levels of lysine (18 g/kg protein), whereas body protein has low levels of cystine (11 g/kg protein) and higher lysine levels (75 g/kg protein). In addition, the feathers and the body mature at different rates (Emmans and Fisher, 1986; Emmans, 1989). Feather protein growth and body protein growth are thus not allometrically related. Consequently, the proportion of feather protein in the total body protein changes as the bird matures. Predictions for feather protein growth can thus not be made from body protein growth. Describing feather growth will help with cost-effective amino acid formulations and predictions as it changes during the production cycle. This study is based on the total feather weight of the birds at each slaughter age and no adjustments were made for feathers lost during general animal husbandry practices.

Nodules are the result of feather follicles on the skin and make it unique both in appearance and to the touch. Nodules are also the factor that distinguishes ostrich leather from competitors. Although no formal standards are available, the size, shape and distribution of these nodules are expected to have an effect on the marketability of the leather product (Cloete *et al*., 2004). Cloete *et al*. (2004) reported that age has an effect on some nodule traits in birds ranging from five to 14 months of age. Mellett *et al*. (1996) reported an increase in nodule size with age and stated that the optimum size is only achieved at 14 to 16 months of age. However, Van Schalkwyk *et al*. (2001) showed that body weight and age have an influence on nodule size. They also reported that an acceptable nodule size could be obtained at around 11 months of age. Nodule shape is determined by the stage of feather growth at slaughter. Swart (1981 as cited by Van Schalkwyk, 2008) stated that “green” body feathers or blood feathers cause inferior nodules. Cooper (2001) advised to exercise caution with feather removal as follicle damage could lead to inferior nodule shapes.

The aim of this study was to define the factors affecting income-generating products by setting up equations to model skin, feather and nodule development (Gous and Brand, 2008).

3.2 Materials and methods

Sixty-five birds were placed in 13 pens with water freely available. Four stages [pre-starter (0-1 months), starter (1-3 months), grower (3-6 months) and finisher (6-9 months)] of a formulated growth diet were used and fed *ad libitum* throughout the trial. The formulated diet ingredients are presented in Table 3.1. The feeds were sampled and analysed (AOAC methods, 2002) for protein, some amino acids, fat, NDF (neutral detergent fibre), ADF (acid detergent fibre), ash and crude fibre (Tables 3.2 and 3.3). The feed intake for the group of birds was determined for the first three phases (pre-starter, starter and grower) of the growth period (Table 3.6). Approximately nine randomly selected birds were slaughtered respectively at 1, 54, 85, 104, 115, 132 or 287 days of age. The trial was terminated on the final slaughter age.

At each slaughter age, each bird was weighed, stunned, exsanguinated, defeathered and eviscerated. The feathers from four regions (Table 3.4) were collected separately and dried in a drying oven at 80 °C for 48 hours. The feathers were then weighed separately according to the body region they derive from, and as total yield. The shafts of 10 randomly selected wing feathers were measured at the base (point of skin entry) using a digital calliper. After feather removal, the skin was removed, weighed and the surface area was determined by spreading the wet skin over a linen cloth and by tracing the outlines. The traced version was cut out and the surface area determined by means of computerised video image analysis. Ten randomly selected nodules were then measured on the tail, median and flank regions (Figure 1.5) of the skin using a digital calliper.

The intestines of each bird were cleaned with water and weighed. The heart and liver were removed and weighed. Thirteen muscles were removed and weighed individually. The neck was separated at the last cervical vertebra and weighed. Bones in the leg (femur, patella and tibiotarsus), the wingtip (metacarpus and digiti manus) and the rib cage were weighed. After weighing, all the components along with the blood and feathers were frozen in separate plastic bags for each bird. The body as a whole was minced in an industrial grounder and mixed thoroughly after which one randomly selected sample (approximately 150g) was used to perform a proximate analysis (AOAC methods, 2002) yielding the chemical composition of the entire bird (Table 3.2).

The requirements for each bird along with the actual nutrient intake were calculated (Table 3.5). As growth is non-linear (Huxley, 1932; McDonald *et al.*, 2002; Lawrie, 1998), the data was transformed into the natural logarithmic form to obtain linear data. Swart *et* al., (1993a) observed considerable quantities of gut fill (8-15% of live weight), and noted that major variation can occur between individuals at any specific time. This motivated the use of empty gut weight rather than live weight. Emmans (1989) also reported that feather protein and body protein should not be analysed

together. However, the feathers were analysed together with the remainder of the body in the current study. After the analysis of ostrich feathers were obtained in a separate study, the proportional protein contribution of the feathers was deducted from the protein analysis obtained above. This yielded an estimation of the featherless empty body protein weight (EBPW) and was used for further statistical analyses (Annexure 1). The natural logarithm of the skin size (dm^2) and weight (kg) were regressed against the natural logarithm of EBPW. The weights from each feather region (kg) were regressed against the total feather weight (kg). The analyses were performed using the common slope procedure of SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC, USA). An adapted form of the Gompertz growth curve (y = a*(exp(-exp(-b*(age-c)))) (Emmans, 1989), was fitted to the skin size data to confirm sigmoid growth. A principle component factor analysis was performed using Statistica, version 8.0 (2008) to determine the effect of various explanatory variables on the average nodule size of the ostrich skin.

Table 3.1 The feed ingredients of the formulated feeds on an as is basis [pre-starter (0-1 months), starter (1-3 months), grower (3-6 months), finisher (6-9 months)].

Ingredients (g/kg)	Feed			
	Pre-starter	**Starter**	**Grower**	**Finisher**
	0 – 1 months	1 – 3 months	6 – 9 months	3 – 6 months
Maize meal	500	200	-	-
Barley grain	-	400	400	200
Wheat bran	50	-	-	-
Lucerne meal	98	143	398	700
Molasses powder	-	-	25	25
Sunflower oil-cake meal	-	-	100	-
Soya bean oil-cake meal	96	80	50	50
Full-fat soya meal	71	50	-	-
Fish meal	150	75	-	-
Plant oil	10	10	-	-
Synthetic lysine	-	0.9	0.6	-
Synthetic methionine	0.7	0.5	1	0.9
Mono-calcium phosphate	-	14	1	6
Limestone	15	18	15	7
Vitamin & Mineral mix	5	5	5	5
Salt	4	4	4	4
Total	1000	1000	1000	1000

Table 3.2 Proximate analysis results of diets fed to ostriches during the pre-starter (0-1 months), starter (1-3 months), grower (3-6 months) and finisher (6-9 months) phases on an as is basis.

Ingredient	**Pre-starter**	**Starter**	**Grower**	**Finisher**
	0 – 1 months	1 – 3 months	3 – 6 months	6 – 9 months
Dry matter (g/kg)	909	918	911	907
ME (MJ/kg)	14.42	13.50	11.26	10.06
Crude protein (g/kg)	248	223	181	155
Fat (g/kg)	60	45	39	23
Ash (g/kg)	90	99	71	84
Fibre (g/kg)	65	97	82	199
ADF (g/kg)	92	129	110	222
NDF (g/kg)	166	197	197	342

Table 3.3 The amino acid composition of the diets on an as is (90% dry matter) basis (g/kg feed).

Amino Acid (g/kg)	**Pre-starter**	**Starter**	**Grower**	**Finisher**
	0 – 1 months	1 – 3 months	3 – 6 months	6 – 9 months
Lysine	13	10	8	5
Methionine	5	4	3	2
Cysteine	2	2	2	1
Threonine	12	11	9	7
Arginine	12	10	9	6
Isoleucine	8	7	6	5
Leucine	20	17	14	9
Histidine	4	4	3	3
Valine	11	10	9	7
Tyrosine	6	5	5	3
Serine	17	14	12	8
Proline	16	15	14	10
Phenylalanine	8	7	6	5
Glysine	25	20	17	11
Glutamate	36	32	28	19
Alanine	22	18	15	11
Aspartate	18	15	12	9

Table 3.4 An explanation of the anatomical positions of the four feather regions in this study as reported by Spark (1999).

Feather type	Description
Wing feathers (white plumes)	First row of big plumes at the wing edge
Byocks	Pied feathers at each end of the row of white feathers
Tail feathers	80 – 100 larger feathers on the tail
Drab floss (short body floss)	Primarily found on the line above the buttocks joint, as well as in the centre of the dorsal surface of the wing just before the long hard body feathers.

3.3 Results and discussion

The actual feed intake by the birds in this study and the nutrient requirements from the literature (Du Preez, 1991; Smith *et al*., 1995 and Cilliers *et al*., 1998) are presented in Table 3.5. When taking into account the energy requirement (MJ/day) of the birds over each growth phase, it is clear that adequate energy was ingested across all the phases. When investigating the protein requirements, with special reference to the ingested amino acids, it is apparent that the birds ingested enough of each amino acid throughout the phases. It is notable that a slight deficit in the lysine content was experienced during the grower phase (6-9 months). This is important as lysine is considered one of the first limiting essential amino acids. A monogastric animal will eat firstly to realise its energy requirement and thereafter to realize the first limiting amino acid (Ferguson, 2006).

Table 3.5 The actual nutrient intake of the birds in this study along with the corresponding requirements as reported by Du Preez, (1991), Smith *et al.* (1995) and Cilliers *et al.* (1998) during the growth period.

NUTRIENTS	Growth period (months)					
	0 – 1		1 – 3		3 – 6	
Average intake (g/bird/day)	132		771		1101	
Total feed intake (g/day)	**Actual**	Req.	**Actual**	Req.	**Actual**	Req.
Metabolizable Energy (MJ/day)	**1.9**	1.9	**10.4**	10.5	**12.40**	11.9
Crude Protein (g/day)	**32.7**	30.2	**171.9**	152.0	**199.3**	162.0
Lysine (g/day)	**1.7**	1.5	**7.7**	7.9	**8.8**	9.3
Methionine (g/day)	**0.7**	0.4	**3.1**	2.5	**3.3**	3.2
Threonine (g/day)	**1.6**	0.8	**8.5**	4.6	**9.9**	5.4
Arginine (g/day)	**1.6**	1.3	**7.7**	7.2	**9.9**	8.8
Cysteine (g/day)	**0.3**	0.3	**1.5**	1.7	**2.2**	2.0
Isoleusine (g/day)	**1.1**	0.9	**5.4**	5.0	**6.6**	6.0
Leucine (g/day)	**2.6**	1.8	**13.1**	9.6	**15.4**	10.9
Histidine (g/day)	**0.5**	0.5	**3.1**	3.3	**3.3**	4.4
Valine (g/day)	**1.5**	1.0	**7.7**	5.3	**9.9**	6.3
Tyrosine (g/day)	**0.8**	0.6	**3.9**	3.4	**5.5**	4.2
Phenylalanine (g/day)	**1.1**	1.1	**5.4**	6.1	**6.6**	7.2
Serine (g/day)	**2.2**	-	**10.8**	-	**13.2**	-
Proline (g/day)	**2.1**	-	**11.6**	-	**15.4**	-
Glysine (g/day)	**3.3**	-	**15.4**	-	**18.7**	-
Glutamate (g/day)	**4.8**	-	**24.7**	-	**30.8**	-
Alanine (g/day)	**2.9**	-	**13.9**	-	**16.5**	-
Aspartate (g/day)	**2.4**	-	**11.6**	-	**13.2**	-
Fat (g/day)	**7.9**	**-**	**34.7**	**-**	**25.3**	**-**
Fibre (g/day)	**8.6**	**-**	**74.8**	**-**	**219.1**	**-**
ADF (g/day)	**12.1**	**-**	**99.5**	**-**	**244.4**	**-**
NDF (g/day)	**21.9**	**-**	**151.9**	**-**	**376.5**	**-**
Ash (g/day)	**11.9**	**-**	**76.3**	**-**	**92.5**	**-**

Table 3.6 Proximate analysis of the whole birds at each slaughter age on an as is basis.

	Slaughter age (days)						
	1	**54**	**85**	**104**	**115**	**132**	**287**
Live weight (kg)	0.85 ± 0.06	6.28 ± 2.78	9.39 ± 3.75	13.2 ± 4.4	21.6 ± 2.8	35.4 ± 7.9	73.9 ± 9.3
Chemical Component							
Moisture (%)	76.9 ± 1.3	68.0 ± 2.0	64.1 ± 4.7	73.9 ± 0.5	65.4 ± 1.9	59.7 ± 2.4	60.7 ± 1.3
Protein (%)	12.1 ± 6.5	20.5± 1.1	25.8 ± 4.1	19.4 ± 1.6	25.7 ± 1.1	19.5 ± 6.5	20.9 ± 1.0
Fat (%)	4.42 ± 1.13	6.24 ± 2.55	3.98 ± 2.43	1.96 ± 0.81	2.91 ± 1.13	11.14 ± 4.77	12.51 ± 1.46
Ash (%)	1.70 ± 1.02	3.95 ± 0.35	6.02 ± 1.95	5.26 ± 0.81	7.09 ± 2.08	4.95 ± 1.97	5.28 ± 2.01

The chemical composition of the whole birds is presented in Table 3.6. The moisture in the body decreased with advanced age, while the protein and ash content remained relatively constant. The proportion of body fat was relatively constant throughout the first few slaughter occasions, but showed a drastic increase during the final two slaughter occasions. The chemical composition of the birds in this study at the final slaughter age was shown to be 60.7 % moisture, 20.9 % protein, 12.5 % fat and 5.28 % ash. This is in accordance with results reported in Chapter 2 where the composition at the final slaughter occasion (285 days) was reported to be 60.1 % for moisture, 20.7 % for protein, 14.5 % for fat and 4.9 % for ash.

The shaft diameter of the wing feathers and the weights of the different feathering regions along with the accompanying standard deviations are presented in Table 3.7. From Table 3.7 it can be seen that the wing feathers contribute the highest proportion in weight units to the total feather weight. This is significant as the wing feather growth appeared to arrest between days 85 and 104 (3 months) and again between days 132 and 287. Birds in this study were hatched in the summer months (February). Three months onwards would relate to late autumn and a subsequent three months from there would be early spring. Feathers mature earlier than the body (Emmans and Fisher, 1986; Emmans, 1989) and a state of mature wing feathers might have been reached at the age of four to five months. Subsequently, daylight length seems to have an effect on ostrich feathering and yield.

The growth (in weight units) of the feathering regions were related to the total feather weight in Table 3.8. Defining feather growth separately from EBPW is necessary as the two differ in growth rate (Emmans and Fisher, 1986; Emmans, 1989). The amino acid composition of feathers and body protein are also different from each other (Emmans, 1989).

Table 3.7 The shaft diameter of the wing feathers and the feather weight (DM basis) at each region, and the accompanying standard deviations at every slaughter age.

Age (days)	Average shaft diameter (mm)	Feather weight (g)				
		Drab floss	Byocks	Tail	Wing	Total feathers
1	0.14 ± 0.03	0.03 ± 0.01	0.04 ± 0.01	0.22 ± 0.08	1.2 ± 0.5	12.9 ± 3.6
54	1.79 ± 0.38	0.2 ± 0.1	2.8 ± 2.1	1.2 ± 1.1	7.9 ± 6.9	38.8 ± 29.2
85	3.39 ± 0.49	0.6 ± 0.3	7.5 ± 5.4	4.8 ± 2.7	35.1 ± 19.1	100.4 ± 39.5
104	2.85 ±0.68	1.1 ± 0.6	22.5 ± 16.4	19.1 ± 15.9	36.6 ± 23.5	154.15 ± 65.6
115	5.47 ± 0.55	3.2 ± 1.7	48.0 ± 10.9	19.2 ± 5.9	112.2 ± 29.6	336.0 ± 82.3
132	5.95 ± 0.84	27.1 ± 4.7	85.3 ± 14.7	39.7 ± 18.4	246.9 ± 75.7	653.0 ± 168.4
287	4.91 ± 0.51	37.2 ± 17.8	140.0 ± 29.4	109.6 ± 40.4	245.6 ± 54.7	836.6 ± 128.2

Table 3.8 Allometric coefficients relating the natural logarithms of the weighed feathers to the natural logarithms of the total feather weight.

Component	Constant Term	Regression Coefficient	R^2
Drab floss	-7.8518 ± 0.3268	1.6550 ± 0.0595	0.94
Byocks	-6.6623 ± 0.4363	1.7621 ± 0.0794	0.91
Tail	-4.9332 ± 0.2299	1.3777 ± 0.0419	0.96
Wing	-2.9282 ± 0.1239	1.2877 ± 0.0226	0.99

The wet skin size (dm^2), wet skin weight (kg), wet crown size (dm^2) and skin nodule sizes on the different skin regions with the accompanying standard deviations are presented in Table 3.9.

Table 3.9 The wet skin data and the accompanying standard deviations at each slaughter age and slaughter weight of birds in the current study.

Slaughter age (days)	Live weight (kg)	Wet skin weight (kg)	Wet unstretched skin size (dm^2)	Wet unstretched crown size (dm^2)	**Wet nodule size (mm)**			
					Flank	Median	Tail	**Average**
1	0.86 ± 0.07	0.08 ± 0.02	5.50 ± 0.53	-	1.14 ± 0.13	1.29 ± 0.13	1.22 ± 0.18	1.22 ± 0.16
54	6.28 ± 2.8	0.35 ± 0.1	19.88 ± 5.89	6.38 ± 1.7	1.66 ± 0.19	1.68 ± 0.17	1.81 ± 0.17	1.72 ± 0.18
85	9.39 ± 3.8	0.46 ± 0.2	25.00 ± 9.97	9.00 ± 3.8	2.71 ± 0.74	2.60 ± 0.66	2.57 ± 0.54	2.62 ± 0.63
104	13.20 ± 4.4	0.57 ± 0.2	27.25 ± 5.56	8.75 ± 1.9	1.92 ± 0.34	2.01 ± 0.15	1.78 ± 0.30	1.90 ± 0.27
115	21.60 ± 2.8	0.73 ± 0.1	35.00 ± 3.97	12.20 ± 1.9	2.53 ± 0.54	2.83 ± 0.19	2.58 ± 0.42	2.73 ± 0.35
132	35.40 ± 7.9	1.88 ± 0.6	61.44 ± 11.10	21.38 ± 4.6	3.31 ± 0.38	3.29 ± 0.35	3.40 ± 0.47	3.33 ± 0.39
287	73.90 ± 9.3	3.91 ± 0.6	96.70 ± 13.27	32.30 ± 4.16	3.18 ± 0.37	3.22 ± 0.52	3.42 ± 0.34	3.27 ± 0.41

Table 3.10 relates the natural logarithms of the skin size and weight to the natural logarithms of the EBPW. The given allometric equations render a portrayal of growth that may aid in predicting and modelling the nutrient requirements of the birds at different stages in the growth cycle.

Table 3.10 Allometric equations relating the natural logarithms of the wet skin size and weight to the natural logarithms of the EBPW (kg).

Component	Constant Term	Regression Coefficient	R^2
Wet skin size (dm^2)	2.8186 ± 0.0291	0.5885 ± 0.0162	0.96
Wet skin weight (kg)	-1.1960 ± 0.0558	0.7938 ± 0.0311	0.92

Figure 3.1 shows the wet skin sizes (dm^2) of the birds with an increase in age (days). When converted, ($y = 0.0277x + 0.6256$, $R^2 = 0.36$, Brand, 2008 – unpublished data), the dry skin weight of birds in this study at the age of 287 was 0.74 kg. Cloete *et al*. (2004) and Van Schalkwyk *et al*. (2002) reported that ostrich raw skin yield increased linearly with an increase in age. However, a Gompertz growth model was fitted to the current data (Figure 3.1). Wet skin yield increased in a sigmoid pattern. However, it is clear that the data will also fit a linear regression line with a reasonable description of variation. Yield predictions with the use of linear equations would thus be possible across certain age ranges. Results on the wet skin size, the wet crown size and the wet skin weight are presented in Table 3.9. The average wet skin size in this study at day 287 or about 10 months (Table 3.10) was shown to be 96.70 dm^2. Mellett (1992) reported an average dry skin size of 124.29 dm^2 for ostriches aged 10 months. When the wet skin size from this study are converted to the dry skin size ($y = 0.791587x + 52.31$, $R^2 = 0.64$; Brand, 2008 – unpublished results) it yielded an average skin size of 128.9 ± 10.5 dm^2. This is in agreement with the values reported by Mellett (1992; 1996) where an acceptable skin size of 120 dm^2 was reported to be obtained at the age of 10 months.

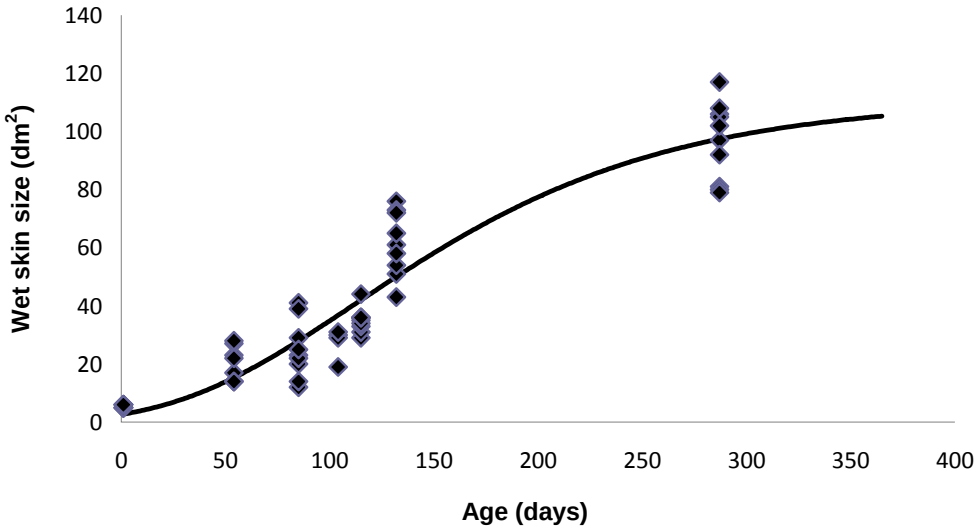

Figure 3.1 A Gompertz model fitted to the wet skin size increase against age [y = 110.9*(exp(-exp(-0.0117*(x-112.5)))), (s.l. = 0.0005)].

Nodules are unique to ostrich leather and it is accepted that age and weight play a role in the growth and development of these feather follicles (Van Schalkwyk, 2008). Table 3.9 indicates the average wet nodule size at different regions for each slaughter age. It can be accepted that feather growth and nodule size will be related. From Table 3.9 a trend similar to that seen in feather data can be observed. Nodule size declined after the age of three months before it started to increase again and no size increase could be reported between day 132 (four months) and day 287 (9-10 months). Daylight length thus seems to affect nodule and feather development in a seasonal manner with feather and nodule growth seemingly maturing at the age of four to five months in ostriches.

Cloete *et* al. (2004) reported differences in the shape of the nodules at the different regions, but this study only investigated nodule size (not shape). In the current study, no apparent size differences could be obtained between the different regions as the birds matured. Mellett *et al*. (1996) reported slaughter age or degree of maturity as the primary factor determining leather quality and that the optimum nodule size may only be achievable at the age of 14 to 16 months. Van Schalkwyk (2008) reported that birds can be slaughtered at 11 to 12 months of age because of improved feeding regimes and Cloete *et* al. (2004) confirmed that acceptable nodule size and shape could be attained at 11 months of age.

The correlation coefficients between the explanatory variables affecting the growth and development of nodules are given in Table 3.11.

Table 3.11 Correlation coefficients (r) between the explanatory variables and nodule size.

Variable	Live Weight (kg)	Age (days)	Shaft diameter (mm)	Total feathers (g)	Skin area (dm^2)	Skin weight (kg)	EBPW (kg)	**Nodule size (mm)**
Live weight (kg)	**1.000**	0.958	0.631	0.941	0.976	0.978	0.995	0.983
Age (days)	0.958	**1.000**	0.654	0.887	0.938	0.930	0.958	0.944
Shaft diameter (mm)	0.631	0.654	**1.000**	0.763	0.692	0.564	0.671	0.688
Total feathers (g)	0.941	0.887	0.763	**1.000**	0.956	0.920	0.944	0.957
Skin area (dm^2)	0.976	0.938	0.692	0.956	**1.000**	0.973	0.972	0.999
Skin weight (kg)	0.978	0.930	0.564	0.920	0.973	**1.000**	0.967	0.977
EBPW (kg)	0.995	0.958	0.671	0.944	0.972	0.967	**1.000**	0.980
Nodule size (mm)	0.983	0.944	0.688	0.957	0.999	0.977	0.980	**1.000**

All correlations are significant at $p < 0.05$

In order to understand the correlations among the explanatory variables, a principal component factor analysis was done. Age, live weight, EBPW, shaft diameter, skin size, skin weight and total feather weight were transformed to the natural logarithmic form. All the explanatory variables except shaft diameter were co-linear and loaded onto the first factor (Table 3.12). Only two factors were identified (Table 3.12). The second factor loads only on the wing feather shaft diameter. When constructing a regression model following a factor analysis, the prediction variables should preferably be derived from different factors to avoid the problem of co-linearity. A multiple linear regression model with independent variables, live weight and shaft diameter was firstly constructed (explaining 93% variation) and then improved with response surface regression to include a quadratic term, thus yielding the equation:

$$y = 2.63 + 0.561x - 0.00111x^2 + 0.133z \qquad (R^2 = 0.93),$$

where y = nodule size (mm),

x = live weight (kg) and

z = shaft diameter (mm).

Table 3.12 Individual factor loadings of the independent variables affecting nodule size as determined by the factor analysis (Significant contributions for each factor are in bold type).

Variable	Factor 1	Factor 2
Skin weight (kg)	**0.9563**	0.2598
Body weight (kg)	**0.9364**	0.3397
EBPW (kg)	**0.9132**	0.3889
Skin surface area (dm^2)	**0.8957**	0.4202
Age (days)	**0.8895**	0.3743
Total feathers (kg)	**0.8135**	0.5361
Shaft diameter (mm)	0.3322	**0.9415**
Proportion of total	0.7130	0.2606

A multiple linear regression model with independent variables, age and shaft diameter was also constructed (explaining 88 % variation) and yielded the following equation:

$$y = -0.47 + 0.12583x + 0.465z \qquad (R^2 = 0.88),$$

where y = nodule size (mm),

x = age (days) and

z = shaft diameter (mm).

The current study identified several factors that affect nodule development. To date no study has been conducted on the effect of season (daylight length) on feather development and natural moulting cycles and its effect on nodule development. The study of Mellett (1992) reported a hatching date of 1 September 1986, but this data is not reported in the other publications. Swart (1981) investigated the effect of forced feather removal on nodule development and showed that nodule development may be correlated to feather development (Swart, 1981 as cited by Van Schalkwyk, 2008). Nevertheless, the factors measured in the current study are co-linear (Table 3.12) which confounds the results. Practical measurable variables that describe model variation sufficiently were

thus used to construct a prediction model. The model allows the prediction of nodule size up to an age of 287 days accurately (R^2 = 0.93).

The shaft diameter as measured on the wing feathers can be discussed further as it is logical that feathers will also have a growth cycle like any biological material. This would imply that some of the feathers would ripen, fall out and be replaced by a new young feather (with a thinner shaft diameter). This may influence the proposed average shaft diameter and, to a certain extent, confound the validity of the proposed method. As the ostrich is a bird, it can be accepted that feather development will be highly influenced by daylight length or season of the year. The average nodule size can thus be estimated, while the bird is still alive (irrespective of gut content), for ostriches hatched during summer and reared under South African conditions. This will aid in least-cost modelling and diet formulations.

3.4 Conclusion

Seasonal feather and nodule development trends were reported. The allometric equations provided in this study offer the ability to predict feather and skin yield in ostriches through most of the growth cycle and especially for birds hatched in the summer months under Southern African conditions. More research is needed in the field of nodule growth and shape prediction. A model that predicts nodule size on the live bird from day old to 16 months of age is required. Results in this study, along with future research, form the basis for constructing a simulation model that accurately predicts changing nutrient requirements in slaughter ostriches. Leather yield is affected by skin size and this reached acceptable marketable sizes at approximately 10 months of age. Leather prices are affected by nodule size and shape and the prediction of this will aid in least-cost modelling, as the age required for a particular size nodule will be known. This, along with the cyclical nature of the leather price, the meat price and feather prices with a careful consideration of raw feed ingredient prices will be used to optimise the economical side of ostrich production.

3.5 References

AOAC, 2002. Official methods of analysis: Revision 1 (17th ed.). Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA, pp. 152-169.

Butterfield, R. M., 1988. New concepts of sheep growth. Dept. Vet. Anat., University of Sydney.

Cilliers, S. C., 1998. Feedstuff evaluation, metabolisable energy and amino acid requirements for maintenance and growth in ostriches. Proc. 2nd International Rat. Congress, Oudtshoorn, South Africa.

Cloete, S. W. P., van Schalkwyk, S. J., Hoffman, L. C., and Meyer, A., 2004. Effect of age on leather and skin traits of slaughter ostriches. S. Afr. J. Anim. Sci., 34 (2), pp. 80-86.

Cooper, R. G., 2001. Ostrich (*Struthio camelus* var. *domesticus*) skin and leather: A review focused on southern Africa. World's Poult. Sci. J. 57, pp. 157-178.

Du Preez, J. J., 1991. Ostrich nutrition and management. In: Recent advances in Animal Nutrition in Australia. D. J. Farrel (Ed)., University of New England, Armidale, Australia, pp. 278-291.

Emmans, G. C., 1989. The growth of turkeys. In: Recent advances in turkey science. Ed: Nixey, C., and Grey, T. C., Butterworths, London, U.K., pp. 135-166.

Emmans, G. C., 1990. Problems modelling the growth of poultry. Georgia Nutrition Congerence, 1990.

Emmans, G. C. and Fisher, C., 1986. Problems in nutritional theory. In Nutrient requirements of poultry and nutritional research (Eds. C. Fisher and K. N. Boorman). Butterworths, London, U.K. pp 9-39.

Ferguson, N. S., 2006. Basic Concepts Describing Animal Growth and Feed Intake. In: Mechanistic Modelling in Pig & Poultry Production. Ed. Gous, R. M., Morris, T. R., and Fisher, C., CAB International, Oxfordshire, pp. 22-54.

Gous, R. M., and Brand, T. S., 2008. Simulation models used for determining food intake and growth of ostriches: an overview. Aust. J. of Exp. Agri., 48, pp. 1266-1269.

Huxley, J. S., 1932. Problems of Relative Growth. Methuen and Co., Ltd., London

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. & Morgan, C. A., 2002. Animal Nutrition, 6th edition. Pearson, Prentice Hall, pp. 365-388.

Mellett, F. D., 1992. Die volstruis as slagdier: aspekte van groei. Ph.D. Thesis, Univ. of Stellenbosch, South Africa.

Mellett, F. D., Fisher, P., and Böhme, H. M., 1996. Grading of ostrich skins. Proc. Europ. Ostrich Conf., November, Henglo, The Netherlands, European Ostrich Association, Banbury.

SAS, 2000. SAS/STAT Users Guide, Version 8, First Edition, Volume 2. SAS Institute Inc., Cary, NC, USA.

Smith, W. A., Cilliers, S. C., Mellett, F. D., and Van Schalkwyk, S. J., 1995. Nutrient requirements and feedstuff values in ostrich production. Feed Compounder, Sep. 1995, pp. 2-29.

Spark, C., 1999. Guidelines for the care and management of ostriches in a commercial situation, p. 64.

StatSoft, Inc., 2008. STATISTICA (data analysis software system), version 8.0. www.statsoft.com.

Swart, D., 1981. Die evaluering van die ekonomiese waarde van die vel, vleis en vere op die lewendige slagvolstruis. Ongepubliseerde verslag, Departement van Landbou en Visserye, Suid Afrika.

Van Schalkwyk, S. J., 2008. Factors affecting ostrich leather traits. Ph.D. Thesis, Univ. of Stellenbosch, South Africa.

Van Schalkwyk, S. J., Cloete, S. W. P., Brand, T. S., & Hoffman, L. C., 2001. Die implikasie van 'n jonger of ouer slagstadium. Volstruisboeredag, Oudstshoorn Proefplaas, 1 August.

Van Schalkwyk, S. J., Cloete, S. W. P., Hoffman, L. C., Brand, T. S., Meyer, A., and Pfister, A. P., 2002. The effect of dietary energy and protein levels on skin size and physical leather parameters of ostriches. *Proc. 2nd World Ostrich Congr.*, Ed. J. O. Horbańczuk, 26-29 September, Warsaw, Poland, pp. 216-217.

Chapter 4

A description of body component growth (muscular, bone, organ) in relation to body protein growth in the ostrich (*Struthio camelus*)

Abstract

The modelling of any system requires an adequate description of that system. The relative maturation rates of certain ostrich body components (muscular, bones and organs) were evaluated over a 287-day growth period. Special attention was given to certain muscles of commercial importance for the industry. Allometric equations were set up that will aid with the prediction of ostrich growth and the changing nutrient requirements. Overall, 65 birds were subjected to a four-stage formulated growth diet (pre-starter, starter grower and finisher). Approximately 9 birds were weighed, stunned, exsanguinated, defeathered and eviscerated at 1, 54, 85, 104, 115, 132 or 287 days of age. Individual body components were dissected and weighed at every slaughter age. These components were ground with the remainder of the carcass, excluding gut content, but including blood and feathers. Proximate analyses were performed on a minced sample. Based on the analysis of ostrich feathers and the known mass of the feathers in the current study, the protein mass contribution of the feathers were deducted from the protein accretion of the bird. All the data were transformed to natural logarithms and regressed against the body protein growth (excluding feathers). The generated equations provide a way to predict body component growth. Results in this study will aid modellers in setting up mathematical optimisation models for ostriches.

Keywords: growth, development, feeding optimisation, proportional changes, allometric coefficients, simulation modelling.

4.1 Introduction

A model simulates a system to enable predictions that are as close to reality as possible. To build a successful model, a sufficient description of the simulated system is required. This is a necessary step to predict the outcome of a particular experiment (Emmans and Fisher, 1986).

A bird will attempt to grow at its absolute genetic potential (Emmans, 1989,1990; Ferguson, 2006), but factors such as the environment, the state of the animal, nutrition, as well as physical attributes like gut capacity and even intake regulation play a deciding role in the potential achievement of this goal (Ferguson, 2006). The body changes in physical and chemical composition when potential growth is realised (Emmans, 1990). The change in the chemical composition of an immature ostrich growing at its assumed potential is described in Chapter 2. Additionally, individual component growth needs to be defined and related to each other to increase prediction accuracy (Emmans and Fisher, 1986; Emmans, 1990). The growth of the empty body (without gut fill) can be seen as the weight accumulation of protein, ash, water and lipid. Biological tissue growth follows a sigmoid pattern (Huxley, 1932; McDonald, 2002). These tissues and components are allometrically related. Relating all components to a standard factor like the featherless empty body protein weight (EBPW) will provide a way to compare and predict body component growth (Emmans, 1989; Ferguson, 2006). Fitting a model such as the Gompertz growth curve to the individual components will provide a growth equation for the potential growth of each component. The generated rate of growth parameters can be used to determine if tissues are allometrically related (Emmans, 1989). The natural logarithms of the components can now be related to the natural logarithms of the EBPW (Gous and Brand, 2008).

The aim of this study was therefore to define the systematic physical change of body components in the ostrich and to create a predictive system by regressing related components against EBPW. Knowledge of the growth of the bird would provide valuable information on the nutrient requirement change in maturing birds (Gous and Brand, 2008).

4.2 Materials and methods

Sixty-five birds were placed in 13 pens with water freely available. Four stages of a formulated growth diet (pre-starter, starter, grower and finisher) were used and *ad libitum* feeding took place throughout the trial. The formulated diet ingredients are presented in Table 4.1.The feeds were sampled and analysed (AOAC methods, 2002) for protein, amino acids, fat, NDF (neutral detergent fibre), ADF (acid detergent fibre), ash and fibre (Tables 4.2 and 4.3). Approximately 9 randomly selected birds were slaughtered respectively at 1, 54, 85, 104, 115, 132 and 287 days of age. The trial was terminated on the final slaughter age.

Each bird was weighed, stunned, exsanguinated, defeathered and eviscerated. Blood was collected in a separate container. The slaughter procedures are described more clearly and in further detail in Chapter 3. The feathers and skin were removed. The intestines, heart and liver, 13

individual muscles (Table 4.5, 1.1 and Figure 1.1–1.4), and certain bones (Table 4.9) were removed and weighed. After weighing, all the individual parts along with the blood and the feathers were frozen in separate plastic bags for each bird until mincing commenced. All the body parts were minced with an industrial grounder and mixed thoroughly after which one randomly selected sample (approximately 150g) was used to perform a proximate analysis (AOAC methods, 2002) yielding the chemical composition of the total bird.

As growth is non-linear (Huxley, 1932; McDonald *et al.*, 2002; Lawrie, 1998), all the data were transformed into the natural logarithmic form to obtain linear data. Swart *et* al. (1993) observed considerable quantities of gut fill (8-15% of live weight), and reported notable variation between individuals at any given time. This motivated the use of empty gut weight rather than live weight. Emmans (1989) reported that feather protein and body protein should be analysed separately. However, the feathers were analysed together with the remainder of the body in the current study. After the analysis of ostrich feathers was obtained in a separate study, the proportional protein contribution of the feathers was deducted from the protein analysis obtained above. This yielded an estimation of the featherless empty body protein weight (EBPW) and was used for further statistical analyses (Annexure 1). Regression lines were fitted to each component using the common slope procedure of SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC, USA).

An adapted form of the Gompertz growth curve (y = a*(exp(-exp(-b*(age-c)))) (Emmans, 1989), was fitted to the body components and growth parameters a, b and c were calculated. A goodness of fit test (Mellett, 1992) determined the fit of the model. The given significance level (s. l.) is a value between zero and one with the hypothesis that the model fits the data.

Table 4.1 The feed ingredients of the formulated feeds on an as is basis [pre-starter (0-1 months), starter (1-3 months), grower (3-6 months), finisher (6-9 months)].

Ingredients (g/kg)	Feed			
	Pre-starter	**Starter**	**Grower**	**Finisher**
	0 – 1 months	1 – 3 months	6 – 9 months	3 – 6 months
Maize meal	500	200	-	-
Barley grain	-	400	400	200
Wheat bran	50	-	-	-
Lucerne meal	98	143	398	700
Molasses powder	-	-	25	25
Sunflower oil-cake meal	-	-	100	-
Soya bean oil-cake meal	96	80	50	50
Full-fat soya meal	71	50	-	-
Fish meal	150	75	-	-
Plant oil	10	10	-	-
Synthetic lysine	-	0.9	0.6	-
Synthetic metionine	0.7	0.5	1	0.9
Mono-calcium phosphate	-	14	1	6
Limestone	15	18	15	7
Vitamin & Mineral mix	5	5	5	5
Salt	4	4	4	4
Total	1000	1000	1000	1000

Table 4.2 Proximate analysis of diets fed to ostriches during the pre-starter (0-1 months), starter (1-3 months), grower (3-6 months) and finisher (6-9 months) phases on an as is basis.

Ingredient	**Pre-starter**	**Starter**	**Grower**	**Finisher**
	0 – 1 months	1 – 3 months	3 – 6 months	6 – 9 months
Dry matter (%)	90.9	91.8	91.1	90.7
ME (MJ/kg)	14.42	13.50	11.26	10.06
Crude protein (g/kg)	248	223	181	155
Fat (g/kg)	60	45	39	23
Ash (g/kg)	90	99	71	84
Fibre (g/kg)	65	97	82	199
ADF (g/kg)	92	129	110	222
NDF (g/kg)	166	197	197	342

Table 4.3 The analysed amino acid composition of the diets on an as is (90% moisture) basis (g/kg feed).

Amino Acid (g/kg)	**Pre-starter**	**Starter**	**Grower**	**Finisher**
	0 – 1 months	1 – 3 months	3 – 6 months	6 – 9 months
Lysine	13	10	8	5
Methionine	5	4	3	2
Cysteine	2	2	2	1
Threonine	12	11	9	7
Arginine	12	10	9	6
Isoleucine	8	7	6	5
Leucine	20	17	14	9
Histidine	4	4	3	3
Valine	11	10	9	7
Tyrosine	6	5	5	3
Serine	17	14	12	8
Proline	16	15	14	10
Phenylalanine	8	7	6	5
Glysine	25	20	17	11
Glutamate	36	32	28	19
Alanine	22	18	15	11
Aspartate	18	15	12	9

Table 4.4 The actual nutrient intake of the birds in this study along with the corresponding requirements as reported by Du Preez (1991), Smith *et al.* (1995) and Cilliers *et al.* (1998) during the growth period.

NUTRIENTS	Growth period (months)					
	0 – 1		1 – 3		3 – 6	
Average intake (g/bird/day)	132		771		1101	
Total feed intake (g/day)	**Actual**	Req.	**Actual**	Req.	**Actual**	Req.
Metabolizable energy (MJ/day)	**1.9**	1.9	**10.4**	10.5	**12.40**	11.9
Crude protein (g/day)	**32.7**	30.2	**171.9**	152.0	**199.3**	162.0
Lysine (g/day)	**1.7**	1.5	**7.7**	7.9	**8.8**	9.3
Methionine (g/day)	**0.7**	0.4	**3.1**	2.5	**3.3**	3.2
Threonine (g/day)	**1.6**	0.8	**8.5**	4.6	**9.9**	5.4
Arginine (g/day)	**1.6**	1.3	**7.7**	7.2	**9.9**	8.8
Cysteine (g/day)	**0.3**	0.3	**1.5**	1.7	**2.2**	2.0
Isoleusine (g/day)	**1.1**	0.9	**5.4**	5.0	**6.6**	6.0
Leucine (g/day)	**2.6**	1.8	**13.1**	9.6	**15.4**	10.9
Histidine (g/day)	**0.5**	0.5	**3.1**	3.3	**3.3**	4.4
Valine (g/day)	**1.5**	1.0	**7.7**	5.3	**9.9**	6.3
Tyrosine (g/day)	**0.8**	0.6	**3.9**	3.4	**5.5**	4.2
Phenylalanine (g/day)	**1.1**	1.1	**5.4**	6.1	**6.6**	7.2
Serine (g/day)	**2.2**	-	**10.8**	-	**13.2**	-
Proline (g/day)	**2.1**	-	**11.6**	-	**15.4**	-
Glysine (g/day)	**3.3**	-	**15.4**	-	**18.7**	-
Glutamate (g/day)	**4.8**	-	**24.7**	-	**30.8**	-
Alanine (g/day)	**2.9**	-	**13.9**	-	**16.5**	-
Aspartate (g/day)	**2.4**	-	**11.6**	-	**13.2**	-
Fat (g/day)	**7.9**	**-**	**34.7**	**-**	**25.3**	**-**
Fibre (g/day)	**8.6**	**-**	**74.8**	**-**	**219.1**	**-**
ADF (g/day)	**12.1**	**-**	**99.5**	**-**	**244.4**	**-**
NDF (g/day)	**21.9**	**-**	**151.9**	**-**	**376.5**	**-**
Ash (g/day)	**11.9**	**-**	**76.3**	**-**	**92.5**	**-**

Table 4.5 The anatomic muscle names of the weighed ostrich muscles accompanied by their commercial names.

Muscle name	Commercial name
M. iliotibialis cranialis	Top Loin
M. iliofemoralis externus	Oyster
M. iliotibialis lateralis	Round; Rump Steak
M. iliofibularis	Fan Fillet
M. iliofemoralis	Eye Fillet; Inside Strip
M. flexor cruris lateralis	Triangle Steak; Outside Strip
M. obturatorius medialis	Long Fillet; Tenderloin
M. femorotibialis medius	Moon Steak; Tip Trimmed
M. femorotibialis accessorius	Tip
M. gastrocnemius pars interna	Big drum; Inside Leg
M. gastrocnemius pars media	Flat Drum; Steak
M. gastrocnemius pars externa	Flat Drum; Outside Leg
M. fibularis longus	Drum Steak; Mid Leg

4.3 Results and discussion

An adapted form of the Gompertz growth model (y = a*(exp(-exp(-b*(age-c)))) (Emmans, 1989) was fitted to the individual muscles and selected organs (Table 4.6). Parameter estimations were derived that predict the maximum weight that the muscle will grow to (a), the day at which maximum growth will be achieved (c) and a growth parameter (b) that gives some indication of individual growth rates of the components. The significance level (s. l.) indicates the goodness of fit as reported by Mellett (1992). The growth curve did not iterate when fitted to the muscles *M. gastrocnemius pars externa, M. gastrocnemius pars media*, *M. iliofemoralis* and the *M. femorotibialis medius* and consequently predictions for these components could not be obtained. Ostrich muscles are usually sold whole (Mellett, 1992; Sales, 1999). Clear indications of how individual muscles react with an age increase will be beneficial to the industry.

Table 4.6 Parameter estimations for selected body components and individual muscles as predicted by the Gompertz growth model.

Component	Gompertz parameters			s. l.
	a	b	c	
	(kg)	-	(days)	
M. iliotibialis cranialis	0.7300	0.0259	122.5	<< 0.05
M. iliofemoralis externus	0.4432	0.0186	138.4	< 0.024
M. iliotibialis lateralis	1.7820	0.0268	126.9	<< 0.05
M. iliofibularis	2.2529	0.0262	128.0	<< 0.05
M. flexor cruris lateralis	0.5349	0.0249	127.7	<< 0.05
M. obturatorius medialis	0.8375	0.0612	126.8	<< 0.05
M. femorotibialis accessorius	1.4318	0.0180	130.0	<< 0.05
M. gastrocnemius pars interna	1.5030	0.0323	120.4	<< 0.05
M. fibularis longus	0.5160	0.0231	119.5	<< 0.05
M. iliofemoralis	-	-	-	-
M. femorotibialis medius	-	-	-	-
M. gastrocnemius pars media	-	-	-	-
M. gastrocnemius pars externa	-	-	-	-
Intestines	7.9072	0.00821	203.2	<< 0.05
Stomach	0.8458	0.0157	129.9	<< 0.05
Heart	0.8464	0.0507	121.4	<< 0.05
Liver	2.7444	0.0107	153.2	<< 0.05

A graphical representation of the Gompertz model fitted to the *M. femorotibialis accessorius* is presented in Figure 4.1 and illustrates a good Gompertz growth model fit. The actual carcass weights from this study (Table 4.7) can be compared to the values reported by Mellett (1992). A carcass weight of 8.0 ± 1.0 kg for birds aged 3 months and 41.08 ± 6.89 kg for 10-month-old birds were reported (Mellett, 1992). Similar results are reported in this study as birds aged 85 days (approximately 3 months) and 287 days (approximately 10 months) had a carcass weight of 5.25 ± 2.13 kg and 41.30 ± 6.09 kg respectively.

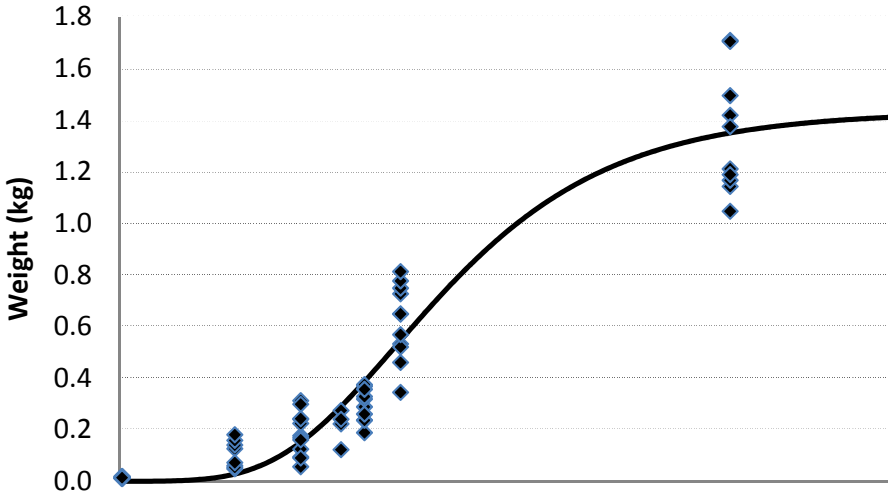

Figure 4.1 Graphical representation of the Gompertz growth model fitted to the *M. femorotibialis accessorius* [y = 1.432*(exp(-exp(-0.018*(x-130.0)))), (s.l. << 0.05)].

Table 4.7 The weights of the individually dissected muscle at each slaughter age.

Age (days)	1	54	85	104	115	132	287
Live weight (kg)	0.9 ±0.068	6.3 ±2.775	9.4 ±3.751	13.2 ±4.364	21.6 ±2.797	35.4 ±7.872	73.9 ±9.252
Carcass weight (kg)	0.32 ±0.04	2.96 ±1.27	5.29 ±2.13	5.71 ±2.08	8.74 ±1.72	21.59 ±5.46	41.30 ±6.09
M. gastrocnemius pars interna	0.013 ±0.004	0.111 ±0.056	0.173 ±0.084	0.208 ±0.089	0.358 ±0.078	0.825 ±0.261	1.487 ±0.402
M. fibularis longus	0.006 ±0.002	0.039 ±0.014	0.074 0.031±	0.104 ±0.061	0.126 ±0.024	0.276 ±0.074	0.503 ±0.090
M. gastrocnemius pars externa	0.008 ±0.001	0.077 ±0.034	0.129 ±0.061	0.166 ±0.082	0.239 ±0.052	0.569 ±0.154	0.857 ±0.210
M. gastrocnemius pars media	0.006 ±0.002	0.060 ±0.033	0.107 ±0.056	0.106 ±0.036	0.220 ±0.064	0.554 ±0.140	0.832 ±0.195
M. iliotibialis lateralis	0.013 ±0.004	0.119 ±0.054	0.173 ±0.093	0.220 ±0.094	0.351 ±0.084	0.808 ±0.222	1.753 ±0.344
M. flexor cruris lateralis	0.004 ±0.002	0.044 ±0.016	0.054 ±0.044	0.081 ±0.043	0.109 ±0.029	0.235 ±0.063	0.524 ±0.109
M. iliofemoralis	0.003 ±0.001	0.039 ±0.019	0.067 ±0.032	0.049 ±0.019	0.114 ±0.035	0.290 ±0.070	0.431 ±0.075
M. iliotibialis cranialis	0.006 ±0.002	0.057 ±0.028	0.092 ±0.046	0.102 ±0.032	0.162 ±0.040	0.373 ±0.087	0.716 ±0.015
M. iliofemoralis externus	0.002 ±0.001	0.021 ±0.009	0.030 ±0.020	0.027 ±0.014	0.075 ±0.024	0.160 ±0.036	0.247 ±0.068
M. iliofibularis	0.013 ±0.002	0.132 ±0.050	0.223 ±0.124	0.262 ±0.131	0.423 ±0.091	0.997 ±0.255	2.211 ±0.410
M. femorotibialis accessorius	0.014 ±0.003	0.105 ±0.052	0.182 ±0.082	0.215 ±0.065	0.295 ±0.064	0.617 ±0.146	1.345 ±0.230
M. femorotibialis medius	0.002 ±0.001	0.019 ±0.009	0.024 ±0.010	0.025 ±0.005	0.057 ±0.016	0.121 ±0.036	0.187 ±0.042
M. obturatorius medialis	0.002 ±0.001	0.031 ±0.018	0.067 ±0.044	0.073 ±0.025	0.096 ±0.034	0.407 ±0.117	0.837 ±0.277

Tables 4.8 to 4.11 indicate allometric equations that relate the natural logarithms of component weight to the natural logarithms of EBPW. The ability to predict muscle growth with special reference to the valuable cuts will aid with least-cost simulation models. There is not much commercial value in predicting bone growth, but knowledge on this is useful when modelling overall bird growth as the proportions (chemical and physical) are changing with age. The prediction of intestinal growth will be useful as the intake of birds on a high roughage diet may be constrained by gut capacity during certain parts of the growth cycle.

Table 4.8 Allometric coefficients relating the natural logarithms of the muscle weight to the natural logarithms of EBPW.

Component	Constant Term	Regression Coefficient	R^2
M. iliotibialis cranialis	-3.1005 ± 0.0555	0.9924 ± 0.0294	0.96
M. iliofemoralis externus	-4.2263 ± 0.0682	1.0880 ± 0.0394	0.93
M. iliotibialis lateralis	-2.3397 ± 0.0481	1.0210 ± 0.0255	0.97
M. iliofibularis	-1.9868 ± 0.1257	0.9326 ± 0.0666	0.81
M. iliofemoralis	-3.6875 ± 0.0645	1.0801 ± 0.0342	0.96
M. flexor cruris lateralis	-3.3917 ± 0.0586	0.9542 ± 0.0311	0.95
M. obturatorius medialis	-3.6663 ± 0.0883	1.1990 ± 0.0468	0.94
M. femorotibialis medius	-4.3658 ± 0.0683	1.0296 ± 0.0362	0.95
M. femorotibialis accessorius	-2.3988 ± 0.0431	0.9410 ± 0.0229	0.97
M. gastrocnemius pars interna	-2.3273 ± 0.0474	0.9854 ± 0.0251	0.97
M. gastrocnemius pars media	-3.0356 ± 0.0528	1.0770 ± 0.0280	0.97
M. gastrocnemius pars externa	-2.7490 ± 0.0425	0.9774 ± 0.0225	0.98
M. fibularis longus	-3.2583 ± 0.0482	0.9254 ± 0.0255	0.97

Table 4.9 Allometric coefficients relating the natural logarithms of bone parts to the natural logarithms of EBPW.

Component	Constant Term	Regression Coefficient	R^2
Femur	-1.4356 ± 0.0448	1.0074 ± 0.0238	0.98
Patella	-3.7353 ± 0.0549	1.0757 ± 0.0291	0.97
Neck	-1.8781 ± 0.0366	0.8843 ± 0.0194	0.98
Tibiotarsus	-1.7592 ± 0.1265	1.1037 ± 0.0671	0.86
Wingtip	-3.5853 ± 0.0588	1.1753 ± 0.0312	0.97

Table 4.10 Allometric coefficients relating the natural logarithms of the organ weights to the natural logarithms of EBPW.

Some organs	Constant Term	Regression Coefficient	R^2
Heart	-2.8826 ± 0.0530	0.9775 ± 0.0281	0.96
Intestines	-1.2020 ± 0.0595	0.9341 ± 0.0315	0.95
Liver	-1.7871 ± 0.0456	0.9082 ± 0.0242	0.97
Stomach	-2.7386 ± 0.0539	0.8459 ± 0.0286	0.95

Table 4.11 Allometric coefficients relating the natural logarithms of chemical body component growth (as is) to the natural logarithms of EBPW.

Body composition	Constant Term	Regression Coefficient	R^2
Moisture	1.3176 ± 0.0243	0.8772 ± 0.0140	0.99
Fat	-1.4934 ± 0.1270	1.1647 ± 0.0734	0.81
Ash	-1.5240 ± 0.0375	1.1128 ± 0.0217	0.98

Table 4.12 and 4.13 give the chemical composition and the amino acid composition of the birds at the different slaughter ages. An animal will require similar nutrient ratios to what is present in the whole body (McDonald, 2002). The amino acid composition of the whole body, at each age will aid in the determination and modelling of the protein requirements of the maturing bird.

Table 4.12 Results of the proximate analyses of the whole birds at each slaughter age on an as is basis.

	Slaughter age (days)						
	1	**54**	**85**	**104**	**115**	**132**	**287**
Live weight (kg)	0.85 ± 0.06	6.28 ± 2.78	9.39 ± 3.75	13.2 ± 4.4	21.6 ± 2.8	35.4 ± 7.9	73.9 ± 9.3
Chemical Component							
Moisture (%)	76.9 ± 1.3	68.0 ± 2.0	64.1 ± 4.7	73.9 ± 0.5	65.4 ± 1.9	59.7 ± 2.4	60.7 ± 1.3
Protein (%)	12.1 ± 6.5	20.5± 1.1	25.8 ± 4.1	19.4 ± 1.6	25.7 ± 1.1	19.5 ± 6.5	20.9 ± 1.0
Fat (%)	4.42 ± 1.13	6.24 ± 2.55	3.98 ± 2.43	1.96 ± 0.81	2.91 ± 1.13	11.14 ± 4.77	12.51 ± 1.46
Ash (%)	1.70 ± 1.02	3.95 ± 0.35	6.02 ± 1.95	5.26 ± 0.81	7.09 ± 2.08	4.95 ± 1.97	5.28 ± 2.01

Table 4.13 The average amino acid composition of the whole bird at the individual slaughter intervals on an as is basis (g/kg).

Amino acid	Interval (days)						
	1	**54**	**85**	**104**	**115**	**132**	**287**
Lysine	25	30	31	29	28	23	23
Methionine	10	11	11	10	10	8	8
Threonine	30	25	30	28	27	24	21
Arginine	32	33	34	32	30	26	24
Isoleucine	18	20	20	18	15	16	11
Leucine	40	39	43	41	38	34	30
Histidine	8	11	12	11	10	8	9
Valine	26	25	28	25	21	22	16
Tyrosine	13	12	13	12	11	10	9
Serine	42	30	38	37	36	29	27
Proline	47	41	52	49	51	42	39
Phenylalanine	17	18	19	18	16	14	13
Glysine	101	83	120	112	116	94	89
Glutamate	66	70	72	69	65	54	53
Alanine	56	52	68	63	63	55	53

Predicting component growth is an important step in the modelling process as an accurate description of the bird is necessary for simulation modelling (Ferguson, 2006). Birds were fed an assumed non-limiting diet. The birds thus attempted to grow to their maximum potential and at a maximum protein deposition rate. Relating the individual body parts to a single factor like EBPW, simplifies predictions and corrects for differences in the physiological state of the birds. This would aid the modeller in predicting body component growth and nutrient requirements in the maturing bird. The age of birds at any EBPW can be derived from the fitted growth model as it predicts EBPW as it changes with age (Chapter 2).

4.4 Conclusion

The fact that the birds were fed to their nutrient requirements is significant, as it can be assumed that bird growth was not inhibited by nutrient deficiencies.

The equations provided in this study contribute to the description of ostrich growth and will serve as prediction instruments for the changing body of the growing ostrich. Describing the body and its components as they grow are necessary steps in simulation modelling as the relative growth of each component will, in one way or another, affect the changing nutrient requirements of the birds.

The next step to optimal, accurate and economical ostrich production is therefore taken and future least-cost simulation modelling is simplified.

4.5 References

AOAC, 2002. Official methods of analysis: Revision 1 (17th ed.). Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA, pp. 152-169.

Cilliers, S. C., 1998. Feedstuff evaluation, metabolisable energy and amino acid requirements for maintenance and growth in ostriches. Proc. 2nd International Rat. Congress, Oudtshoorn, South Africa.

Du Preez, J. J., 1991. Ostrich nutrition and management. In: Recent advances in Animal Nutrition in Australia. D. J. Farrel (Ed)., University of New England, Armidale, Australia, pp. 278-291.

Emmans, G. C., 1989. The growth of turkeys. In: Recent advances in turkey science. Ed: Nixey, C., and Grey, T. C., Butterworths, London, U.K., pp. 135-166.

Emmans, G. C., 1990. Problems modelling the growth of poultry. Georgia Nutrition Congerence, 1990.

Emmans, G. C. and Fisher, C., 1986. Problems in nutritional theory. In Nutrient requirements of poultry and nutritional research (Eds. C. Fisher and K. N. Boorman). Butterworths, London, U.K. pp 9-39.

Ferguson, N. S., 2006. Basic Concepts Describing Animal Growth and Feed Intake. In: Mechanistic Modelling in Pig & Poultry Production. Ed. Gous, R. M., Morris, T. R., and Fisher, C., CAB International, Oxfordshire, pp. 22-54.

Gous, R. M., and Brand, T. S., 2008. Simulation models used for determining food intake and growth of ostriches: an overview. Aust. J. of Exp. Agri., 48, pp. 1266-1269.

Huxley, J. S., 1932. Problems of Relative Growth. Methuen and Co., Ltd., London

Lawrie, R. A., 1998. Lawrie's Meat Science, 6th edition, Woodhead Publishing Limited, pp.11-30.

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. & Morgan, C. A., 2002. Animal Nutrition, 6th edition. Pearson, Prentice Hall, pp. 365-388.

Mellett, F. D., 1985. The ostrich as meat animal: Anatomical and muscle characteristices. M. Sc. Thesis, Univ. of Stellenbosch, South Africa, pp. 1-35.

Mellett, F. D., 1992. Die volstruis as slagdier: aspekte van groei. Ph.D. Thesis, Univ. of Stellenbosch, South Africa, pp. 49-55.

Sales, J. (1999). Slaughter and products. In: The Ostrich, biology, production and health. Ed: Deeming, D. C., CABI Publishing, Wallingford, Oxon., pp. 231-274.

SAS, 2000. SAS/STAT Users Guide, Version 8, First Edition, Volume 2. SAS Institute Inc., Cary, NC, USA.

Smith, W. A., Cilliers, S. C., Mellett, F. D., and Van Schalkwyk, S. J., 1995. Nutrient requirements and feedstuff values in ostrich production. Feed Compounder, Sep. 1995, pp. 2-29.

Swart, D., Mackie, R. I., and Hayes, J. P., 1993. Influence of live mass, rate of passage and site of digestion on energy metabolism and fibre digestion in the ostrich (*Struthio camelus* var. *Domesticus*). S. Afr. J. Anim. Sci. 23, pp. 119-126.

Chapter 5

The effect of dietary energy and protein level on feather, skin and nodule growth of the ostrich (*Struthio camelus*)

Abstract

Accurate and cost-effective predictions and diet formulations are required to withstand the cyclical state of economics. Knowing how the skin, nodules and feathers react in the presence of different nutrient-density diets will assist least-cost modelling. Feather growth and nodule development are factors previously neglected in ostrich diet formulation. Both factors are essential for the development of a predictive quality model. Overall, 120 birds were placed in 15 pens. Varying energy regimes (high, medium and low) and accompanying protein and amino acid profile levels (level 1 - 5) were supplied *ad libitum* to each pen. A randomly selected bird from each pen was slaughtered at 1, 35, 63, 103, 159, 168, 244 and 285 days of age. Each bird was weighed, stunned, exsanguinated, defeathered and eviscerated. Feathers from four regions were plucked and weighed. The shaft diameter of the wing feathers was measured. The nodule size of the skin was measured at each slaughter age. The data were transformed to natural logarithms and regressed against the total feather weight and the total featherless empty body protein weight to set up allometric equations. A prediction equation to determine nodule size on the live bird is proposed. Feed cost optimisation is paramount and results from this study will aid in setting up least-cost optimisation (simulation) formulation models.

Keywords: growth, ostrich, dietary energy, dietary protein, feeding optimisation, feather growth, nodule development

5.1 Introduction

Ostriches are primitive, flightless birds that were originally domesticated for the use of their feathers, as it was popular in the fashion industry. With the increasing popularity of the meat and leather, the income contribution from the feathers is on a constant decline (SA ostrich business chamber, 2002). Depending on the quality of the product, leather can contribute more than 50 percent to the income of ostrich producers (Hoffman, 2005).

As the leather is marketed as a luxury product (Cooper, 2001), knowledge of the factors affecting the physical properties thereof is required (Sales, 1999). Skin nodules are the result of feather follicles on the ostrich skin. Nodules distinguish ostrich leather from competitors and make it unique in appearance and to the touch. Although no formal standards are available, the size, shape and distribution of these nodules are expected to have an effect on the marketability of the product (Cloete *et al*., 2004). Cloete *et al*. (2004) reported that age has an effect on some nodule traits for birds up to 14 months of age. Mellett *et al*. (1996) reported that nodule size increased with an increase in age and that the optimum nodule size is only achieved at 14 to 16 months of age. However, Van Schalkwyk *et al*. (2001) showed that age, along with body weight, influence nodule size and that acceptable nodule sizes could be achieved at 11 months of age. Since it is known that plane of nutrition affects body weight gain (Brand, 2000, 2003; Swart and Kemm, 1985), investigating the plane of nutrition is of importance to test this result.

Nodule shape is determined by the stage of feather growth at slaughter (Mellett, 1996). (Swart, 1981 as cited by Van Schalkwyk, 2008) reported that green body feathers or blood feathers lead to inferior nodules. Cooper (2001) also advised a cautious approach to feather removal as damage to the follicle could lead to inferior nodule shapes. The combination of the above-mentioned factors on the growth and development of nodule size and shape is a topic of much discussion and deliberation.

The body grows and develops in a systematic way. Therefore, it is expected that the requirements for dietary nutrients in growing animals will also be changing systematically (Bradford and Gous, 1991). Feather protein differs from body protein in amino acid composition (Emmans, 1989). The proportion of feather protein in the total protein portion, changes as the bird grows and develops. This needs to be taken into account when determining amino acid requirements of the birds (Emmans, 1989). A starting point for such calculations is an adequate description of feather growth (Gous *et* al., 1999). Knowing how the skin and feathers develop and how changes in dietary nutrients affect this is necessary for accurate nutrient requirement determination.

This study was conducted to investigate the effect of dietary energy and protein levels on various skin and feather traits and to describe nodule and feather growth with the various factors affecting it from one day old up to trial termination.

5.2 Materials and methods

Overall, 120 day old birds were randomly allocated to 15 pens. Varying energy regimes (high, medium and low) and accompanying protein (amino acid) levels (level 1 – 5) were formulated. Four stages (pre-starter, starter, grower and finisher) of feeding were used and supplied *ad libitum* throughout the trial (Figure 5.1 and 5.2). The median feeding regime was chosen according to standard requirement levels for energy and protein (amino acids) from the literature (Du Preez, 1991; Smith *et al,.*1995 and Cilliers *et al,.*1998, as summarised by Brand, 2008). An average feed intake per bird (Table 5.1 and 5.2) was determined by weighing the supplied feed and the feed leftovers for each pen throughout each phase. The feeds were sampled and analysed (AOAC methods, 2002) for protein, amino acids, fat, NDF (neutral detergent fibre), ADF (acid detergent fibre), ash and fibre (Annexure 2). Water was freely available throughout the trial. A randomly selected bird from each pen was slaughtered at 1, 35, 63, 103, 159, 168 and 244 days of age. Only six birds survived to the slaughter age of 285 days. Due to the high cost of such trials, the data of these six birds were included in the current study.

At each slaughter age, birds were weighed, stunned, exsanguinated, defeathered and eviscerated. Blood was collected in a separate container. The feathers from each region (Table 5.3) were plucked and dried at 80 °C for 48 hours in a drying oven. The feathers were then weighed separately by body region and as total yield. The shafts of 10 randomly selected wing feathers (five on each side) were measured at the base (point of skin entry) using a digital calliper. After feather removal, the skin was removed, weighed and the surface area was determined by spreading the wet skin over a linen cloth and by tracing the outlines. The traced version was cut out and the surface area was determined with computerised video image analysis. Ten randomly selected nodules were then measured on the tail, median and flank regions using a digital calliper (Figure 1.5, Chapter 1).

The intestines of each bird were cleaned with water and weighed. The heart and liver were removed and weighed. Thirteen muscles were removed and weighed individually. The neck was separated at the last cervical vertebra and weighed. Bones in the leg (femur, patella and tibiotarsus), the wingtip (metacarpus and digiti manus) and the rib cage were weighed. After weighing, all the components along with the blood and feathers were frozen in separate plastic bags for each bird. The body as a whole was minced and mixed thoroughly after which one randomly selected sample (approximately 150g) was used to perform a proximate analysis (AOAC methods, 2002) yielding the chemical composition of the entire bird.

As growth is non-linear (Huxley, 1932; McDonald *et al.*, 2002; Lawrie, 1998), all the data were transformed into the natural logarithmic form in order to obtain linear data. Swart *et* al., (1993a) observed considerable quantities of gut fill (8-15% of live weight), and noted that major variation can occur between individuals at any specific time. This motivated the use of empty gut weight rather than live weight. Emmans (1989) reported that feather protein and body protein should not be

analysed together. However, the feathers were analysed together with the remainder of the body in the current study. After the analysis of ostrich feathers was obtained in a separate study, the proportional protein contribution of the feathers was deducted from the protein analysis obtained above. This yielded an estimation of the featherless empty body protein weight (EBPW) and was used for further statistical analyses (Annexure 1). Using the Mixed Models Procedure of SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC, USA) the data were analysed for differences between birds on different treatments by comparing the slopes and intercepts independently. In the cases where no differences were found between the treatments, a general regression line was fitted to the data. This would provide an equation to compare and predict body component growth by utilising the existing allometric relationships between components and EBPW. Dietary protein had no effect on all the investigated variables and these results are not reported.

A principle component factor analysis was performed using Statistica, version 8.0 (2008) to determine the effect of certain explanatory variables on the average nodule size of the ostrich skin.

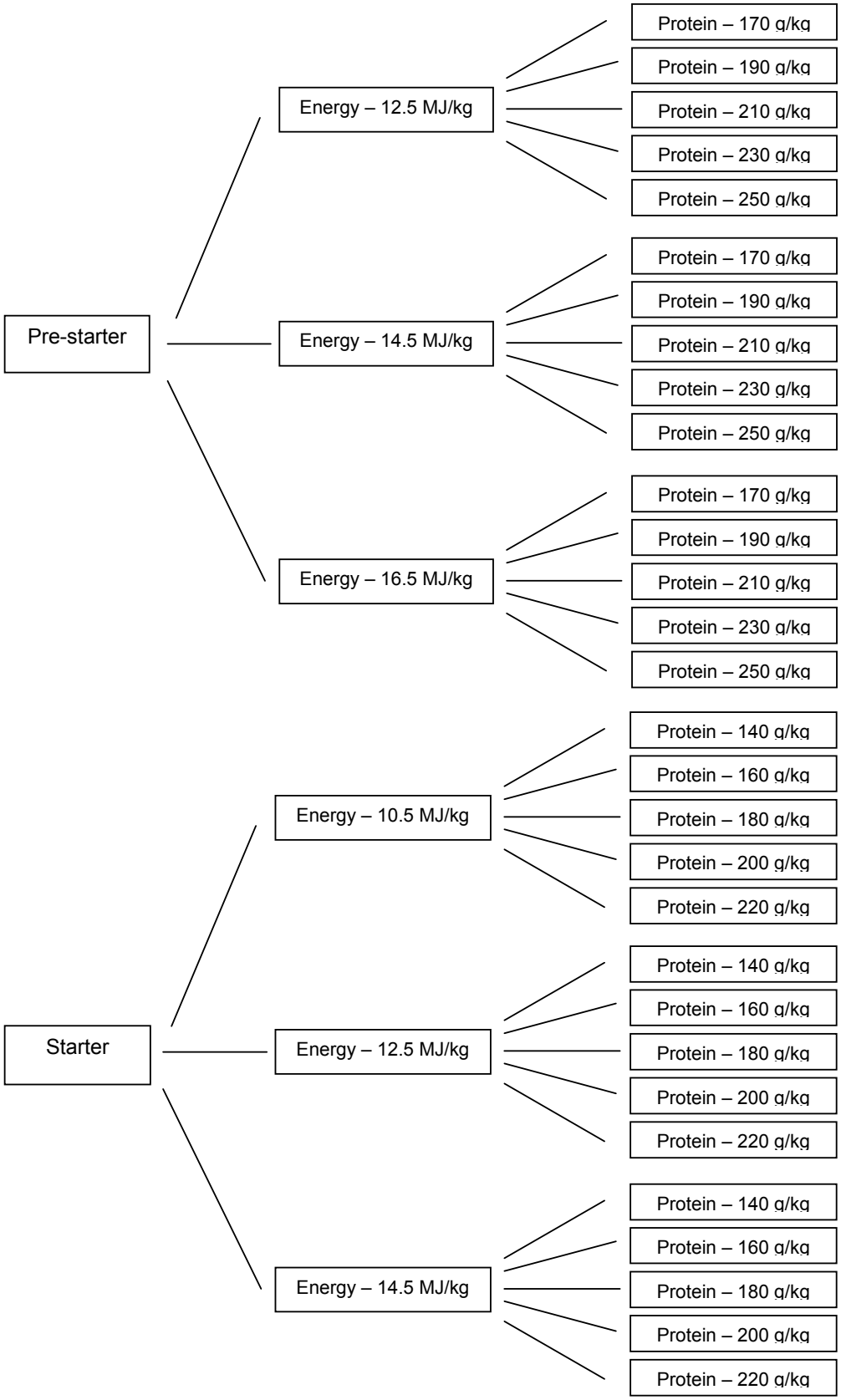

Figure 5.1 A schematic representation of the pre-starter and starter diets as formulated by energy (low, medium and high) and protein (level 1 – 5).

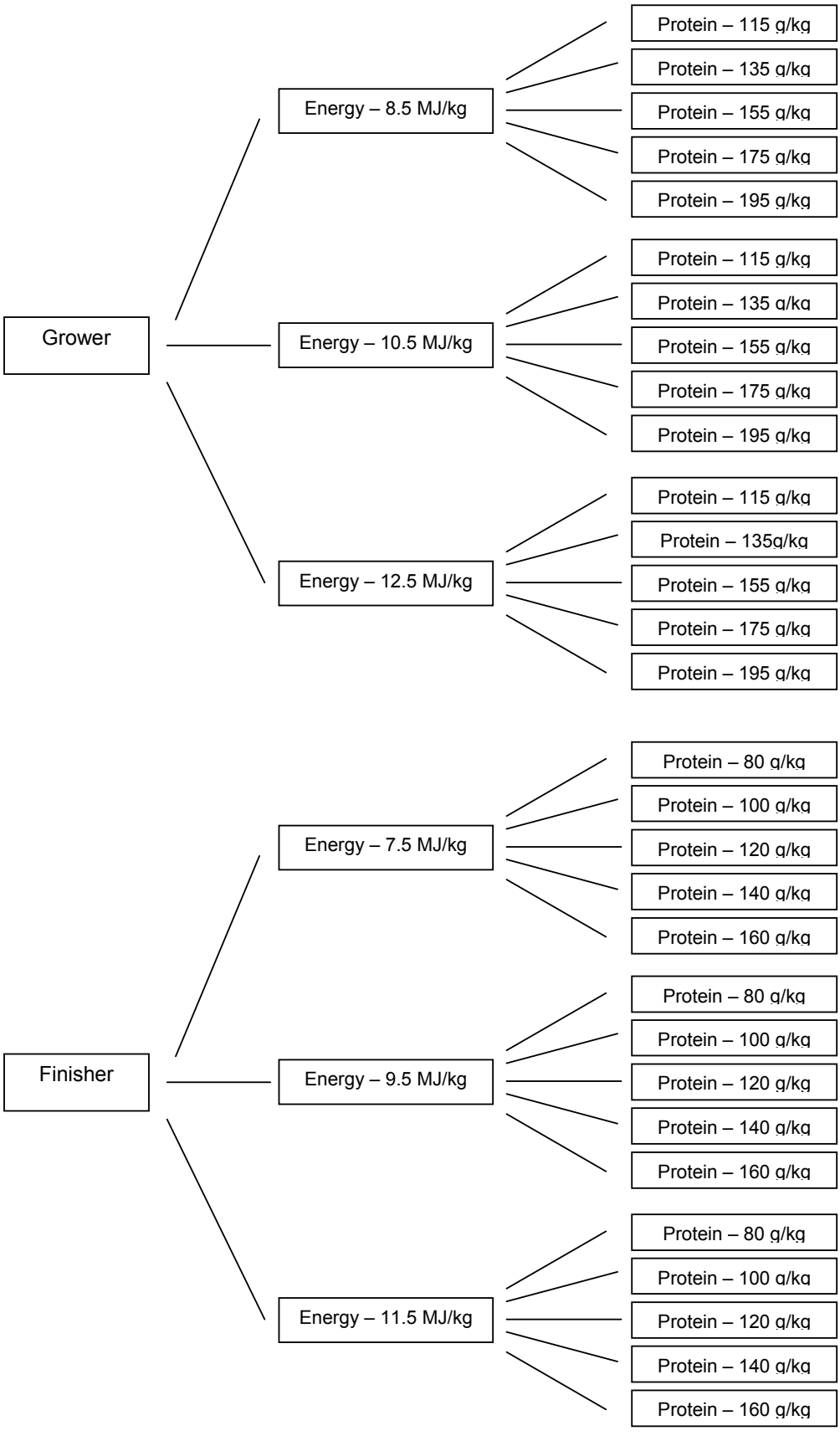

Figure 5.2 A schematic representation of the grower and finisher diets as formulated by energy (low, medium and high) and protein (level 1 – 5).

Table 5.1 The feed intake of the birds during the pre-starter and starter phases on the various energy and protein levels of the formulated diets on an as is basis.

			Pre-starter (0-1 months)	Starter (1-3 months)
Feeding regime	**Energy level**	**Protein level***	**Feed intake (g/bird/day)**	
1	**Low**	1	392	556
2	**Low**	2	421	907
3	**Low**	3	445	796
4	**Low**	4	353	873
5	**Low**	5	384	723
6	**Medium**	1	433	539
7	**Medium**	2	489	612
8	**Medium**	3	209	742
9	**Medium**	4	473	486
10	**Medium**	5	228	531
11	**High**	1	195	581
12	**High**	2	212	486
13	**High**	3	162	438
14	**High**	4	133	891
15	**High**	5	161	464

*Figure 5.1 and 5.2

Table 5.2 The feed intake of the birds during the grower and finisher phases on the various energy and protein levels of the formulated diets.

			Grower (3-6 months)	Finisher (6-9 months)
Feeding regime	**Energy level**	**Protein level***	**Feed intake (g/bird/day)**	
1	**Low**	1	2526	4778
2	**Low**	2	2581	4356
3	**Low**	3	2577	4217
4	**Low**	4	2530	4001
5	**Low**	5	2959	4038
6	**Medium**	1	2210	3854
7	**Medium**	2	2162	3447
8	**Medium**	3	2264	2997
9	**Medium**	4	2249	3808
10	**Medium**	5	2690	3602
11	**High**	1	2292	3210
12	**High**	2	2131	2909
13	**High**	3	2191	2992
14	**High**	4	2004	2815
15	**High**	5	1710	2773

*Figure 5.1 and 5.2

Table 5.3 An explanation of the anatomical positions of the four feather regions in this study as reported by Spark (1999).

Feather type	**Description**
Wing feathers (white plumes)	First row of big plumes at the wing edge
Byocks	Multicoloured feathers at each end of the row of white feathers
Tail feathers	80 – 100 larger feathers on the tail
Drab floss (short body floss)	Primarily found on the line above the buttocks joint, as well as in the centre of the dorsal surface of the wing just before the long hard body feathers.

5.3 Results and discussion

The average feed intake per bird for each growth phase is presented in Tables 5.1 and 5.2. The average feed intake per bird appears to decrease from the low to the high energy regimes. This is not in conjunction with the popular belief that monogastric animals would eat to fulfil their energy requirements (Schinckel and de Lange, 1996; McDonald, 2002). However, the possibility that the birds would eat to satisfy the requirement of the most limiting nutrient (either energy or amino acid) should also not be ruled out (Ferguson, 2006).

Table 5.4 shows the effect of the energy regimes on the wet skin size and wet skin weight of the ostrich. The data were analysed by comparing the slopes and the intercepts independently using the Mixed Models Procedure of SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC, USA). Significant differences are indicated between the intercepts of the analysed data. To increase the accuracy of the results, the least square means were included (Table 5.5) as these results are adjusted for differences that might occur between the intercepts. Increasing the energy density of the diet had a significant ($p < 0.05$) effect on the skin weight (kg) and skin size (dm^2) at each increasing energy level (Table 5.4 and 5.5). This is in conjunction with the literature in which Van Schalkwyk *et al*. (2002) and Brand *et al*. (2000; 2004; 2005) reported that ostriches consuming high energy concentrations produced skins with a larger surface area than birds consuming lower energy diets. Cloete *et al*. (2006) reported heavier raw skin weights in ostriches consuming higher energy density diets than those on lower dietary energy levels. The increase in size and weight of the skin with an increase in dietary energy level could be ascribed to the increase in total body fat of the birds, as they will consume more nutrients than they require. It is known that ostriches deposit large amounts of fat both in the body cavity and subcutaneously (under the skin) (Brand *et* al., 2004; Cloete *et al.*, 2006; Swart *et al*., 1993b). Brand *et al*. (2000; 2004; 2005) and Cloete *et al*. (2006) reported that dietary protein failed to influence the measured skin characteristics. One must also bear in mind that an increase in mass of any animal will result in a larger surface area of the body. The larger surface area alone may be responsible for the increased size and mass of the skin.

Table 5.4 Allometric equations relating the natural logarithm of the skin characteristics to the natural logarithm of the EBPW (kg) for each energy level.

	Constant Term			Regression Coefficient			R^2
Energy level	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	
Skin size (dm^2)	2.63^{a}±0.14	3.21^{b}±0.14	3.60^{c}±0.10	0.30^{a}±0.07	0.39^{ab}±0.07	0.47^{b}±0.05	0.72
Skin weight (kg)	-1.44^{a}±0.18	-0.66^{b}±0.18	-0.13^{c}±0.13	0.32^{a}±0.10	0.50^{ab}±0.09	0.62^{b}±0.07	0.72

a-c Values with different superscripts in the same row, differ significantly ($p < 0.05$)

Table 5.5 A comparison of the least square means of the natural logarithms of the skin size and weight regressed against the natural logarithm of EBPW as adjusted for intercept.

	Least square means			
Energy level	**Low**	**Medium**	**High**	**R^2**
Skin size (dm^2)	$2.953^a \pm 0.084$	$3.639^b \pm 0.081$	$4.117^c \pm 0.080$	0.72
Skin weight (kg)	$-1.086^a \pm 0.110$	$-0.107^b \pm 0.106$	$0.549^c \pm 0.104$	0.72

a-c Values with different superscripts in the same row, differ significantly ($p < 0.05$)

Figure 5.3 illustrates the growth pattern of the feathers in this study. Although the linear equation gives a relatively good fit, it is clear that feather growth was non-linear and that it peaked and evens out on the graph beyond the age of 150 days.

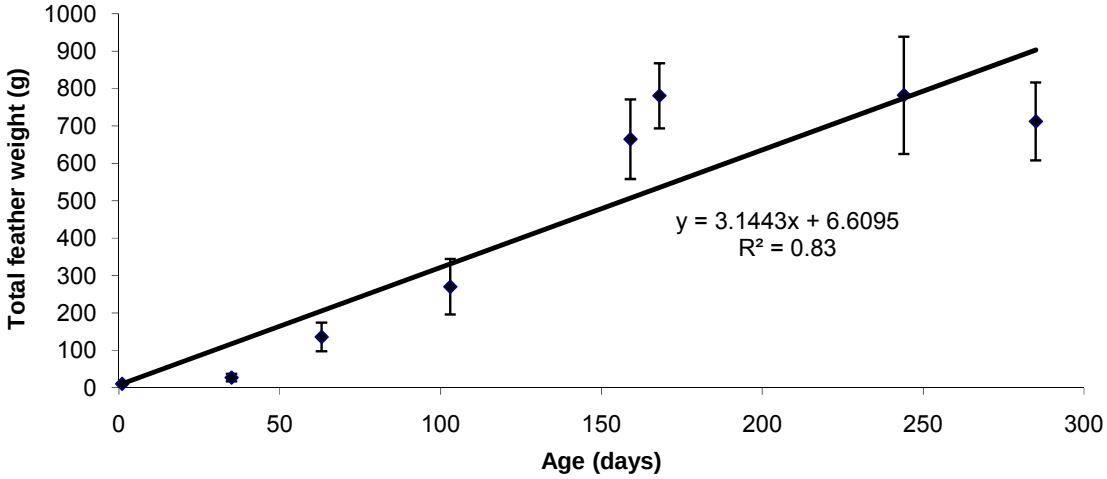

Figure 5.3 The total feather weight with the accompanying standard deviation bars with an increase in age.

Table 5.6 shows the allometric coefficients of the different feather groups after evaluation for treatment differences. No differences ($p > 0.05$, Table 5.6) were found between the energy treatments for either the constant term or the regression coefficient. The natural logarithm of the feather weights at each region were regressed against the natural logarithm of the total feather weight in Table 5.6. The maturation rate of feathers and the protein weight of the empty body differ and justify the separate prediction of these two variables. Defining feather growth separately from EBPW is important as the two differ in growth rate (Emmans and Fisher, 1986; Emmans, 1989). The amino acid composition of feathers is different to the amino acid composition of body protein (Emmans, 1989). The feather growth per region in relation to total feather growth of the current study compares favourably with similar results on one diet (Chapter 3). This is a confirmation of results in this study, namely that diet does not significantly affect feather growth.

Table 5.6 Allometric coefficients relating the natural logarithms of the weighed feathers from different regions to the natural logarithms of the total feather weight.

Feathers	**Constant Term**			**Regression Coefficient**			**R^2**
Energy level	Low	Medium	High*	Low	Medium	High*	
Drab floss		-7.7412 ± 0.1996			1.5914 ± 0.0351		0.95
Tail		-4.5449 ± 0.1631			1.3239 ± 0.0287		0.95
Wing		-3.4884 ± 0.1551			1.3577 ± 0.0273		0.96
Byocks		-5.9769 ± 0.2679			1.6250 ± 0.0471		0.91

*No differences were found between treatments

Figure 5.4 indicates the relationship between the increases in skin size (dm^2) and age (days) of all the birds. The birds were on different treatments, but results are included as the general trends and approximate sizes will still be applicable from this data. The linear relationship between the increase in skin size of all the birds and age (Figure 5.3) is due to the fact that it was measured over a short interval. Generally it is accepted that biological tissues, including ostrich skin, would follow a non-linear growth pattern (Huxley, 1932; McDonald, 2002; ; Chapter 3), but this would only become evident over extended periods of growth (Mellett, 1992). The fact that the skin size increase linearly for the first 285 days of the growth cycle can be a useful prediction instrument and is in accordance with reports from Van Schalkwyk *et al*. (2002), as they reported a linear increase in skin area with an increase in age. Mellett (1996) stated that the required skin size of 120 dm^2 could be obtained at the age of ten months. When converted from the wet skin weight to the dry skin weight ($y = 0.791587x + 52.31$, $R^2 = 0.64$; Brand, 2008 – unpublished results), results from this study confirm this observation, as the equation predicts a skin size of 136.8 ± 5.0 dm^2 for the 285-day-old birds. The increase in skin size will decline on the growth curve and the use of the regression equation in Figure 5.4 is thus not to be used for birds falling outside of the tested ages.

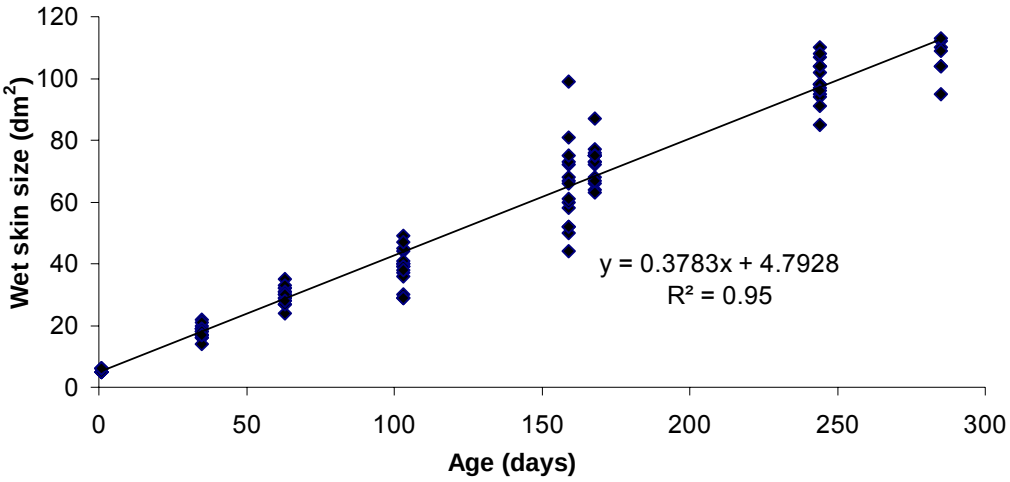

Figure 5.4 Illustration of the relationship between skin size (dm^2) and age (days).

Table 5.7 shows the nodule size (diameter, mm) as measured on the different regions of the skin and the average nodule size of the same skin. Nutrient density (energy or protein level) had no effect ($p > 0.05$) on the nodule sizes of the different regions or on the average nodule size. In reports by Van Schalkwyk *et al*. (2001), it was indicated that protein levels had no effect on nodule development and similar results are reported in this study. No differences ($p > 0.05$) were found between the nodule sizes of the different regions and this may be due to relatively large intra-group variation. Therefore, the data in Table 5.7 are reported per age group. There is a general increase in nodule size with an increase in age.

Mellett *et* al. (1996) reported slaughter age or degree of maturity as the primary factor driving leather quality, and that the optimum nodule size is only achievable at the age of 14 to 16 months. Van Schalkwyk (2008) reported that birds can be slaughtered at 11 to 12 months of age as a result of improved feeding regimes and Cloete *et* al. (2004) confirmed that acceptable nodule size and shape could be attained at 11 months of age.

Table 5.7 Nodule size (mm) and the standard deviations of the measured nodules for every slaughter age

Age (days)	Nodule size (mm)			
	Flank	Median	Tail	**Average**
1	1.13 ± 0.13	1.26 ± 0.15	1.22 ± 0.19	1.22 ± 0.16
35	1.63 ± 0.18	1.65 ± 0.22	1.61 ± 0.21	1.63 ± 0.20
63	2.11 ± 0.22	2.18 ± 0.21	2.15 ± 0.17	2.15 ± 0.20
103	2.94 ± 0.34	3.01 ± 0.40	3.06 ± 0.31	3.00 ± 0.35
159	3.38 ± 0.34	3.32 ± 0.38	3.55 ± 0.39	3.42 ± 0.38
168	2.98 ± 0.27	2.60 ± 0.24	3.06 ± 0.28	2.88 ± 0.33
244	3.30 ± 0.31	3.38 ± 0.36	3.67 ± 0.31	3.45 ± 0.36
285	3.05 ± 0.58	3.28 ± 0.26	3.18 ± 0.26	3.17 ± 0.45

The current study identified several factors that affect nodule development. All these factors are co-linear (Table 5.8), which complicates the interpretation of the results. Practical variables that describe model variation sufficiently were used to construct the prediction model for this study. The model allows the prediction of the nodule size up to an age of 285 days (R^2 = 0.85). The average nodule size can now be estimated while the bird is still alive and this will aid in least-cost simulation modelling by determining the live weight (irrespective of gut content) and feather shaft diameter.

Table 5.8 Correlation coefficients (r) between the measured explanatory variables affecting nodule size. All correlations are significant at $p < 0.05$.

Variable	EBPW (kg)	Live Weight (kg)	Age (days)	Total feathers (g)	Shaft diameter (mm)	Skin weight (kg)	Skin area (dm^2)	**Nodule size (mm)**
EBPW (kg)	**1.000**	0.970	0.961	0.857	0.815	0.916	0.946	0.817
Live weight (kg)	0.970	**1.000**	0.969	0.840	0.784	0.978	0.962	0.781
Age (days)	0.961	0.969	**1.000**	0.889	0.876	0.935	0.975	0.832
Total feathers (g)	0.857	0.840	0.889	**1.000**	0.897	0.779	0.909	0.824
Shaft diameter (mm)	0.815	0.784	0.876	0.897	**1.000**	0.722	0.870	0.902
Skin weight (kg)	0.916	0.978	0.935	0.779	0.722	**1.000**	0.929	0.730
Skin area (dm^2)	0.946	0.962	0.975	0.909	0.870	0.929	**1.000**	0.830
Nodule size (mm)	0.817	0.781	0.832	0.824	0.902	0.730	0.830	**1.000**

To understand the correlations among the explanatory variables, a principal component factor analysis was done. Age, live weight, EBPW, shaft diameter, skin size, skin weight and total feather weight were transformed to the natural logarithmic form. All the explanatory variables except shaft diameter and total feather weight were co-linear and loaded onto the first factor (Table 5.9). Only two factors were identified (Table 5.9). The second factor loads only on the wing feather shaft diameter and the total feather weight. When constructing a regression model following a factor analysis, the prediction variables should preferably come from different factors to avoid the problem of co-linearity. A multiple linear regression model with independent variables, live weight and shaft diameter was firstly constructed (explaining 83 % variation) and then improved with response surface regression to include a quadratic term, thus yielding the equation:

$$y = 1.258943 + 0.047555x - 0.000375x^2 + 0.130603z \qquad (R^2 = 0.85),$$

Where y = nodule size (mm)

x = live weight (kg)

z = shaft diameter (mm)

Table 5.9 Individual factor loadings as determined by the factor analysis (Significant contributions for each factor are in bold type).

Variable	Factor 1	Factor 2
Skin weight (kg)	**0.910**	0.382
Weight (kg)	**0.876**	0.478
EBPW (kg)	**0.807**	0.548
Age (days)	**0.771**	0.622
Skin surface area (dm^2)	**0.755**	0.637
Total feathers (kg)	0.507	**0.825**
Shaft diameter (mm)	0.409	**0.891**
Proportion of total	0.548	0.420

A multiple linear regression model with independent variables, age and shaft diameter was also constructed (explaining 82 % variation) and yielded the following equation:

$$y = 1.179158 + 0.001674x + 0.318662z \qquad (R^2 = 0.82),$$

where y = nodule size (mm),

x = age (days) and

z = shaft diameter (mm).

5.4 Conclusion

The effect of different dietary energy and protein levels on various skin and feather characteristics was investigated in this study, while feather and nodule growth was also described. Higher dietary energy levels increase skin yield, but increasing dietary protein levels have no effect. A prediction equation is given that enables the determination of nodule size directly from the live bird. Simulation modelling will increase the effectiveness and usefulness of the results in this study as the

combining effect will aid in optimising feed costs and add to the ability of the ostrich industry to adapt to challenging and changing economic environments.

5.5 References

AOAC, 2002. Official methods of analysis: Revision 1 (17th ed.). Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA, pp. 152-169.

Bradford, M. M. V., and Gous, R. M., 1991. The responce of growing pigs to a choice of diets differing in protein content. Anim. Prod., 52, pp. 185-192.

Brand, T. S., 2008. Volstruisvoeding: 'n Wetenskaplike Benadering. SUN Print, University of Stellenbosch, Stellenbosch, pp. 6-35.

Brand, T. S., Aucamp, B. B., Kruger, A. C. M., and Sebake, Z., 2003. Ostrich Nutrition. Progress Report 2003. Ostrich Research Unit, Private Bag X1, Elsenburg 7607, pp. 1-19.

Brand, T. S., Gous, R. M., Horbaňczuk, J. O., Kruger, A. C. M., Aucamp, B. B., and Brand, Z., 2004. The effect of dietary energy and protein (amino acid) concentrations on the end products of slaughter ostriches. S. Afr. J. of Anim. Sci., 34, pp. 107-109.

Brand, T. S., Gous, R. M., Horbaňczuk, J. O., Kruger, A. C. M., Aucamp, B. B., and Brand, Z., 2005. The effect of dietary energy and protein (amino acids) on the carcass and skin characteristics of slaughter ostriches. *Proc. 3rd Int. ratit Sci. Symp. & World Ostrich Congr*., Ed., Carbajo, E., 14-16 October, Madrid, Spain, p. 261.

Brand, T. S., Nel, C. J., and van Schalkwyk, S. J., 2000. The effect of dietary energy and protein level on the production of growing ostriches. S. Afr. J of Anim. Sci., 80, pp.15-16.

Cilliers, S. C., 1998. Feedstuff evaluation, metabolisable energy and amino acid requirements for maintenance and growth in ostriches. Proc. 2nd International Rat. Congress, Oudtshoorn, South Africa.

Cloete, S. W. P., Van Schalkwyk, S. J., Brand, T. S., Hoffman, L. C., and Nel, C. J., 2006. The effects of dietary energy and protein concentration on ostrich skin quality. S. Afr. J. of Anim. Sci., 36 (1), pp. 40-44.

Cloete, S. W. P., van Schalkwyk, S. J., Hoffman, L. C., and Meyer, A., 2004. Effect of age on leather and skin traits of slaughter ostriches. S. Afr. J. Anim. Sci., 34 (2), pp. 80-86.

Cooper, R. G., 2001. Ostrich (*Struthio camelus* var. *domesticus*) skin and leather: A review focused on southern Africa. World's Poult. Sci. J. 57, pp. 157-178.

Du Preez, J. J., 1991. Ostrich nutrition and management. In: Recent advances in Animal Nutrition in Australia. D. J. Farrel (Ed)., University of New England, Armidale, Australia, pp. 278-291.

Emmans, G. C., 1989. The growth of turkeys. In: Recent Advances in Turkey Science. Ed: Nixey, C., and Grey, T. C. Butterworths, London, U. K., pp. 135-166.

Gous, R. M., Moran, E. T., JR.,† Stilborn, H. R., Bradford, G. D., and Emmans, G. C., 1999. Evaluation of the Parameters Needed to Describe the Overall Growth, the Chemical Growth, and the Growth of Feathers and Breast Muscles of Broilers. Poul. Sci., 78, pp. 812-821.

Hoffman, L. C., 2005. A review of the research conducted on ostrich meat. Proc. 3rd Int. Ratite Sci. Symp. & XII World Ostrich Cong., 14-16 October. Ed: Carbajo, E., Madrid, Spain., pp. 113-120.

Huxley, J. S., 1932. Problems of Relative Growth. Methuen and Co., Ltd., London

Lawrie, R. A., 1998. Lawrie's Meat Science, 6th edition, Woodhead Publishing Limited, pp.11-30.

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. & Morgan, C. A., 2002. Animal Nutrition, 6th edition. Pearson, Prentice Hall, pp. 365-388

Mellett, F. D., 1992. Die volstruis as slagdier: aspekte van groei. Ph.D. Thesis, Univ. of Stellenbosch, South Africa, pp. 49-55.

Mellett, F. D., Fisher, P., and Böhme, H. M., 1996. Grading of ostrich skins. Proc. Europ. Ostrich Conf., November, Henglo, Ther Netherlands, European Ostrich Association, Banbury.

Sales, J., 1999. Slaughter and products, In: The Ostrich – Biology, Production and Health. Ed. Deeming, D. C., United Kingdom, CABI Publishing, Cab International, Oxon OX10 8 DE., pp. 191-216.

SAS, 2000. SAS/STAT Users Guide, Version 8, First Edition, Volume 2. SAS Institute Inc., Cary, NC, USA.

Smith, W. A., Cilliers, S. C., Mellett, F. D., and Van Schalkwyk, S. J., 1995. Nutrient requirements and feedstuff values in ostrich production. Feed Compounder, Sep. 1995, pp. 2-29.

South African Business chamber, 2002. Report of the South African Ostrich Business chamber. Oudtshoorn, South Africa.

Spark, C., 1999. Guidelines for the care and management of ostriches in a commercial situation, p. 64.

StatSoft, Inc., 2008. STATISTICA (data analysis software system), version 8.0. www.statsoft.com.

Swart, D., 1981. Die evaluering van die ekonomiese waarde van die vel, vleis en vere op die lewendige slagvolstruis. Ongepubliseerde verslag, Departement van Landbou en Visserye, Suid Afrika.

Swart, D., and Kemm, E. H., 1985. The effect of diet protein and energy levels on the growth performance and feather production of slaughter ostriches under feedlot conditions. S. Afr. J. of Anim. Sci., 15, pp.146-150.

Swart, D., Mackie, R. I., and Hayes, J. P., 1993a. Influence of live mass, rate of passage and site of digestion on energy metabolism and fibre digestion in the ostrich (*Struthio camelus* var. *Domesticus*). S. Afr. J. Anim. Sci. 23, pp. 119-126.

Swart, D., Mackie, R. I., and Hayes, J. P., 1993b. Growth, feed intake and body composition of ostriches (*Struthio camelus*) between 10 and 30 kg live mass. S. Afr. J. Anim. Sci. 23, pp. 142-150.

Van Schalkwyk, S. J., 2008. Factors affecting ostrich leather traits. Ph.D. Thesis, Univ. of Stellenbosch, South Africa.

Van Schalkwyk, S. J., Cloete, S. W. P., Brand, T. S., & Hoffman, L. C., 2001. Die implikasie van 'n jonger of ouer slagstadium. Volstruisboeredag, Oudstshoorn Proefplaas, 1 August.

Van Schalkwyk, S. J., Cloete, S. W. P., Hoffman, L. C., Brand, T. S., Meyer, A., and Pfister, A. P., 2002. The effect of dietary energy and protein levels on skin size and physical leather parameters of ostriches. *Proc. 2nd World Ostrich Congr*., Ed. J. O. Horbaňczuk, 26-29 September, Warsaw, Poland, pp. 216-217.

Chapter 6

The manipulation of growth of certain muscles, bones and organs in relation to body protein growth of ostriches by varying nutrient densities (*Struthio camelus*)

Abstract

An increase in size and weight is the simplest manifestation of growth. The influence of varying protein and energy levels on the relative growth of certain body components of ostriches was evaluated over a 285 day growth period. Overall, 120 birds were placed in 15 individual pens. Varying energy regimes (high, medium and low) and accompanying protein (level 1 - 5) levels were supplied *ad libitum* to each pen. A randomly selected bird from each pen was slaughtered at 1, 35, 63, 103, 159, 168, 244 or 285 days of age. Each bird was weighed, stunned, exsanguinated, defeathered and eviscerated. Individual body components were dissected and weighed at every slaughter age. These components were ground with the remainder of the carcass, excluding gut content, but including blood and feathers. Proximate analysis was performed on this ground mass. Based on the analysis of ostrich feathers and the known mass of the feathers in the current study, the protein mass contribution of the feathers was deducted from the protein accretion of the bird. All the data were transformed to natural logarithms and regressed against the body protein growth (excluding feathers). Intercepts and slopes were compared to determine differences in growth rate ascribed to nutrient densities. Neither dietary energy nor dietary protein level had a significant effect on the relative growth of the measured components in this study. Total body fat increased with increasing energy level, indicating that birds consumed more nutrients than their nutrient requirements. The effect of dietary energy (in conjunction with adequate protein levels) on ostrich growth and development needs to be defined clearly. Allometric coefficients were established that will be helpful to improve the accuracy of simulation modelling attempts for ostrich nutrition.

Keywords: ostrich, growth, dietary energy, dietary protein, least cost modelling, allometric coefficients.

6.1 Introduction

Although the popularity of ostrich feathers in the fashion industry gave initial rise to the domestication of ostriches, the income generated from their meat is today a bigger factor, as it is on a constant rise (SA Ostrich Business Chamber, 2002). With the relatively decreasing skin value, meat comprises a large proportion of the income generated from the ostrich and this emphasises the importance of research to optimise production costs. Knowledge of how and if body component growth is affected by changing diets will aid formulators with the optimisation of feed costs.

With growth being a simple increase in size and weight, the effect of different nutrient density diets on the change in live weight of the animal along with the characterisation of these effects usually comprise a growth study (McDonald *et al.*, 2002).

Swart and Kemm (1985) fed slaughter birds (60-110 kg live weight) diets containing three energy levels (8.1, 9.5 and 10.7 MJ ME/kg) and three protein levels (140, 160 and 180g/kg). They reported that growth, expressed as g live weight/day, increased with an increase in energy level for each protein level, but an increase in dietary protein had no effect on growth as such. Cornetto *et al*. (2003) supplied ostriches with three levels of dietary energy (11.71, 12.90 and 14.09 MJ ME/kg) up to 148 days of age and reported improved growth on the higher energy diets. Brand *et al*. (2000) provided ostrich chicks ranging from 13 to 34 kilograms in mass with feeds containing three energy levels (10.5, 12.5 and 14.5 MJ ME/kg) and increasing protein levels (140 to 220g/kg). They reported that increases in dietary energy increased the growth rate of the birds. In another study (Brand *et al.,* 2003), diets varying in energy (8.5, 10.5 and 12.5 MJ ME/kg) and protein (115, 135, 155, 175 and 195g/kg) were fed to ostriches. A difference of up to 15 percent was reported in the average daily gain values between the high and low energy treatments, while protein had no effect on these values. Furthermore, Gandini *et al.* (1986) conducted a study on the growth of young birds and reported no differences between the growth of birds fed diets formulated on an iso-energy basis (11.5 MJ ME/kg) and varying protein levels (160, 180 and 200g/kg).

The effect of diet density on the proportional change of chemical components in the whole body of the ostrich is unclear. An increase in body weight and whole body fat percentage is expected when a high-density diet is consumed (McDonald *et al.*, 2002). This is not necessarily beneficial as it points to the consumption of more than the required amount of nutrients and higher costs. Ostriches deposit fat reserves in the body cavity around the intestines, as well as subcutaneously (under the skin) (Brand *et* al., 2004; Cloete *et al.*, 2006; Swart *et al*., 1993d). Care must be taken when evaluating ostrich growth in terms of average daily gain since an increase in live weight does not necessarily signify an increase in commercially marketable products.

There is a need to develop a system to predict the nutritional requirements of ostriches in all the different phases of production. Such a system should be able to predict the effects of the

environment, genotype and feed on the growth of the individual body components. This could be achieved by predicting body component growth as a proportion of the featherless empty body protein weight (EBPW) as measured in weight units (Danisman and Gous, 2007). Individual components growth can be related to each other by relating these to a constant factor such as the EBPW (Emmans, 1989, 1990; Chapter 3). Knowledge of the nutritional influence on the relationship of body components to EBPW will be valuable when modelling nutrient requirements as it changes throughout the growth cycle. Current standards are inappropriate as they are based on studies that do not separate the growth of the body components and body protein from the feather protein. This separation is necessary to enable simulation modelling to play an important role in the future of ostrich production (Brand, 2008).

The aim of this study was therefore to describe the growth of carcass components as a proportion of the EBPW by confirming the findings in Chapter 3 and to determine if nutrition could be used to manipulate component growth and the chemical composition of the body of the ostrich.

6.2 Materials and methods

Overall, 120 birds were placed in 15 individual pens. Varying energy regimes (high, medium and low) and accompanying protein (amino acid) levels (level 1 – 5) were formulated. Four stages (pre-starter, starter, grower and finisher) of feeding were used and supplied *ad libitum* throughout the trial (Figure 6.1 and 6.2). The median feeding regime was chosen according to standard requirement levels for energy and protein (amino acids) from the literature (Du Preez, 1991; Smith *et al,.*1995 and Cilliers *et al,.*1998). An average feed intake per bird (Table 6.1 and 6.2) was determined by weighing the supplied feed and the feed leftovers for each pen throughout each phase. The feeds were sampled and analysed (AOAC methods, 2002) for protein, amino acids, fat, NDF (neutral detergent fibre), ADF (acid detergent fibre), ash and fibre and are reported in Annexure 2. Water was freely available throughout the trial. A bird was selected at random from every pen and slaughtered at 1, 35, 63, 103, 159, 168, 244 or 285 days of age. Only six birds survived to the slaughter age of 285 days. The data of these six birds were not included in the current study.

At each slaughter age, birds were weighed, stunned, exsanguinated, defeathered and eviscerated. Blood was collected in a separate container. The feathers and skin were removed (Chapter 5). The intestines, heart and liver, 13 individual muscles (Table 6.3 and Figures 1.1 to 1.4, Chapter 1), and certain bones were removed and weighed (Chapter 5). After weighing, all the individual parts along with the blood and the feathers were frozen in separate plastic bags for each bird until mincing commenced. All the body parts were minced and mixed thoroughly after which one randomly selected sample (Approx. 150g) was used to perform a proximate analysis (AOAC methods, 2002) yielding the chemical composition of the entire bird.

As growth is non-linear (Huxley, 1932; McDonald *et al.*, 2002; Lawrie, 1998), all the data were transformed into the natural logarithmic form in order to obtain linear data. Swart *et* al. (1993a) observed considerable quantities of gut fill (8-15% of live weight), and also noted that major variation

can occur between individuals at any specific time. This motivated the use of empty gut weight rather than live weight. Emmans (1989) reported that feather protein and body protein should be analysed separately. However, the feathers were analysed together with the remainder of the body in the current study. After the analysis of ostrich feathers was obtained in a separate study, the proportional protein contribution of the feathers was deducted from the protein analysis obtained above (Annexure 1). This yielded an estimation of the featherless empty body protein weight (EBPW) and was used for further statistical analyses (Annexure 1). The final slaughter date (285 days) was excluded from the following analysis, as only six birds remained. Inclusion of this data in the analyses may cause a skewing effect on the picture as a whole. Using the Mixed Models Procedure of SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC, USA) the data were analysed to check for treatment differences by comparing the slopes and the intercepts independently. Treatments were combinations of different levels of dietary energy and protein (Figure 6.1 and 6.2). Where no differences were found between treatments, a general regression line was fitted to the data. This will provide future modellers with an equation to compare and predict carcass component growth by utilising the existing allometric relationships between component and EBPW growth. This method of analysis was repeated for all the measured variables.

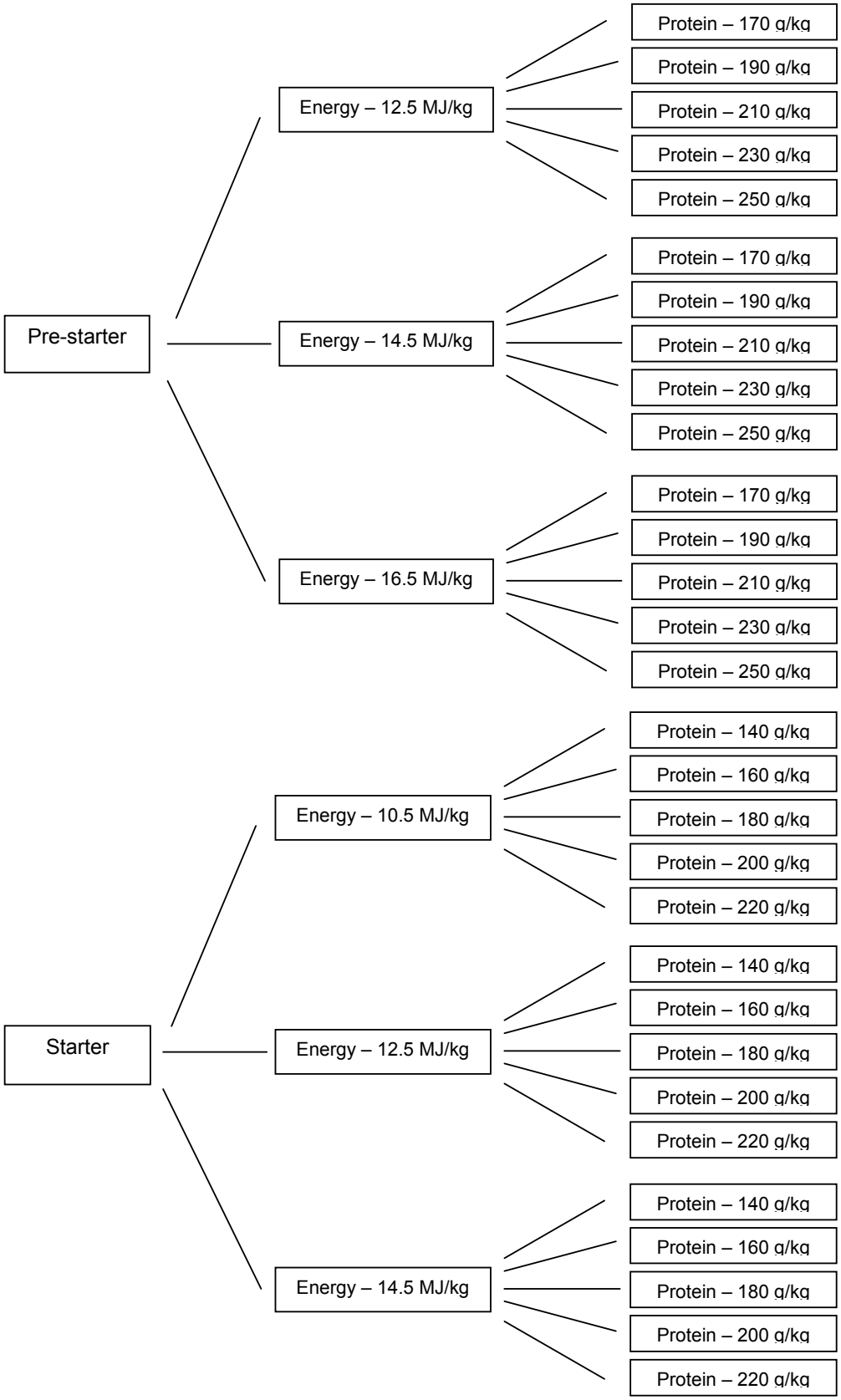

Figure 6.1 A schematic representation of the pre-starter and starter diets as formulated by energy (low, medium and high) and protein (level 1 – 5).

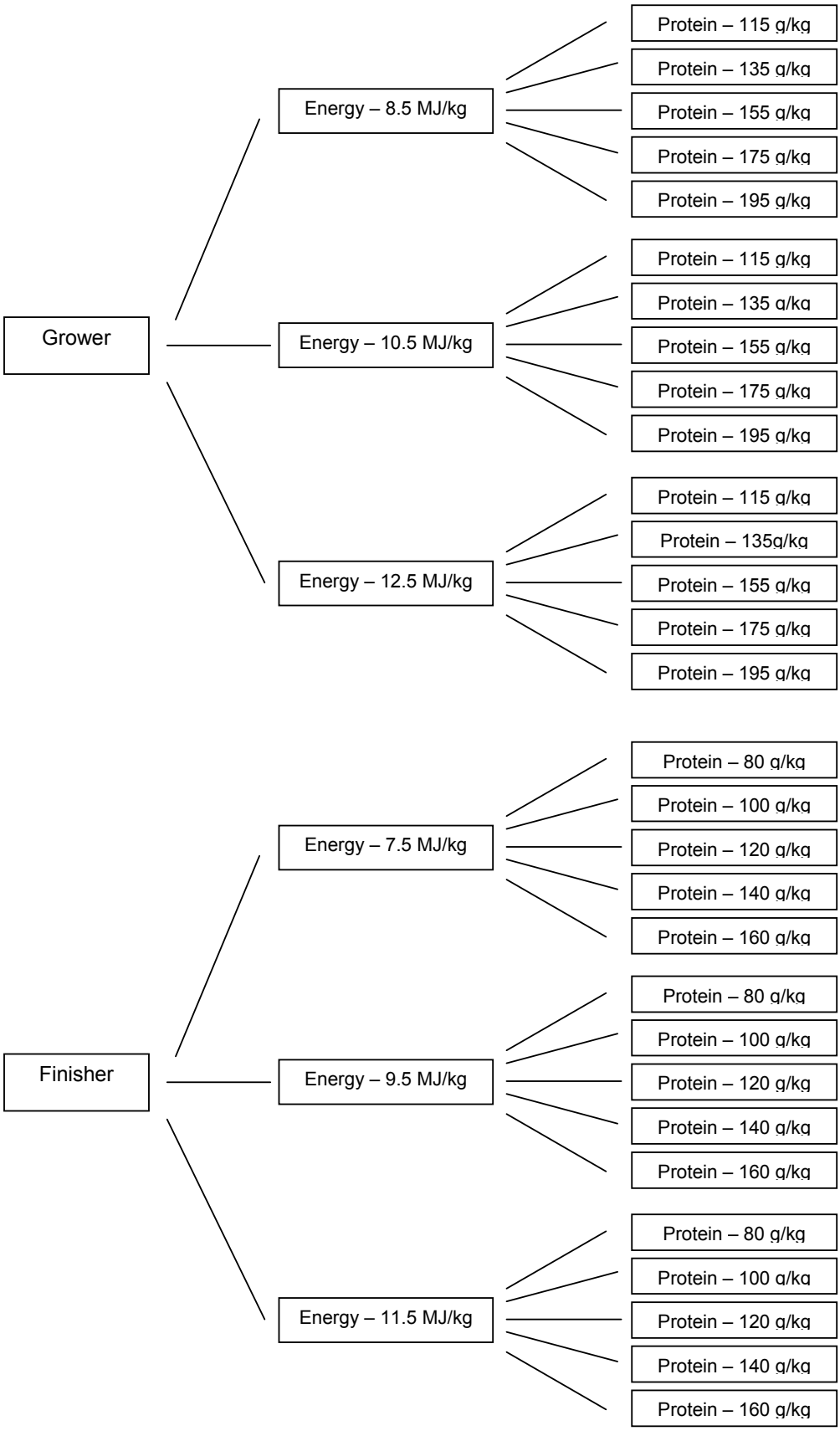

Figure 6.2 A schematic representation of the grower and finisher diets as formulated by energy (low, medium and high) and protein (level 1 – 5).

Table 6.1 The feed intake of the birds during the pre-starter and starter phases on the various energy and protein levels of the formulated diets.

			Pre-starter (0-1 months)	Starter (1-3 months)
Feeding regime	**Energy level**	**Protein level**	**Feed intake (g/bird/day)**	
1	**Low**	1	392	556
2	**Low**	2	421	907
3	**Low**	3	445	796
4	**Low**	4	353	873
5	**Low**	5	384	723
6	**Medium**	1	433	539
7	**Medium**	2	489	612
8	**Medium**	3	209	742
9	**Medium**	4	473	486
10	**Medium**	5	228	531
11	**High**	1	195	581
12	**High**	2	212	486
13	**High**	3	162	438
14	**High**	4	133	891
15	**High**	5	161	464

Table 6.2 The feed intake of the birds during the grower and finisher phases on the various energy and protein levels of the formulated diets.

			Grower (3-6 months)	Finisher (6-9 months)
Feeding regime	**Energy level**	**Protein level**	**Feed intake (g/bird/day)**	
1	**Low**	1	2526	4778
2	**Low**	2	2581	4356
3	**Low**	3	2577	4217
4	**Low**	4	2530	4001
5	**Low**	5	2959	4038
6	**Medium**	1	2210	3854
7	**Medium**	2	2162	3447
8	**Medium**	3	2264	2997
9	**Medium**	4	2249	3808
10	**Medium**	5	2690	3602
11	**High**	1	2292	3210
12	**High**	2	2131	2909
13	**High**	3	2191	2992
14	**High**	4	2004	2815
15	**High**	5	1710	2773

Table 6.3 The anatomic muscle names of the weighed ostrich muscles accompanied by their commercial names.

Muscle name	Commercial name
M. iliotibialis cranialis	Top Loin
M. iliofemoralis externus	Oyster
M. iliotibialis lateralis	Round; Rump Steak
M. iliofibularis	Fan Fillet
M. iliofemoralis	Eye Fillet; Inside Strip
M. flexor cruris lateralis	Triangle Steak; Outside Strip
M. obturatorius medialis	Long Fillet; Tenderloin
M. femorotibialis medius	Moon Steak; Tip Trimmed
M. femorotibialis accessorius	Tip
M. gastrocnemius pars interna	Big drum; Inside Leg
M. gastrocnemius pars media	Steak
M. gastrocnemius pars externa	Flat Drum; Outside Leg
M. fibularis longus	Drum Steak; Mid Leg

6.3 Results and discussion

The objective of the trial was to establish if the relationships between the physical body components and the EBPW were affected by differing dietary energy and protein levels. The allometric relationships between the individual body components and EBPW (of birds given a single diet) were shown in Chapter 4. In this study, differences in the relationships, as a result of nutrition, would therefore imply that tissues other than protein (such as lipid) are deposited in or with the component to increase the weight. Differing dietary protein levels had no effect on component or body weight change in this study and were thus excluded from any further analyses.

Butterfield (1988) argues that live weight as opposed to carcass weight should be used in growth studies as he classifies the intestinal content as a physiological part of the animal. Mellett (1992) ascribes this problem to the fact that animal industries want to predict yield in terms of time units where science uses allometric equations to make predictions in weight units. Growth is influenced in various ways by environmental conditions, stocking density and the state of the animal at certain stages of the growth cycle. Therefore, it is more accurate to work with weight units as the precision of measurements is improved. Ostriches show great variability in intestinal (Swart *et al*., 1993a; Cilliers *et al*., 1998) and fat (Mellett, 1992) content, and this will influence the validity of the results found when working with live weight. The analyses in this study were conducted using the featherless empty body protein weight (EBPW), as there are known relationships between the EBPW and the weighed components.

The effects of the different dietary energy regimes on the weighed muscles, bones and organs are given in Tables 6.4, 6.5 and 6.6. No differences ($p > 0.05$) were found between any of the muscles (Table 6.4) for the different treatment groups (dietary energy levels). Danisman and Gous (2007) reported that broilers deposit variable amounts of lipid in the individual components and stated that the protein content of the body components should be regressed against the EBPW. The protein content of the individual muscles in this study was not determined and the variable amounts of lipid deposited in the muscles because of normal growth and treatment differences are thus not accounted for. Hoffman and Fisher (2001) and Sales and Hayes (1996) reported small amounts of fat deposition in ostrich muscle. Although this study did not investigate changes in muscle lipid as nutrient density changes, the differences because of diet are expected to be minimal in ostrich studies. It is known that body fat increases with an increase in age (Huxley, 1932; Lawrie, 1998; McDonald *et al.*, 2002). From Table 6.4 it can thus be concluded that the majority of lipid in the ostrich body is deposited at sites other than the individual muscles, as a statistical difference would indicate the deposition of enough fat in the muscle or component to constitute a difference. Ostriches are reported to deposit vast amounts of fat reserves subcutaneously (under the skin) and in the body cavity around the intestines (Brand *et* al., 2004; Cloete *et al.*, 2006; Swart *et al*., 1993d). Table 6.4 suggests nothing to discourage this finding.

Table 6.4 Allometric coefficients relating the natural logarithm of muscle weight to the natural logarithm of EBPW with dietary energy levels as groups to determine if different dietary energy levels affect relative component weight.

	Constant Term			Regression Coefficient			R^2
Energy level	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	
M. iliotibialis cranialis	-3.2889 ± 0.0371			1.0834 ± 0.0212			0.96
M. iliofemoralis externus	-4.3223 ± 0.0312			1.2045 ± 0.0178			0.98
M. iliotibialis lateralis	-2.5638 ± 0.0405			1.1276 ± 0.0232			0.96
M. iliofibularis	-2.37611± 0.0245			1.1607± 0.0140			0.99
M. iliofemoralis	-3.7584 ± 0.0332			1.1884 ± 0.0190			0.97
M. flexor cruris lateralis	-3.6823 ± 0.0529			1.1164 ± 0.0302			0.93
M. obturatorius medialis	-3.9692 ± 0.0536			1.3710 ± 0.0306			0.95
M. femorotibialis medius	-4.4431 ± 0.0443			1.1302 ± 0.0254			0.95
M. femorotibialis accessorius	-2.5680 ± 0.0264			1.0253 ± 0.0151			0.98
M. gastrocnemius pars interna	-2.5991± 0.0315			1.1027 ± 0.0180			0.97
M. gastrocnemius pars media	-3.2352 ± 0.0347			1.1780 ± 0.0198			0.97
M. gastrocnemius pars externa	-2.9485 ± 0.0358			1.0762 ± 0.0205			0.96
M. fibularis longus	-3.4922 ± 0.0347			1.0277 ± 0.0199			0.96

Figure 6.3 illustrates the fitted and compared regression lines for the *M. iliofibularis* (fan fillet). The lack of differences in the slopes and/or intercepts is apparent. In the cases where no differences were found, a common regression line was fitted to the data to simplify future applications of the results.

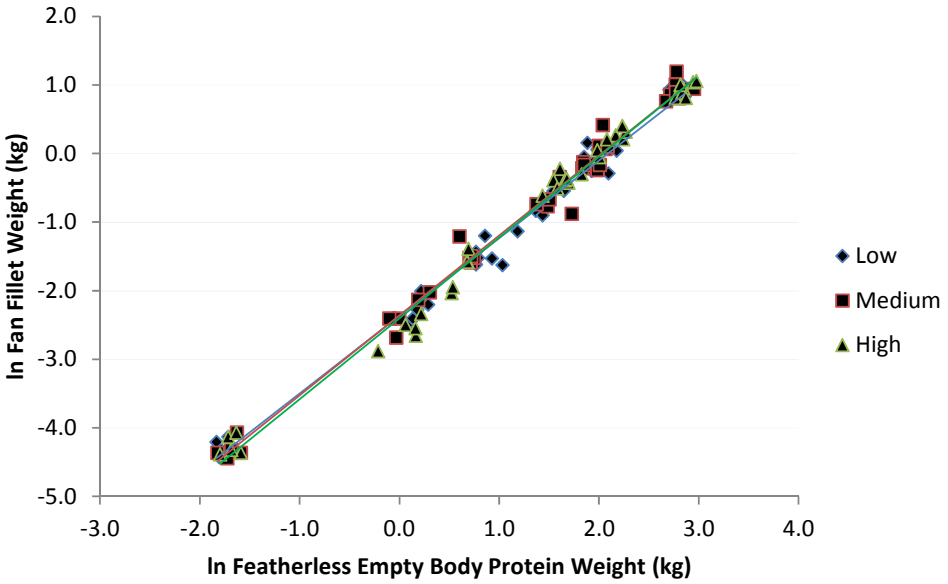

Figure 6.3 Regression lines fitted to the natural logarithms of the *M. iliofibularis* (fan fillet) weights (kg) against the natural logarithms of the EBPW (kg) for the different dietary energy levels (8.5, 10.5, 12.5 MJ ME/kg).

The allometric relationships between the weighed bones (femur, rib cage, patella, neck, tibiotarsus and wingtip) and EBPW are given in Table 6.5. The reported relationship (Chapter 2) between body ash and body protein are re-established in this study (Table 6.7). Bone consists mainly out of minerals (measured as ash) and a small proportion of fat (surrounding neurons). Bone density is expected to stay constant in animals with a functioning sympathetic nervous system, as the formation of osteoblasts and osteoclasts are dependent on sympathetic signalling (Elefteriou *et al*. 2005). It is therefore unlikely that changes in nutrient density will cause changes to the relationships of the individual bone components and EBPW.

Table 6.5 Allometric coefficients relating the natural logarithms of the weighed bone components to the natural logarithms of EBPW with dietary energy levels as groups to determine the effects on component growth (kg).

Bones	Constant Term			Regression Coefficient			R^2
Energy level	Low	Medium	High	Low	Medium	High	
Femur	-1.6565 ± 0.0441			1.1030 ± 0.0252			0.95
Rib cage	-0.2894 ± 0.0429			1.0782 ± 0.0242			0.95
Patella	-3.8800 ± 0.0373			1.1741 ± 0.0213			0.97
Neck	-2.0512 ± 0.0226			1.0013 ± 0.0129			0.98
Tibiotarsus	-2.0010 ± 0.0903			1.1423 ± 0.0516			0.83
Wingtip	-3.8174 ± 0.0423			1.2407 ± 0.0242			0.96

The allometric coefficients between some of the ostrich organs and EBPW are shown in Table 6.6. Increasing the dietary energy levels had no effect ($p > 0.05$) on the relationship of organ weight against EBPW. As the organs (heart, intestines and stomach) are expected to consist mostly out of protein, the results are as expected. However, special note should be given to the liver. Although the different levels of dietary energy did not alter the allometric relationships (of weight to EBPW), a proximate analysis on the liver was not performed in this investigation. It is therefore unclear how the chemical components of the liver change due to dietary differences, as it is known that diet type can alter the fatty acid profile of the liver (Tahin *et al*. 1981).

Table 6.6 Allometric coefficients relating the natural logarithm of the organ weights (kg) to the natural logarithm of EBPW (kg) with dietary energy levels as groups to determine the effect on component growth (kg).

Some organs	Constant Term			Regression Coefficient			R^2
Energy level	Low	Medium	High	Low	Medium	High	
Heart	-3.0500 ± 0.0358			1.0977 ± 0.0205			0.97
Intestines	-1.4941 ± 0.0479			0.9034 ± 0.0479			0.92
Liver	-1.9477 ± 0.0314			0.9652 ± 0.0180			0.96
Stomach	-2.7089 ± 0.0502			1.0335 ± 0.0287			0.93

The differences between the chemical components of the whole body (on an as is basis) as a result of increasing dietary energy levels are shown in Table 6.7. Increases in dietary energy did not affect ash or moisture when regressed against EBPW. Fat deposition was altered ($p < 0.05$) and increased as the energy in the diet increased. The findings of Gous (1972) and Du Preez *et al*. (1967) are thereby confirmed, as they reported that increases in the nutrient density of the diet will lead to

increased amounts of deposited body fat because the animal consumes more than the required nutrients.

Table 6.7 Allometric coefficients relating the natural logarithms of the chemical component growth (kg) in the whole body (as is) to the natural logarithms of EBPW (kg) with dietary energy levels as groups.

Body composition	**Constant Term**			**Regression Coefficient**			R^2
Energy level	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	
Moisture		1.4013 ±0.0168			0.8685 ±0.0091		0.99
Fat	-1.6434[a] ±0.1955	-1.4322[b] ±0.1956	-1.0468[c] ±0.1380	0.8301[a] ±0.1058	1.0129[ab] ±0.1069	1.1531[b] ±0.0756	0.84
Ash		-1.5312 ±0.0257			1.0970 ±0.0141		0.98

a-b Values with the same superscript in the same row do not differ significantly ($p < 0.05$)

Although body fat is expected to increase relatively as the bird matures (Degen *et al*, 1991), the presence of increasing levels of dietary energy contributed to significant increases in fat deposition in this study. The effect of fat deposition in growth studies where animals consume more nutrients than they require for maintenance should not be overlooked.

Results obtained from the current study confirm the findings of Gandini *et al.* (1986) and Brand *et al*. (2000; 2003) where they reported that different levels of protein in ostrich diets do not have a significant effect on the growth rate (live weight increase over time) of the ostrich. With regards to energy, the results of Swart and Kemm (1985), Cornetto *et al*. (2003) and Brand *et al*. (2000; 2003) are not rejected as birds in this study could not be tested in a repeated measurements trial. Killing of the birds occurred at each interval, eliminating the correlation found in such measurements (Mellett & Randall, 1994). However, it was found that the increase in dietary energy leads to a direct increase of fat deposited in the whole carcass. The apparent increase in growth rate that accompanies increasing dietary energy levels in repeated measurement trials, as reported by Swart and Kemm (1985), Cornetto *et al*. (2003) and Brand *et al*. (2000; 2003), can partly be ascribed to an increase in fat deposition in the body and the subsequent changing of the body composition as a whole. Optimising the ever increasing feeding costs when producing ostriches would be beneficial for the industry.

Gous and Stielau (1976) reported that broilers performed better when consuming a diet with high levels of energy and protein. For optimal production, broilers need more protein in their diets than ostriches do. This could be the result of the selection pressure that exists in broiler strains to improve growth and rate of feed conversion efficiency. It could also be a result of the differences in the functioning of the digestive tract between the two species.

Body protein deposition is the main factor that determines live weight gain (Van Es, 1982 as cited by Swart *et al*., 1993d). The energy cost of body protein accretion is greater than that required for fat deposition (Swart *et al*., 1993d). The efficiency of metabolisable energy utilisation in the ostrich is a complex concept as the ratio of energy directed toward the separate deposition of protein and fat changes in maturing animals (Swart *et al*., 1993d). Decreasing dietary energy levels frequently amounts to increasing levels of crude fibre in diet formulations. This increases the passage rate of the digesta and more nutrients will pass through the small intestine (Just, 1982; Just *et al*., 1983). An increase in intestinal passage rate will shorten the time that the digesta are subjected to microbial hindgut fermentation (Swart *et al*., 1993c).

Swart *et al*. (1993b) reported that fermentative digestion of fibre (cellulose and hemicellulose) can contribute to the energy requirements of the growing ostrich in the form of

volatile fatty acids (VFA). Musara *et al*. (2003) defined the mechanism for VFA uptake from the hindgut as H^+-K^+-ATPase activity that utilises H^+-ions from a source other than the hydration of CO_2. This differs from the pig and equine large intestine where the predominant system appears to be the Na^+-H^+ exchanger. The uptake of VFA from the ostrich hindgut is thus a process of secondary active transport which is highly dependent on intracellular hydrogen ion generation (Musara *et* al., 2003). The manipulation and improvement of VFA uptake could lead to improved energy efficiency with obvious economic advantages.

The question raised by Swart *et al*. (1993a) as to the efficiency of the utilisation of energy absorbed from the foregut and the hindgut remains unanswered. The protein:fat deposition rate, as determined by factors such as genotype, environmental conditions and stress susceptibility, changes in the maturing animal. This could cause changes in the way that absorbed energy and non-limiting protein are directed toward maintenance and growth functions in the maturing animal. Defining the mechanisms and factors affecting the relative protein:fat deposition rate and the efficiency of energy uptake and utilisation is vital for the accurate determination of the changing ostrich nutrient requirements.

6.4 Conclusion

The effect of various diets on some muscles, organs and bones was investigated in this study. It was shown that increasing dietary energy levels did not affect the size (measured in weight) of the individual body components when expressed as allometric equations of EBPW. The increase in growth rate (weight gain per day) because of increased dietary energy levels as reported in repeated measurement trials can thus be partly ascribed to an increase in fat deposition in the whole body. However, protein deposition is the main factor that determines live weight gain (Van Es, 1982 as cited by Swart *et al*., 1993d). The energy cost of protein deposition is greater than that required for fat deposition (Swart *et* al., 1993d). Consequently, the effect of higher energy intakes on the protein deposition rate in the body is not yet known as dietary protein had no effect on the weighed variables. More research on the exact combining effects of dietary energy and protein, the efficiency of nutrient utilisation and the possible manipulation of these factors are required.

Incorporating and combining the results obtained in this study with previous and future research will provide the means for simulation modelling to be the spearhead in ostrich nutrition and production.

6.5 References

AOAC, 2002. Official methods of analysis: Revision 1 (17th ed.). Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA, pp. 152-169.

Brand, T. S., 2008. Volstruisvoeding: 'n Wetenskaplike Benadering. SUN Print, University of Stellenbosch, Stellenbosch, pp. 6-35.

Brand, T. S., Aucamp, B. B., Kruger, A. C. M., and Sebake, Z., 2003. Ostrich Nutrition. Progress Report 2003. Ostrich Research Unit, Private Bag X1, Elsenburg 7607, pp. 1-19.

Brand, T. S., Gous, R. M., Brand, Z., Aucamp, B. B., Kruger, A. C. M., and Nel, J., 2003b. Review: Research on ostrich nutrition in South Africa. Proc. of the 11th World Ostrich Conference, Vienna, Austria.

Brand, T. S., Gous, R. M., Horbańczuk, J. O., Druger, A. C. M., Aucamp, B. B. and Brand, Z., 2004. The effect of dietary energy and protein (amino acid) level on the end products of slaughter ostriches. S. Afr. J. Anim. Sci., 34 (6 – SASAS Congress), pp. 107-109.

Brand, T. S., Nel, C. J., and van Schalkwyk, S. J., 2000. The effect of dietary energy and protein level on the production of growing ostriches. S. Afr. J of Anim. Sci., 80, pp.15-16.

Butterfield, R. M., 1988. New concepts of sheep growth. Dept. Vet. Anat., University of Sydney.

Cilliers, S. C., Hayes, J. P., Chwalibog, A., Sales, J., and Du Preez, J. J., 1998. Determination of energy, protein and amino acid requirements for maintenance and growth in ostriches. Anim. Feed Sci. and Tech., 72, pp. 283-293.

Cloete, S. W. P., Van Schalkwyk, S. J., Brand, T. S., Hoffman, L. C., and Nel, C. J., 2006a. The effects of dietary energy and protein concentration on ostrich skin quality. S. Afr. J. Anim. Sci., 36 (1), pp. 40-44.

Cornetto, T., Angel, R., and Palmer, T., 1994. Influence of stocking density and dietary energy on ostrich performance. Int. J. of Poul. Sci., 2, pp.102-106.

Danisman, R. and Gous, R. M., 2007. Predicting the weights of the physical parts of broilers. Poc. 26th Sci. Day., October, Pretoria, South Africa.

Degen, A. A., Kam, M., Rosenstrauch, A., and Plavnik I., 1991. Growth rate, total body water volume, dry-matter intake and water consumption of domesticated ostriches (*Struthio camelus*). Anim. Prod., 52, pp. 225-232.

Elefteriou, F., Ahn, J. D., Takeda, S., Starbuck, M., Yang, X., Liu, X., Kondo, H., Richards, W. G., Bannon, T. W., Noda, M., Clement, K., Vaisse, C., Karsenty, G., 2005. Leptin regulation of bone resorption by the sympathetic nervous system and CART. Nat., 434, 7032, pp. 514-520.

Emmans, G. C., 1989. The growth of turkeys. In: Recent Advances in Turkey Science. Ed: Nixey, C., and Grey, T. C. Butterworths, London, U. K., pp. 135-166.

Emmans, G. C., 1990. Problems modelling the growth of poultry. Georgia Nutrition Congerence, 1990.

Gandini, G. C. M., Burroughs, R. E. J., and Ebedes, H., 1986. Preliminary investigation into the nutrition of ostrich chicks (*Struthio camelus*) under intensive conditions. J. of S. Afri. Vet. Assoc., 57, pp. 39-42.

Gous, R. M., 1972. The influence of dietary protein and energy concentration on the body composition of broiler breeder pullets. S. Afr. J. Anim. Sci. 2, pp. 51-58.

Gous, R. M., and Stielau, W. J., 1976. The effects of alternate feeding and fasting on growth and feed utilization by broiler chickens fed diets differing in protein and energy content. S. Afr. J. Anim. Sci. 6, pp. 49-52.

Hoffman, L. C., and Fisher, P., 2001. Comparison of meat quality characteristics between young and old ostriches. Meat Science, 59, pp. 335-337.

Huxley, J. S., 1932. Problems of Relative Growth. Methuen and Co., Ltd., London

Just, A., 1982. The net energy value of crude fat for growth in pigs. Livestk. Prod. Sci., 9, pp. 501-509.

Just, A., Fernandez, J. A., and Jorgensen, H., 1983. The net energy value of diets for growth in pigs in relation to the fermentative processes in the digestive tract and site of absorption of the nurtients. Livestk. Prod. Sci., 10, pp. 171-186.

Lawrie, R. A., 1998. Lawrie's Meat Science, 6th edition, Woodhead Publishing Limited, pp.11-30.

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. & Morgan, C. A., 2002. Animal Nutrition, 6th edition. Pearson, Prentice Hall, pp. 365-388.

Mellett, F. D., 1985. The ostrich as meat animal: Anatomical and muscle characteristices. M. Sc. Thesis, Univ. of Stellenbosch, South Africa, pp. 1-35.

Mellett, F. D., 1992. Die volstruis as slagdier: aspekte van groei. Ph.D. Thesis, Univ. of Stellenbosch, South Africa, pp. 49-55.

Mellett, F. D. & Randall, J. H., 1994. A note on the growth of body parts of the ostrich (*Struthio camelus*). Anim. Prod., 58, pp. 291-293.

Musara, C., Chamunorwa, J., Holtug, K., and Skadhauge, E., 2003. Insight into the mechanism of short chain fatty acid absorption in the ostrich (*Struthio camelus*) proximal colon. Brit. Poul. Sci., 44, 2, pp. 316-326.

Sales, J., and Hayes, J. P., 1996. Proximate, amino acid and mineral composition of ostrich meat. Food Chemistry, 56, nr. 2, pp. 167-170.

SAS, 2000. SAS/STAT Users Guide, Version 8, First Edition, Volume 2. SAS Institute Inc., Cary, NC, USA.

South African Business chamber, 2002. Report of the South African Ostrich Business chamber. Oudtshoorn, South Africa.

Swart, D., and Kemm, E. H., 1985. The effect of diet protein and energy levels on the growth performance and feather production of slaughter ostriches under feedlot conditions. S. Afr. J. of Anim. Sci., 15, pp.146-150.

Swart, D., Mackie, R. I., and Hayes, J. P., 1993a. Influence of live mass, rate of passage and site of digestion on energy metabolism and fibre digestion in the ostrich (*Struthio camelus* var. *Domesticus*). S. Afr. J. Anim. Sci. 23, pp. 119-126.

Swart, D., Mackie, R. I., and Hayes, J. P., 1993b. Fermentative digestion in the ostrich (*Struthio camelus* var. *domesticus*), a large avian species which utlises cellulose. S. Afr. J. Anim. Sci. 23, pp. 127-135.

Swart, D., Mackie, R. I., and Hayes, J. P., 1993c. Utilization of metabolizable energy by ostrich (*Struthio camelus*) chicks at two different concentrations of dietary energy and crude fibre originating from lucerne. S. Afr. J. Anim. Sci. 23, pp. 136-141.

Swart, D., Mackie, R. I., and Hayes, J. P., 1993d. Growth, feed intake and body composition of ostriches (*Struthio camelus*) between 10 and 30 kg live mass. S. Afr. J. Anim. Sci. 23, pp. 142-150.

Tahin, Q. S., Blum, M., and Carafoli, E., 1981. The fatty acid compsition of subcellular membranes of rat liver, heart and brain: Diet induced modifications. Eur. J. Biochem. 121, pp. 5-13.

Van Es, A. J. H. M., 1982. Energy metabolism in pigs. A review. Proc. 9th Symp. Energy Metab. Lillehamer, Norway. EAAP 29, pp. 249.

Chapter 7
General conclusion and future prospects

In this research study, three trials were performed to gain additional information pertaining to the growth, development and intake behaviour of growing ostriches produced primarily under feedlot production systems. Emphasis was placed on establishing equations to enable the prediction of body growth and that of the separate body components.

From the first trial, when given the choice, ostriches preferred a high density feed (high levels of energy and protein) throughout the growth cycle. It was assumed that ostriches would select feed according to protein and energy requirements and thereby grow close to their optimum potential, without being constrained by the quality of feed supplied to them. A Gompertz growth curve predicted the age at which maximal growth occurs (c) at 153 days with a mature weight (a) of 119.4 kg and a rate of maturing parameter (b) of 0.009. Body protein and body water content was shown to decline and the body fat content was shown to increase with an increase in age, while body ash content was shown to stay constant as the bird matured. Regression lines fitted to the natural logarithms of the data provided equations to predict chemical body composition of ostriches. Production results from this study can thus be viewed as birds growing as close to their genetic potential as possible (barring environmental effects) and can be used as the foundation for least cost simulation modelling.

The second trial was conducted with the aim of establishing prediction equations to model the growth of the income generating products of the birds that were not constrained by nutrient requirements. A four stage formulated growth diet was fed and allometric equations were established to model and predict the growth of the feathers, skin, commercially valuable muscles and certain other characteristics like skin nodule size and other body components. Modelling is the description of a system. Predicting the functioning of a system without any knowledge of that system is impossible. Therefore, defining the growth of the individual body components throughout the growth cycle is the fulfilment of the requirements for system modelling. As the growth of the body components were defined for each age level, this enabled the modelling of the changing nutrient requirements throughout the growth cycle.

The final trial was performed to investigate to what extent dietary energy and protein levels could be used to manipulate the growth of the individual body components of the ostrich. A four-stage (pre-starter, starter, grower and finisher), 3 x 5, energy and protein (amino acids), feeding regime was formulated. The effect of dietary energy and protein (with specific accompanying amino acid

profile) on the development of feathers, skin nodules, skin size, skin weight, bones, organs and the commercially valuable muscles of the ostrich body was investigated. It was found that ostrich growth and individual body component growth was unaffected by the protein. Energy regime and amino acid level, as used in this study, had no affect on the growth of the feathers, the skin nodules, the bones, the organs and the muscles, but had a significant effect on skin size, skin weight and the total body fat. The increase in skin size and weight as a result of increased dietary energy levels is an indication of the size increase of the birds. Overall, results in this study indicated that birds consuming more energy than they require will increase in size and weight, mainly due the conversion of the expendable nutrients into body fat.

Growth is non-linear (MacDonald, 2002, Huxley, 1932) and various curves can be used to predict growth. However, not many of them have a biological meaning or fit the growth data of biological tissues as good as the Gompertz growth model. When conducted accurately, research predicting the growth of animals and biological tissues is of great value to livestock producers as it enables precise diet formulation.

If the modelling of ostrich growth and development is viewed as the modelling of a system, then the description of the system, as described in this research study, provides sufficient tools for simulation modelling. The next step is the verification and improvement of the model. This needs to be done in the form of problem-solving research, with the ultimate goal of increasing the accuracy of the predictions.

The model proposed here, similarly to the pig and broiler models, work at the level of the individual (Gous and Berhe, 2006). By focusing on the individual, genetic variation, variation in feed composition and environmental variation (between pens) are being ignored. For optimization purposes, this variation needs to be accounted for in order to simulate a realistic population response (Gous and Berhe, 2006).

The natural variation in genotype is used by geneticists to move the performance of a strain in a favourable direction. Information on the differences within a genotype can be used to optimize the production system. Variation occurring between holding pens should be defined so that problems may be identified and minimized. Modelling the exact effects of temperature, humidity and wind speed on ostrich production needs to be approached in a mechanistic way, because of the expected interactions between these factors. It is more challenging to model the effects of a varying feed content. Each feed ingredient will have subtle variations brought about by the pre-harvesting environment, post-harvesting storage and the processing and mixing procedures. It would be useful to strive to predict the response of an individual bird to certain variations in feed quality for each day of production. The exact effect of variable feeds will thus be clearer (Gous

and Berhe, 2006). Modern techniques like near-infrared spectroscopy (NIR) allow formulators to instantly determine the quality and ingredients of raw materials. When used, this will minimize variations in nutrient ingredients and simplify the mechanistic approach.

Verification, improvement and the practically addressing problems of this model will lead to a powerful prediction instrument that will benefit the ostrich industry in the long term.

References

Gous, R. M., and Berhe, E. T., 2006. Modeling Populations for Purposes of Optimization. In: Mechanistic Modeling in Pig and Poultry Production. Ed. Gous, R. M., Morris, T. R., and Fisher, C., CAB International, Oxfordshire, pp. 76-96.

Huxley, J. S., 1932. Problems of Relative Growth. Methuen and Co., Ltd., London.

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. & Morgan, C. A., 2002. Animal Nutrition, 6th edition. Pearson, Prentice Hall.

Annexure A

In Chapters 3 – 6, the feathers were minced with the entire bodies of the birds. The feather weight was determined at each age for each individual bird. The feather protein weight was then determined and deducted for each bird individually and this yielded the featherless empty body protein weight (EBPW) of each bird.

Table A1 The amino acid composition (g/kg) and the protein content (%) of a representative sample of the total feathers of five ostriches with varying ages (Brand, 2008 – unpublished data).

Bird	1	2	3	4	5	Average
Protein (%)	87.5	87.2	83.4	82.0	82.8	84.6
Alanine	28.9	39.4	36.1	33.0	35.0	34.5
Threonine	50.4	68.9	59.9	65.3	64.8	61.9
Serine	10.4	13.0	13.1	13.1	12.6	12.4
Arginine	48.0	59.6	60.3	61.7	64.6	58.8
Glutamine	100.5	149.3	143.8	141.5	131.5	133.3
Valine	43.7	64.0	62.1	57.7	56.9	56.9
Histidine	0.6	4.0	1.9	1.3	1.7	1.9
Aspartate	63.0	89.7	85.7	81.5	80.0	80.0
Lysine	21.0	37.8	29.2	24.8	25.4	27.6
Proline	81.8	106.1	105.9	104.8	99.5	99.6
Methionine	1.8	3.6	2.8	2.7	2.7	2.7
Tyrosine	30.1	48.7	41.8	40.5	40.7	40.4
Cysteine	56.6	77.9	75.4	70.3	69.8	70.0
Isoleucine	28.0	42.1	40.1	38.2	35.7	36.8
Phenylalanine	31.0	40.6	37.8	39.2	38.7	37.4
Leucine	82.6	111.7	107.5	108.2	105.5	103.1
Glysine	102.0	132.9	100.3	128.5	137.4	120.2

Annexure B

Table B1 Table of the feeding regimes as formulated for each phase.

Feeding regime	Energy level	Protein level
1	Low	1
2	Low	2
3	Low	3
4	Low	4
5	Low	5
6	Medium	1
7	Medium	2
8	Medium	3
9	Medium	4
10	Medium	5
11	High	1
12	High	2
13	High	3
14	High	4
15	High	5

Table B2 The feed ingredients of the feeding regimes (Table 1) for the pre-starter phase.

Pre-starter Ingredients (g/kg)	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Maize meal	200	175	150	125	100	431	387	343	299	255	663	600	536	473	410
Wheat bran	542	508	475	442	408	271	260	250	239	228	-	12	24	36	49
Lucerne meal	100	100	100	100	100	50	50	50	50	50	-	-	-	-	-
Soya bean oil-cake meal	49	107	165	223	281	24	72	119	166	214	-	37	73	110	146
Full-fat soya meal	-	-	-	-	-	113	121	130	138	146	226	243	259	276	292
Fishmeal	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Plant Oil	20	20	20	20	20	23	22	21	21	20	25	24	23	21	20
Synthetic Lysine	1.5	1.1	0.7	0.4	-	0.7	0.6	0.4	0.2	-	-	-	-	-	-
Synthetic Metionine	1.5	1.7	1.9	2.1	2.4	1	1.2	1.5	1.7	2	0.4	0.7	1	1.3	1.6
Mono-calcium phosphate	-	-	-	-	-	-	2.8	2.1	1.4	0.7	6.9	5.5	0.4	2.8	1.5
Limestone	30	30	31	31	32	26	27	27	27	28	22	23	23	23	24
Vitamin & Mineral mix	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Salt	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table B3 The feed ingredients of the feeding regimes (Table 1) for the starter phase.

Starter Ingredients (g/kg)	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Maize meal	202	176	151	126	100	397	335	273	212	150	592	494	396	298	200
Oat bran	-	75	150	225	300	-	38	75	113	150	-	-	-	-	-
Barley meal	-	25	50	75	100	-	38	75	113	150	-	50	100	150	200
Wheat bran	-	-	-	-	-	-	5	9	14	19	-	9	19	28	37
Lucerne meal	720	590	460	330	200	461	396	330	265	200	201	201	200	200	200
Soya bean oil-cake meal	-	26	53	79	105	-	19	39	58	78	-	13	25	38	50
Full-fat soya meal	-	-	-	-	-	62	71	80	88	97	125	142	159	176	193
Fishmeal	25	-	97	132	168	25	51	76	102	127	25	40	56	71	86
Plant Oil	20	15	10	5	-	20	16	13	9	5	20	18	15	13	10
Synthetic Lysine	0.4	0.3	0.2	0.1	-	0.6	0.5	0.3	0.2	-	0.9	0.7	0.4	0.2	-
Synthetic Metionine	1	0.9	0.8	0.8	0.7	0.8	0.8	0.9	0.9	0.9	0.6	0.8	0.9	1	1
Mono-calcium phosphate	23	19	15	11	7	14	11	9	6	4	5	4	3	1	-
Limestone	-	2	5	7	10	11	11	11	11	11	22	20	18	16	13
Vitamin & Mineral mix	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Salt	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table B4 The feed ingredients of the feeding regimes (Table 1) for the grower phase.

Grower Ingredients (g/kg)	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Oat bran	523	547	571	595	619	272	281	291	300	310	21	16	10	5	-
Barley meal	100	75	50	25	-	332	310	288	266	244	563	545	526	507	488
Wheat bran	53	40	26	13	-	105	79	53	26	-	157	118	79	39	-
Lucerne meal	200	175	150	125	100	200	189	179	168	158	200	204	208	211	215
Soya bean oil-cake meal	87	84	81	78	74	44	69	94	118	143	-	53	106	159	212
Full-fat soya meal	-	-	-	-	-	-	0.6	1.3	2	2.5	-	1.3	2.5	4	5
Fishmeal	-	44	89	133	177	-	22	44	66	-	-	-	-	-	-
Plant Oil	-	-	-	-	-	10	8	5	3	-	20	15	10	5	-
Synthetic Lysine	1.1	0.8	0.6	0.3	-	1.3	1	0.7	0.3	-	1.5	1.1	0.8	0.4	-
Synthetic Metionine	1.3	1.1	0.9	0.7	0.6	1.1	1	1.1	1.1	1.1	0.9	1.1	1.2	1.4	1.6
Mono-calcium phosphate	-	2	5	7	9	-	1	2	4	5	-	-	-	-	-
Di-calcium phosphate	10	8	5	3	-	11	9	8	6	4	12	11	10	10	9
Limestone	15	14	13	12	11	15	15	14	13	13	15	15	15	15	15
Vitamin & Mineral mix	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Salt	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table B5 The feed ingredients of the feeding regimes (Table 1) for the finisher phase.

Finisher Ingredients (g/kg)	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Maize meal	-	-	-	-	-	158	119	79	40	-	316	237	158	79	-
Oat bran	737	643	550	456	363	541	451	361	271	181	345	259	172	86	-
Barley meal	-	50	100	150	200	67	116	165	215	264	134	182	231	279	328
Wheat bran	90	68	45	23	-	66	50	33	17	-	42	32	21	11	-
Lucerne meal	100	107	114	121	128	100	158	215	273	331	100	208	317	425	534
Sunflower oil-cake meal	-	49	98	148	197	-	25	50	74	98	-	-	-	-	-
Soya bean oil-cake meal	27	33	39	44	50	13	23	32	41	50	-	13	25	38	50
Full-fat soya meal	-	-	-	-	-	-	8	17	25	33	-	17	33	49	66
Fishmeal	-	8	15	23	30	-	4	8	11	15	-	-	-	-	-
Plant Oil	-	-	-	-	-	-	8	5	3	-	20	15	10	5	-
Synthetic Lysine	1.3	1.1	0.8	0.5	0.2	1.3	1	0.7	0.4	0.1	1.2	0.9	0.6	0.3	-
Synthetic Metionine	1.4	1.2	1.1	0.9	0.8	1	1	0.9	0.9	0.9	0.5	0.7	0.8	0.9	1.1
Di-calcium phosphate	20	17	14	11	8	19	16	13	10	6	18	15	12	8	5
Limestone	15	15	15	15	15	15	14	13	12	11	15	13	11	9	7
Vitamin & Mineral mix	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Salt	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table B6 The amino acid composition of the feeding regimes (Table 1) for the pre-starter phase on an as is basis (g/kg).

Pre-starter	Feed number														
Amino acid	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lysine	7	9	9	11	13	7	9	10	10	12	6	4	8	9	8
Methionine	3	4	4	4	5	3	4	4	4	4	3	2	3	3	3
Threonine	7	9	9	11	11	7	9	9	10	11	7	7	8	10	10
Arginine	8	10	11	12	13	8	9	11	11	13	7	5	9	10	10
Isoleucine	5	6	6	8	9	5	6	7	7	8	5	4	6	7	7
Leucine	12	14	15	17	19	13	14	16	17	19	14	10	16	18	16
Histidine	3	4	4	5	5	3	4	4	4	5	3	3	4	4	4
Valine	7	8	9	10	11	7	8	9	9	10	7	6	8	9	9
Tyrosine	4	5	5	6	7	4	5	5	6	6	4	3	5	6	5
Serine	10	12	14	16	18	11	12	14	14	17	12	10	14	15	16
Proline	11	13	14	16	17	12	12	14	14	16	12	9	14	15	16
Phenylalanine	5	7	7	8	9	6	6	7	8	9	6	4	7	8	7
Glysine	15	17	19	21	22	15	16	18	18	21	13	12	16	17	17
Glutamate	24	26	33	34	41	23	28	32	33	41	27	19	32	37	36
Alanine	13	16	16	18	20	14	15	17	17	19	14	11	16	17	17
Aspartate	9	10	16	14	20	9	12	13	14	21	13	07	17	20	21
Cysteine	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2

Table B7 The amino acid composition of the feeding regimes (Table 1) for the starter phase on an as is basis (g/kg).

Starter	Feed number														
Amino acid	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lysine	6	6	10	11	12	5	7	8	10	13	5	7	7	9	9
Methionine	2	2	3	4	4	2	2	2	3	3	2	2	3	3	4
Threonine	8	7	10	11	11	6	8	9	10	12	6	8	9	9	10
Arginine	5	6	9	10	11	5	7	9	10	11	6	8	8	10	10
Isoleucine	5	5	6	7	7	4	5	6	7	8	4	6	6	6	7
Leucine	10	12	14	16	16	10	12	14	15	17	11	13	14	15	16
Histidine	2	3	3	4	4	2	3	3	3	4	2	3	3	3	4
Valine	7	7	9	10	10	5	7	8	9	11	6	8	8	9	10
Tyrosine	4	4	5	5	5	3	4	5	5	6	3	4	5	5	6
Serine	9	9	12	14	15	8	10	12	13	15	8	11	12	13	13
Proline	10	10	12	14	14	9	11	12	12	15	10	12	12	13	14
Phenylalanine	5	5	6	7	7	4	5	6	7	8	4	6	6	7	7
Glysine	12	13	18	21	22	10	13	16	18	22	10	14	15	16	18
Glutamate	15	18	24	28	31	15	22	25	28	34	18	24	25	29	29
Alanine	12	13	16	18	19	11	13	15	16	19	11	14	14	15	17
Aspartate	13	11	15	16	16	9	14	15	17	20	9	11	11	15	12
Cysteine	1	1	2	2	2	1	2	2	2	2	1	2	2	2	2

Table B8 The amino acid composition of the feeding regimes (Table 1) for the grower phase on an as is basis (g/kg).

Grower	Feed number														
Amino acid	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lysine	4	6	8	10	13	4	11	8	8	10	4	5	6	8	11
Methionine	1	2	2	3	3	2	3	3	3	3	2	2	2	2	3
Threonine	5	5	7	10	14	5	11	8	8	10	5	6	7	8	11
Arginine	5	6	7	10	15	5	11	8	8	10	5	6	7	9	13
Isoleucine	3	4	5	7	10	3	8	6	6	7	4	4	5	7	9
Leucine	7	8	10	15	21	7	16	13	13	14	8	9	11	14	18
Histidine	2	2	2	4	6	2	4	3	3	4	2	2	3	3	5
Valine	5	6	7	9	13	5	10	8	8	9	6	6	7	9	11
Tyrosine	2	3	4	5	7	3	5	4	4	5	3	3	4	5	6
Serine	6	7	9	13	21	7	14	11	11	13	7	8	10	12	17
Proline	7	8	9	14	18	8	14	11	11	13	10	10	12	14	17
Phenylalanine	3	4	5	7	10	3	8	6	6	7	4	4	6	7	9
Glysine	8	10	14	17	26	8	20	14	15	19	9	10	12	14	19
Glutamate	15	17	20	31	46	16	32	23	24	29	17	20	25	31	42
Alanine	7	9	12	16	22	8	17	13	14	16	8	9	11	13	17
Aspartate	8	9	11	19	32	6	17	10	12	16	6	7	12	15	24
Cysteine	1	1	1	2	2	1	2	2	2	2	1	1	2	2	2

Table B9 The amino acid composition of the feeding regimes (Table 1) for the finisher phase on an as is basis (g/kg).

Finisher	Feed number														
Amino acid	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lysine	4	4	5	6	5	3	4	4	5	6	2	4	5	5	6
Methionine	2	2	2	3	2	1	2	2	2	2	1	1	2	2	2
Threonine	4	5	6	7	6	4	5	5	6	7	4	5	6	6	7
Arginine	4	5	7	9	7	3	5	5	6	8	3	4	5	6	6
Isoleucine	3	3	4	5	5	2	3	3	4	5	2	3	4	4	5
Leucine	6	7	9	11	9	5	8	8	9	11	5	7	9	10	10
Histidine	2	1	2	3	2	1	2	2	2	3	1	2	2	2	2
Valine	4	5	6	7	6	3	5	5	5	7	3	4	5	6	7
Tyrosine	3	3	3	4	3	2	3	3	3	4	2	3	3	4	4
Serine	6	6	8	10	9	5	6	7	8	10	4	6	7	8	9
Proline	6	6	8	9	8	5	7	7	8	9	5	7	9	9	11
Phenylalanine	3	4	5	6	5	2	3	4	4	5	2	3	4	5	5
Glysine	8	9	12	15	13	6	9	9	10	13	6	7	9	10	11
Glutamate	10	14	21	22	22	10	14	16	19	23	11	12	17	18	21
Alanine	7	8	10	12	11	6	8	9	9	12	6	8	10	10	11
Aspartate	2	5	8	7	10	4	5	8	9	11	5	4	8	11	12
Cysteine	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1

Table B10 Proximate analysis of the pre-starter diets (g/kg) on an as is basis.

Pre-starter	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ash	92	95	84	100	98	79	83	86	87	84	62	110	106	90	88
Fibre	97	90	91	89	85	63	61	57	65	61	33	37	35	34	42
Fat	55	55	50	51	49	63	71	71	71	68	50	43	49	43	41
Crude Protein	169	195	201	227	260	165	188	205	223	249	136	184	195	231	223
BE (MJ/kg)	16.7	16.7	16.7	16.8	17.0	16.8	17.1	17.2	17.2	17.3	16.4	13.5	14.3	15.4	14.8
ADF	127	119	112	116	112	80	81	79	82	83	46	49	46	49	50
NDF	273	267	232	237	213	203	179	148	169	124	118	123	88	82	75

Table B11 Proximate analysis of the starter diets (g/kg) on an as is basis.

Starter	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ash	105	100	97	92	97	86	93	84	82	91	78	101	85	82	93
Fibre	209	169	185	166	153	151	141	127	121	119	84	91	82	94	137
Fat	39	30	32	33	23	47	52	45	33	40	60	44	63	59	42
Crude Protein	153	187	190	198	228	146	169	178	191	220	148	163	189	193	209
BE (MJ/kg)	16.2	16.6	16.4	16.2	16.3	16.4	16.6	16.8	16.5	16.8	16.7	15.5	16.9	17.0	16.8
ADF	258	217	228	202	205	195	172	166	159	155	112	117	108	117	178
NDF	313	281	357	282	319	246	162	259	249	258	155	105	172	191	294

Table B12 Proximate analysis of the grower diets (g/kg) on an as is basis.

Grower	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ash	87	90	93	84	89	75	84	84	89	84	66	89	73	88	73
Fibre	234	216	219	177	193	160	156	161	160	155	108	117	111	120	110
Fat	19	21	19	33	18	20	21	23	23	23	22	25	24	26	26
Crude Protein	101	133	144	172	217	109	131	144	167	193	110	136	150	172	211
BE (MJ/kg)	16.0	16.1	16.1	10.9	16.0	15.9	15.9	16.3	16.2	16.3	15.9	15.8	16.2	16.1	16.5
ADF	284	257	278	224	247	207	201	191	200	182	134	144	137	147	134
NDF	479	448	477	385	416	260	374	250	383	346	311	335	208	280	253

Table B13 Proximate analysis of the finisher diets (g/kg) on an as is basis.

Finisher	Feed number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ash	98	99	97	84	100	98	94	83	91	95	82	91	96	100	99
Fibre	266	249	266	263	265	230	231	235	217	235	181	182	178	221	183
Fat	10	12	11	14	14	16	15	18	19	20	22	24	30	26	28
Crude Protein	59	93	108	116	132	77	93	104	129	156	78	110	120	146	157
BE (MJ/kg)	16.0	15.9	16.3	16.4	16.4	16.0	16.1	16.5	16.0	16.3	16.0	16.2	16.2	16.4	16.4
ADF	355	334	339	338	354	299	295	303	275	293	235	237	228	273	230
NDF	627	588	601	583	533	533	485	496	439	456	452	427	384	412	360

****