Studies to develop a mathematical optimisation model to describe the effect of nutrition on the growth of ostriches (*Struthio camelus* var. *domesticus*)

by

Petrus Daniel Carstens

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Supervisor: Prof. T.S. Brand
Co-supervisor: Prof. L.C. Hoffman

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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 be 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 other qualification.

Date: December 2013

Note

The language and style used in this thesis are in accordance with the requirements of British Poultry Science. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetitions between the chapters have therefore been unavoidable. It should be noted that each chapter has its own reference list instead of one comprehensive list appearing at the end of the thesis.

The following contributions arising from this study have been presented at the South African Society for Animal Science congresses:

BRAND, T.S., CARSTENS, P.D., KRITZINGER, W.J., HOFFMAN, L.C. & GOUS, R.M. (2012) The effect of dietary bulk density on the feed intake of ostrich chicks (*Struthio camelus var. domesticus*) Book of abstracts, *South African Journal of Animal Science Congress*. pp.126. East London.

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CARSTENS, P.D., BRAND, T.S. & HOFFMAN, L.C. (2013) The effect of dietary protein and amino acid concentration on certain production parameters of growing ostrich chicks (*Struthio camelus var. domesticus*) Book of abstracts, *South African Journal of Animal Science Congress*. pp.19. Bloemfontein.

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Table of contents

Abstract

The first study (Chapter 3) evaluated the growth response of ostrich chicks on diets containing three different levels of protein and amino acids. Linear and nonlinear models were fitted to the data and compared by using Akaike's information criterion (AIC). The linear polynomial of the third degree had the lowest AIC value for all three treatments thus making it the most suitable model for the data. Significant differences were found between treatments for growth data. The results from this study can aid in describing the growth of ostriches subjected to assumed optimum feeding conditions.

In the second study (Chapter 4), a range of diets was formulated for the five growth stages of ostriches (pre-starter, starter, grower, finisher and maintenance) according to their nutrient requirements. The diets were diluted with wheat straw. Three dilution levels (0%, 10% and 20%) were used for the pre-starter and starter phases, five dilution levels (0%, 15%, 30%, 45% and 60%) were used for the grower and the finisher phases, and five dilution levels (0%, 20%, 40%, 60% and 80%) were used for the maintenance phase. Weekly intake data were collected throughout each phase. Feed bulk restricted intake by 21% and 52% at the 10% and 20% dilution level, respectively ($P < 0.05$) in the pre-starter phase, whereas intake was not restricted during the starter phase($P > 0.05$). Intake was constrained by 39% and 42% at the 45% and 60% dilution levels in the grower phase, respectively ($P < 0.05$), and by 17% and 39% at the 45% and 60% dilution levels ($P < 0.05$) in the finisher phase, respectively. Feed bulk restricted intake by 60% and 69% for the 60% and 80% dilution levels ($P < 0.05$), respectively, in the maintenance phase. Defining the bulk density that will constrain feed intake, as established in this study, will aid in least-cost feed formulations, feed intake modelling and growth predictions.

In the third study (Chapter 5) the effect of three different dietary protein (with a specific associated amino acid content) concentrations on certain production parameters in growing ostriches were investigated. Significant differences were found for the final live weight of birds, cold carcass weight, thigh weight as well as for most of the weighed muscles at slaughter (350 days old). Concerning the growth and feed related parameters, only average daily gain (ADG) was influenced by dietary treatment ($P < 0.05$). Results indicated that birds on the diet with the medium protein performed optimally. One exception is the starter phase (26 – 47 kg) where chicks on the high protein diet outperformed those on the medium protein diet.

In the fourth study (Chapter 6) the effects of different dietary energy concentrations on ostrich production parameters were examined in two different trials. The first trial included measurements from the pre-starter phase through the starter phase until the grower phase. The second trial was based on the finisher phase *per se*. Overall dietary levels provided in the pre-starter, starter and grower phases indicated better growth, FCR, skin size and grade, thigh weight, live weight, and carcass weight for the birds fed the medium energy diet. Dietary energy levels provided during the finisher phase indicated that the energy level above the medium level used improved growth rate and tanned skin size. The gender of the birds influenced carcass weight, growth rate, and certain feather parameters ($P < 0.05$).

In the fifth study (Chapter 7) the effect of feather clipping at six to eight months of age on the production parameters of ostrich chicks were investigated. The study was conducted in three different trials. In each of the trials the feathers of half the amount of birds were clipped at six to eight months of age. Significant differences ($P < 0.05$) were found for the feed conversion ratio (FCR), the average daily gain (ADG) and for the quantity of valuable feathers. Results indicated that the growth rate and FCR was better for the birds which had their feathers clipped at six to eight months of age. Results also showed that the quantity of feathers with commercial value were significantly higher for the clipped group.

This study showed that there may be an advantage for ostrich producers concerning the harvesting of feathers at six to eight months of age.

The work in this thesis is a follow up on the framework set by Kritzinger (2011) and is part of the same project. Most of the results obtained in these studies will be incorporated in to the mathematical optimisation model of Gous and Brand (2008) for more accurate predictions concerning feed intake and other production parameters that may lower feeding costs.

Opsomming

Die eerste studie (Hoofstuk 3) evalueer die groei van volstruiskuikens op diëte met drie verskillende vlakke van proteïene en aminosure. Liniêre en nie-liniêre regressiemodelle is op die data gepas en met Akaike se inligting kriterium (AIC) vergelyk. Die liniêre polinoom van die derde graad het die laagste AIC waarde vir al drie behandelings gehad. Daarom is die voorspellings van hierdie model gebruik om die groeidata te interpreteer. Beduidende verskille tussen behandelings vir groeidata ($P < 0.05$) is gevind. Die resultate van hierdie studie kan help met die beskrywing van die groei van volstruise, onderworpe aan aangeneemde optimale voedingsbehoeftes.

In die tweede studie (Hoofstuk 4) is 'n verskeidenheid diëte geformuleer vir die vyf groeistadiums van volstruise (voor-aanvangs, aanvangs, groei, afronding en onderhoud) volgens hul voedingsbehoeftes. Die diëte is verdun met koringstrooi. Drie verdunningsvlakke (0%, 10% en 20%) is gebruik vir die voor-aanvangs- en aanvangsfase, vyf verdunningvlakke (0%, 15%, 30%, 45% en 60%) is gebruik vir die groei- en die afrondingsfase en vyf verdunningsvlakke (0%, 20%, 40%, 60% en 80%) is gebruik vir die onderhoudsfase. Weeklikse inname-data is ingesamel gedurende elke fase. In die voor-aanvangsfase het voerlywigheid (verhoging van ruvesel) inname beperk met 21% en 52% vir die 10% en 20% verdunningsvlakke ($P < 0.05$) onderskeidelik, terwyl inname nie beperk is gedurende die aanvangsfase nie ($P > 0.05$). Inname is beperk met 39% en 42% op die 45% en 60% verdunningsvlakke in die groeifase ($P < 0.05$) onderskeidelik, en met 17% en 39% op die 45% en 60% verdunningsvlakke in die afrondingsfase ($P < 0.05$), onderskeidelik. Voerdigtheid het inname beperk met 60% en 69% vir die 60% en 80% verdunningsvlakke, onderskeidelik, in die onderhoudsfase ($P < 0.05$). Die definiëring van die digtheid of ruvoerinhoud van voer wat inname beperk, soos in die studie bepaal, sal help met die optimering van voerformulasies, voerinname-modellering en groeivoorspellings.

In die derde studie (Hoofstuk 5) is die effek van drie verskillende dieëtproteïenkonsentrasies (met 'n spesifieke gepaardgaande aminosuurinhoud) op sekere produksieparameters in die groei van volstruise ondersoek. Beduidende verskille is gevind vir die finale lewende gewig, koue karkasmassa, boudgewig sowel as vir die meeste van die geweegde spiere van voëls op slagouderdom (350 dae oud). Met betrekking tot die groei en voedingsverwante parameters, is slegs die gemiddelde daaglikse toename (GDT) beïnvloed deur die dieet ($P < 0.05$). Resultate het aangedui dat voëls op die medium-proteïendieet

optimaal presteer. Een uitsondering is die aanvangsfase (26 – 47 kg), waar kuikens op die hoë-proteïendieet beter gevaar het as die voëls wat die medium-proteïendieet ontvang het.

In die vierde studie (Hoofstuk 6) is die invloed van verskillende dieet-energie-konsentrasies op volstruis-produksieparameters in twee verskillende proewe ondersoek. Die eerste proef het gestrek vanaf die voor-aanvangsfase, deur die aanvangsfase tot en met die einde van die groeifase. Die tweede proef is gedoen vir die afrondingsfase.

In die voor-aanvangs-, aanvangs- en groeifase is beter groei, voeromsetverhouding (VOV), velgrootte en -graad, boudgewig, lewende gewig en karkasgewig verkry vir die voëls wat die standaard-energie dieet ontvang het ($P < 0.05$). Dieet-energievlakke wat tydens die afrondingsfase fase verskaf is, het aangedui dat die energievlak bo die medium-vlak verbeterde groeitempo en gelooide velgrootte tot gevolg het ($P < 0.05$). Die geslag van die voëls het ’n invloed gehad op karkasgewig, groei, en sekere veerparameters.

In die vyfde studie (Hoofstuk 7) is die effek van die knip van vere, op die ouderdom van ses tot agt maande, op die produksieparameters van volstruiskuikens ondersoek. Die studie is uitgevoer in drie verskillende proewe. In elk van die proewe is die vere van die helfte van die hoeveelheid voëls geknip op ses tot agt maande ouderdom. Beduidende verskille is gevind vir die VOV, die gemiddelde daaglikse toename (GDT) en vir die hoeveelheid waardevolle vere ($P < 0.05$). Die groeitempo en VOV was beter vir die voëls waarvan die vere op ses tot agt maande ouderdom geknip is ($P < 0.05$). Resultate het ook getoon dat die hoeveelheid waardevolle vere aansienlik hoër was vir die groep waarvan die vere op ses tot agt maande ouderdom geknip is ($P < 0.05$). Hierdie studie het getoon dat daar 'n voordeel mag wees vir volstruisprodusente indien vere geknip word op die ouderdom van ses tot agt maande.

Die werk in hierdie tesis volg op die raamwerk van Kritzinger (2011) en was deel van dieselfde projek. Die meeste van die resultate wat verkry is in die studies sal in die wiskundige optimeringsmodel van Gous en Brand (2008) geïnkorporeer word vir meer akkurate voorspellings van voerinname en produksieparameters wat die voerkostes kan verlaag.

Chapter 1

1.1. GENERAL INTRODUCTION

Ostrich farming is the backbone of the Klein Karoo's economy and it plays a vital role in farming practices in other parts of the Western and Southern Cape. The reason for its particular importance in the Klein Karoo is that the ostrich is the livestock species that produces the most profit per hectare in this hot arid region. This is very important as the farms in the Klein Karoo are relatively small and the ostrich is an ideal species to farm on limited surface areas, especially when farmed in a feedlot (intensive) system.

Feed prices comprise 70% to 80% of the costs of an intensive ostrich production unit. Feed prices are volatile and changes in feed prices may affect the profitability of ostrich production. This scenario may be exacerbated if the diet is not balanced especially as pertaining to the amino acid profile of the feed, as the ostriches would then have a low feed conversion ratio, thus drastically reducing profits. A feed must be formulated so that no nutrients are over or under supplied, thus ensuring maximum profits by maximising growth and reducing feeding costs.

In an attempt to decrease feeding costs, least-cost diet formulations are used when formulating ostrich (and other animal) diets. To formulate a feed that is balanced and has a balanced amino acid profile requires in-depth knowledge of the intake, digestion and metabolism of the ostrich. The most effective way of understanding the metabolic processes is to use mathematical modelling to simulate growth (in the ostrich of importance is muscle/body, skin and feathers growth rates), predict the feed intake and thus the nutritional requirements of ostriches during the complete growth cycle (pre-starter, starter, grower and finisher). Energy and protein (including amino acids) values are the main factors that need to be taken into account while formulating an animal/bird's feed. By feeding different levels of energy and protein and measuring feed intake of ostriches and measuring their growth, equations can be derived and a model can be developed. Such a prelimnary model has been developed by Professor Robert Gous of the University of KwaZulu-Natal and Professor Tertius Brand of Western Cape Department of Agriculture (Gous and Brand, 2008). However the mathematical optimisation model for ostriches is more complex than the models for poultry and pigs as poultry and pigs have only one product, meat, as opposed to the ostrich which has three economically important products: feathers, skin and meat. Thus the model needs to predict what will happen to each of these products when the diet is altered, and

ultimately the diet may be changed so that production of the most profitable product is favoured.

This study was conducted to verify and optimise this growth model and to obtain a better understanding of the growth of ostriches. Finally the growth model will help to predict accurate nutrient requirements that will aid with formulations of least-cost ostrich diets. This will help ostrich producers to ensure that there is no over or under feeding of certain nutrients (energy, protein or certain amino acids).

In a commercial production unit, ostriches are raised to be slaughtered at approximately 10.5 months. The diet starts with the pre-starter phase, moving on to starter, grower and eventually the finisher phase. The nutrient density decreases from the pre-starter to the finisher phase as the younger the bird, the less the intake; thus to fulfil the needs of the chick, the nutrient concentrations must be high enough. These studies were done by using the mathematical optimisation model for ostriches (Gous and Brand, 2008) to predict the requirements of the chicks in each phase.

Another aspect of ostrich rearing is feather harvesting. In a commercial ostrich production unit, at six to eight months of age the feathers of the chicks are clipped to have better quality feathers at slaughter. The effect of feather clipping on production has also been evaluated in this dissertation as the industry is interested in the effect it may have on daily feed intake and production as well as feather quality.

This thesis was written in the format for British Poultry Science as most of the chapters will be submitted as articles to this journal.

1.2 REFERENCES

GOUS, R.M. & BRAND, T.S. (2008) Simulation models used for determining food intake and growth of ostriches: an overview. *Australian Journal of Experimental Agriculture*, **48**: 1266-1269.

Chapter 2

Literature review

2.1 INTRODUCTION

The Klein Karoo is the largest area of ostrich production in South Africa and for this reason it is also known as South Africa's ostrich capital. The ostrich industry has faced challenges in the past because it is consumer driven and is thus susceptible to sudden changes in economic cycles that influence consumers' income and spending ability. Furthermore ostrich leather and feathers compete in the exclusive fashion market while ostrich meat is a healthy nishe market commodity.

Revenue from ostriches is generated from skin, feathers and meat (Gous and Brand, 2008). The price of each of these products constantly changes and the ratio of the prices to each other also changes. The ostrich industry was established between 1838 and 1866. At this time ostriches were farmed extensively and the main product was feathers (Jordaan *et al*., 2008). The feather market collapsed in the early 1900s and gradually the emphasis shifted to skin production. From the 1960s ostrich producers started to farm intensively with ostriches due to their farms becoming smaller; there were no other animal species that could give the same amount of profit per hectare as the ostrich. From the 1990s the emphasis shifted towards meat production, while income from feathers comprised seven to ten per cent (Jordaan *et al*., 2008; Nel, 2010). From 2000 meat prices increased steeply, partly because of health benefits perceived by consumers, and more importantly, after outbreaks of BSE (bovine spongiform encephalopathy) in Europe and foot and mouth disease in the United Kingdom and Europe (Horbańczuk *et al*., 2008). However in 2003, due to local outbreaks of bird flu, exports were stopped and this decreased South African ostrich producers' profit from meat by approximately 300% as the meat now had to be marketed locally (Anon, 2011). The industry recovered and in 2010 it had a gross value for meat alone of approximately R300 million, with 350 000 birds slaughtered that year (Anon, 2011). However, in 2011 there were bird flu outbreaks once again and the ban on export has not yet been lifted, except for cooked (*sous vide*) meat. Thus the feathers and skin prices play a vital role, while the meat price has declined (Brand and Cloete, 2009). Presently, the skin price is approximately 50% of the total value of a slaughter ostrich (Engelbrecht *et* al., 2009; Engelbrecht, 2010).

It is clear that the ostrich industry constantly faces challenges and for this reason it is important to optimise those aspects of the production system which the ostrich producers can control, such as nutrition.

Nutrition comprises 70 – 80% of overall production costs in ratite production systems (Brand *et al*., 2002b; Kritzinger, 2011). Research is aimed at decreasing feed costs by increasing the efficiency of feed utilisation and by testing different diets with different nutrient contents, thus optimising the nutritional requirements of the ostrich (Kritzinger, 2011). Nutrient requirements constantly change in poultry and ratites as they grow and develop, thus the diet needs to be changed in accordance with growth and the stage of development (Swart, 1988; Cilliers and Angel, 1999). The following diets are used in ostriches: pre-starter, starter, grower, finisher and breeder rations (Cilliers, 1994; Brand *et al*., 2003; Brand and Gous, 2006a; Brand and Olivier, 2011). Typically, the nutrient density of the diet decreases over time because the animal has a higher feed intake as it ages (Gous, 1986). Diets for poultry and ostriches are changed in accordance with the requirements to obtain optimal growth and to utilise the feed to an economical maximum (Polat *et al*., 2003). The diet must be balanced, meaning that the levels and balances of protein, vitamins, minerals and energy must be in the correct ratio to each other while the nutrients are included in adequate levels for the specific diet, otherwise nutrients may be oversupplied and lost (McDonald *et al.*, 2002).

Market trends have a large effect on production of ostriches, and as protein and energy sources become more expensive, pressure is placed on the ostrich producer to develop methods for rearing and marketing ostriches at a profitable level (Deeming, 1999; Bhiya, 2006). Therefore, some commercial producers are cutting costs by compromising protein and energy levels in the feed. If the protein and energy are too low, or if low quality nutrients are used, they can be a restraining factor in production (Brand *et al*., 2002b). The importance of this research is to optimise nutrient requirements of the ostrich. By optimising nutrient requirements, nutrients will not be over- or undersupplied, thus avoiding a negative effect on production and profits.

2.2 NUTRITIONAL REQUIREMENTS

There is a lack of knowledge concerning ostrich nutrition as compared to other farm animals (Brand and Gous, 2006 b; Olivier, 2010). Nutrient requirements depend on the stage of growth of the ostrich and will change as the body's composition and the protein: fat ratio changes (Oldham and Emmans, 1990; Brand and Olivier, 2011). According to Gous (1986), the aim of the nutritionist must not be to only estimate the requirements of the animal, but rather to understand how the animal responds to incremental inputs of a given nutrient.

The requirement for potential growth can briefly be described as free access to a balanced diet, feed intake that is not constrained, and a thermally neutral environment (Emmans, 1989). The growth rate in ostriches increases from hatching to six months of age, and from month six to month fourteen of age the growth rate decreases, although currently the trend is to slaughter ostriches around month ten to eleven (Table 2.1).

In the past, ostrich diets were formulated on limited data, poultry diets were used as a base and from there ostrich diets were derived, this led to an oversupply of nutrients such as energy and protein (Brand and Gous, 2006a). The ostrich is a hind gut fermenter and has the ability to utilise more energy from feed as compared to poultry (Kruger, 2007). Fibre can be used efficiently for volatile fatty acid (VFA), and thus energy production by hind gut fermenters (Swart, 1988). Other research focussed on usage of pastures together with concentrates to reduce the cost of feed (Strydom, 2010).

Table 2.1. *Average growth rate of ostriches when fed ad libitum (adapted from Brand and Olivier, 2011)*

Age (months)	Live weight (kg)	Growth rate (g/bird/day)
0 – 1	0.85 – 5.1	107
1 – 2	5.1 – 10.8	191
2 – 3	10.8 – 19.2	280
3 – 4	19.2 – 29.7	350
4 – 5	29.7 – 41.5	390
5 – 6	41.5 – 53.4	397
6 – 7	53.4 – 64.7	377
7 – 8	64.7 – 74.9	340
8 – 9	74.9 – 83.7	294
9 – 10	83.7 – 91.1	247
10 – 11	91.1 – 97.2	203
11 – 12	97.2 – 102.1	163
12 – 13	102.1 – 105.9	130
13 – 14	105.9 – 109.1	102

2.3 ENERGY REQUIREMENTS

Energy requirements of ostriches are around 0.44 ME/kg $W^{0.75}$ per day and the efficiency of utilisation for metabolisable energy for tissue synthesis is 0.32 (Swart *et al*., 1993). According to Cilliers *et al*. (1998), true metabolisable energy corrected for nitrogen retention (TME_n) required for maintenance for ostriches is 0.43 ME/empty body weight (EBW), $kg^{0.75}$/day, this is more or less in the same order as noted by Swart *et al.* (1993). The efficiency of utilisation for TME_n is 0.414 (Cilliers *et al*., 1998), which is higher than was noted by Swart *et al*. (1993). The efficiency of utilisation is less than in other domesticated monogastrics, for example pigs and poultry (Olivier, 2010). Higher fibre level feeds will yield the highest TME when fed to the ostrich in comparison to other domesticated farm animals such as pigs, poultry and ruminants (Brand *et al*., 2006).

Dry matter intake as well as TME is presented in Table 2.2, together with the commercial feeding stages and energy requirements of ostriches. When formulating feeds, feed intake is an important factor to be considered. If feed intake of the animal is not clear and an incorrect value for intake is used when the feed is formulated, the nutrient density will not be at an optimal level (Gous and Brand, 2008). Concerning slaughter ostriches, intake and energy value are inversely correlated and as the energy value increases, intake will decrease proportionally (Brand *et al*., 2000; Brand *et al*., 2002b).

Table 2.2. *Commercial feeding stages and energy requirements for growing ostriches (adapted from Brand and Gous, 2006b; Brand and Olivier, 2011)*

	Stage of production				
Predicted parameter	Pre-starter	Starter	Grower	Finisher	Maintenance
Live weight (kg)	0.8 – 10	10 – 40	40 – 60	60 – 90	90 – 100
Age (months)	0 – 2	2 – 4.5	4.5 – 6.5	6.5 – 10.5	10.5 – 12
Feed intake (g/day)	275	875	1603	1915	2440
TME (MJ ME/kg feed)	14.5	13.5	11.5	9.5	8.5
Predicted growth rate (g/bird/day)	150	400	330	250	200

2.4 PROTEIN AND AMINO ACID REQUIREMENTS

The protein and amino acid requirements of ostriches depend on several factors, including age, live weight, feed intake, stage of production and amino acid composition of the protein in the feed. Protein concentrations that are very high (28%) are not recommended, because this may cause leg abnormalities and would also have a negative cost implication. Protein requirements for ostriches are summarised in Table 2.3 for different diets, ages, live weight and feed intake.

Table 2.3. *Predicted dry matter intake as well as protein and amino acids requirements for ostriches (adapted from Cilliers et al., 1998; Brand and Gous, 2006b; Brand and Olivier, 2011)*

	Stage of production				
Predicted parameter	Pre-starter	Starter	Grower	Finisher	Maintenance
Live weight (kg)	0.85 – 10	10 – 40	40 – 60	60 – 90	90 – 120
Age (months)	0 – 2	2 – 5	5 – 7	7 – 10	10 – 20
Feed intake (g/day)	275	875	1603	1915	2440
Protein(g/100g feed)	22.9	19.7	14.7	12.2	6.9
Lysine (g/100g feed)	1.10	1.02	0.84	0.79	0.58
Methionine (g/100g feed)	0.33	0.33	0.29	0.28	0.24
Cysteine (g/100g feed)	0.23	0.22	0.18	0.17	0.14
Total SAA (g/100g feed)	0.56	0.55	0.47	0.45	0.38
Threonine (g/100g feed)	0.63	0.59	0.49	0.47	0.36
Arginine (g/100g feed)	0.97	0.93	0.80	0.78	0.63
Leucine (g/100g feed)	1.38	1.24	0.99	0.88	0.59
Isoleucine (g/100g feed)	0.70	0.65	0.54	0.51	0.38
Valine (g/100g feed)	0.74	0.69	0.57	0.53	0.36
Histidine (g/100g feed)	0.40	0.43	0.40	0.40	0.37
Phenylalanine (g/100g feed)	0.85	0.79	0.65	0.61	0.45
Tyrosine (g/100g feed)	0.45	0.44	0.38	0.38	0.31
Phenylalanine and Tyrosine (g/100g feed)	1.30	1.23	1.03	0.99	0.76

2.5 PAST STUDIES

Wide-ranging studies have been reported on ostriches to determine the nutrient requirements for all the growth phases (Swart *et al.,* 1993*;* Cilliers *et al.,* 1998; Brand *et al.,* 2000; Brand *et al*., 2002a Brand *et al*., 2002b; Brand *et al*., 2006; Brand and Gous, 2006 b*;* Gous and Brand, 2008; Olivier, 2010; Brand and Olivier*,* 2011). Further studies have also been conducted to determine the optimum nutrient levels for production, the main nutrients being energy and protein/amino acids.

Energy

Salih *et al*. (1998) found significant differences for the average daily gain and feed conversion ratio in the starter phase for ostrich chicks when fed different energy levels (Table 2.4). Three diets were fed with energy levels of 9.5MJ ME/kg feed, 12 MJ ME/kg feed and 14.5 MJ ME/kg feed. There were no significant differences for dry matter intake noted.

Table 2.4. *Production data of ostrich chicks (6.12 ± 1.94 kg) fed a starter diet with three different energy levels from 4 to 12 weeks of age (adapted from Salih et al. (1998)*

Dietary Treatment	High energy 14.5 MJ ME/kg feed	Medium energy 12.0 MJ ME/kg feed	Low energy 9.5 MJ ME/kg feed
Dry matter intake (g/d)	817[a]	818[a]	773[a]
Average daily gain (g/d)	368[ab]	392[a]	321[b]
Feed conversion ratio	2.09[a]	2.02[a]	2.42[b]

Means in the same row with different superscripts differ ($p < 0.05$).

In the grower/finisher phase of the same trail, the levels of energy in the feed were adjusted to 9 MJ ME/kg feed, 11.5 MJ ME/kg feed and 14 MJ ME/kg feed for the L, M and H diets respectively. There were no significant differences for the ADG or the FCR, however the intake for the medium diet was significantly higher than the intake of the low diet.

Brand *et al.* (2000) fed diets containing the following energy values to ostriches during the grower and finisher phases: 9.0, 10.5 and 12 MJ ME/kg, but there were no significant growth differences noted. There was however a higher feed intake as the energy concentration decreased. A better (lower) FCR were obtained for the lower energy levels than the high level. Interestingly, the skin surface area was significantly higher for the birds

fed the high energy level than the low energy diet; this has economical implications as producers are paid, amongst others, for crusted skin surface area.

Brand *et al.* (2004) showed an optimum energy level of 12.5 MJ ME/kg feed for the grower phase and a level of 11.5 MJ ME/kg feed for the finisher phase. In the grower phase the following levels of energy were tested: 8.5, 10.5 and 12.5 MJ ME/kg feed. In the finisher phase the levels of energy tested were: 7.5, 9.5 and 11.5 MJ ME/kg feed.

Cloete *et al.* (2006) also found that raw skin weight and skin thickness increased as the energy level of feed increased. The trial diets that were fed contained the following energy values: 9.0, 10.5 and 12 MJ ME/kg, in both the grower and finisher phase.

Glatz *et al*. (2008) found that an energy concentration of 10 MJ ME/kg feed to be the optimum for the grower phase concerning weight gain. The following energy levels were compared in their study: 10 MJ ME/kg feed, 10.7 MJ ME/kg feed and 12.5 MJ ME/kg feed.

Protein and amino acids

Gandini *et al*. (1986) found that isocaloric diets with protein ranging from 16% to 20% resulted in net growth. The mean body weight gains in the pre-starter phase were not influenced by the protein level. The FCR was the highest (worst) for the 14% protein concentration. The study concluded that for the pre-starter phase the protein concentration must not be lower than 16%. The different protein concentrations that were fed were: 14%, 16%, 18% and 20%. In a latter study by Brand *et al.* (2000), diets containing the following protein concentrations were fed to ostriches during the grower and finisher phases: 13, 15 and 17%, none of the production parameters were influenced by the level of protein in this study. There was however a higher percentage (59%) of Grade 1 skins for the low protein treatment, significantly less (40%) for the medium treatment and the lowest (34%) for the high protein treatment.

Brand *et al.* (2004) tested the following levels of protein for the grower phase: 11.5, 13.5, 15.5, 17.5 and 19.5 % (with corresponding lysine contents of 5.8, 6.8, 7.8, 8.8 and 9.8 g/kg respectively) and for the finisher phase: 8, 10, 12, 14 and 16% with corresponding lysine concentrations of 3.3, 4.1, 5.0, 5.8 and 6.6 g/kg feed respectively. Unfortunately, this study did not find many significant differences for production parameters for different dietary protein concentrations, thus no optimum could be determined. Skin quality parameters were also not influenced by varying protein (lysine) levels.

Cloete *et al.* (2006) also fed diets containing the following protein concentrations to ostriches during the grower and finisher phases: 13, 15 and 17%; and found that protein had no significant effect on skin quality parameters. Glatz *et al*. (2008) found that a protein concentration of 12.6% to be the optimum for the grower phase concerning weight gain. Diets containing the following protein concentrations were fed: 12.6%, 13.6%, 13.8% and 14.3% in their study.

Azahan and Noraziah (2011) indicated that for the starter phase, the most optimum level of protein is 17.5% (Table 2.5). The three different concentrations of dietary protein fed were: 12.5%, 17.5% and 22.5%.

Table 2.5. *Effect of dietary crude protein (CP) level on growth performance (Means ± Standard errors) of ostriches over six weeks (adapted from Azahan and Noraziah, (2011))*

Performance	Low protein (12.5% CP)	Medium protein (17.5% CP)	High protein (22.5% CP)
Body weight gain (kg/bird)	$9.49^{a} \pm 1.91$	$13.76^{b} \pm 0.98$	$14.64^{b} \pm 1.28$
Feed intake (kg/bird)	$30.32^{a} \pm 6.87$	$38.64^{b} \pm 2.88$	$37.18^{ab} \pm 4.07$
Protein intake (kg/bird)	$3.79^{a} \pm 0.86$	$6.73^{b} \pm 0.5$	$8.36^{c} \pm 0.92$
FCR	$3.19^{a} \pm 0.28$	$2.79^{b} \pm 0.02$	$2.56^{b} \pm 0.43$

Means in the same rows with different superscripts differ ($p < 0.05$).

2.6 PRODUCTS OF THE OSTRICH

In the past the market interest for ostrich products has shifted from one product to the other. As mentioned, initially the main product was the feathers, then the skins, and later, as meat consumers became more health conscious, the focus of ostrich products shifted to meat. Recently, the market interest has shifted to a multiproduct approach where all three of these products are economically important as main sources of income (Adams and Revell, 2003).

According to Jordaan *et al.*(2008), the relative income contribution of the three main products (skin, meat, feathers) for the ages of slaughtering of 8.5 – 10.5 months, 10.5 – 12.5 months, 12.5 – 14.5 months and 14.5 – 16.5 months is in a ratio of 47:53:0; 52:47:1; 47:50:3; 44:51:5 and 39:56:5 respectively. An ostrich at the age of 14 months can provide a skin with a surface area of 108–26 dm^2, 34 – 41 kg meat and 1.4 – 1.8 kg of feathers (Cooper, 2000).

Skins

The ostrich has a very distinctive skin. The crown area is diamond shaped and it extends along the back, down the wing fold and the stomach (Figure 2.1). The skin of an ostrich contains nodules, the feather sockets, which make it very distinct. As the bird ages, the nodules develop more and increase in size (Sales, 1999). If the main aim of production is skin, ostriches must be slaughtered at an age of 12 – 14 months. At this stage the skin will have developed well and its minimum size will be 120 dm^2, with well-developed and rounded nodules (Strydom, 2010). The ideal shape of the nodules is achieved at around 14 months of age, but the optimal size is reached at 10 months of age (Sales, 1999).

When ostriches are mainly produced for meat, they will reach slaughter weight at a younger age through improved nutrition, although the skins will not be developed completely at this stage. Depending on the focus of the market interest and whether the skins have a significant higher income per bird than meat, one can decide if it would be economical to feed the birds for an extra few months (up to 14 months of age).

According to Cooper (2000), the following can be produced from the crown area: briefcases, key purses, credit card holders, cellular phone covers, handbags, licence card holders, wallets, and so on. The thinner skins of younger birds are used for clothes.

However, research on the effect of nutrition on the skin quality attributes is sparse, therefore in this thesis, research was done on the skins of the ostrich, including the effects of dietary protein and energy on nodule development, skin size, nodule size and pin holes.

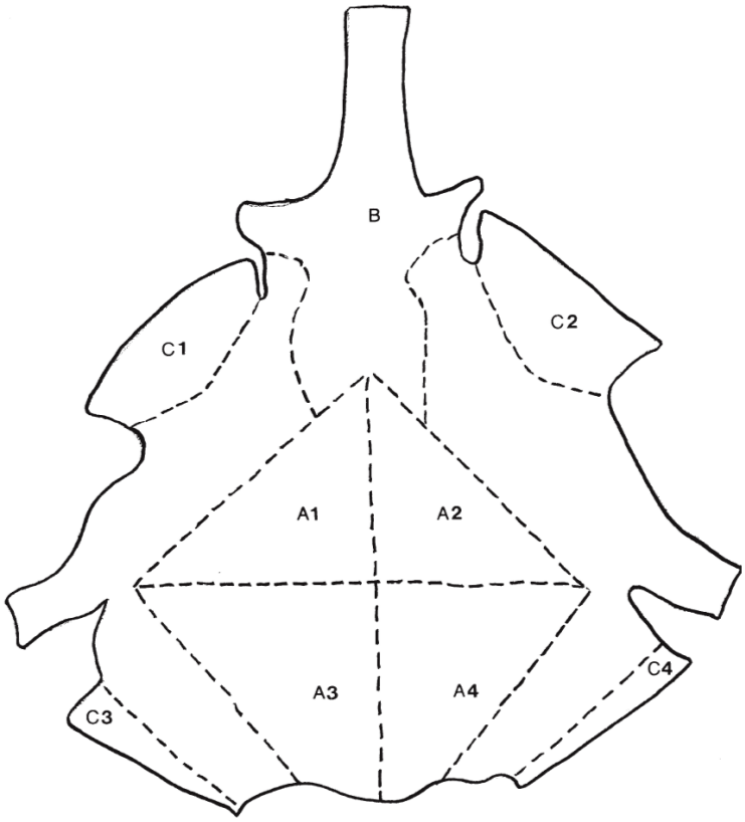


Figure 2.1. *The various quill areas of a tanned ostrich skin viewed from the dorsal aspect, with the neck at the top and the tail at the bottom. A (1–4), main 'diamond' area of crown; B, neck; C (1–2), upper belly flap; C (3–4), lower belly flap (Sales, 1999).*

Feathers

The ostrich has a symmetrical feather, in contrast to other birds (Figure 2.2). Due to fashion trends during the 1900s, most of the production attention was focussed on ostrich feathers as these were harvested and used in the fashion industry (Sales 1999). For optimal production of feathers, the old feathers of chicks must be clipped at an age of approximately six months to promote new feather growth (Sales, 1999). The potential feather yield of an adult ostrich is 400 – 450 g of white plumes and 1 000 – 1 200 g of short feathers (Sales, 1999). The potential feather yield of a slaughter bird is approximately 700 g body feathers. Ostrich feathers are durable for about 35 years and the best quality feathers are produced by ostriches from the age of 3 to 12 years.

South Africa is the only country where ostrich feathers are harvested. The modern general practice is to clip feathers with a feather clipper above the bloodline of the shaft. A week later the dried-out shafts that are still attached to the skin will be removed (T.S. Brand,

2012 Pers. Comm., Elsenburg Animal Production Institute, Department of Agriculture: Western Cape, Private Bag X1, Elsenburg, 7607). This is an almost painless procedure.

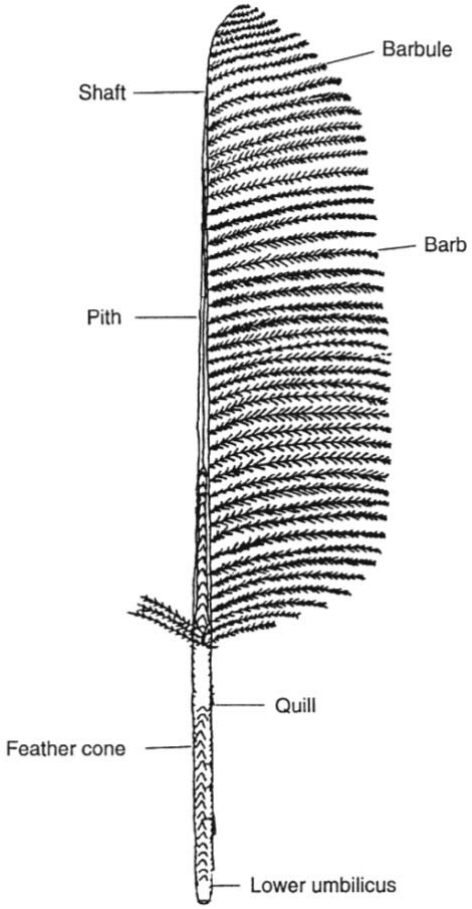


Figure 2.2. *Different parts of the ostrich feather (Sales, 1999). One side of the feather is illustrated and the spaces between the barbs have been exaggerated for clarity.*

Growth of feathers

It is difficult to describe feather growth, since the weight of feathers is not a simple power function of body protein weight. Feathers that have been shed are not present at slaughter and the genotypes may differ for feather growth due to the absence or presence of a few single genes (Emmans, 1989).

The protein composition of feathers differs from the protein composition of the rest of the body therefore feather growth must be separated from body growth (Emmans, 1989). Emmans confirmed this by revealing that body protein had relative low levels of cystine (11

g/kg protein) and high lysine levels of (75 g/kg protein) and feathers had higher levels of cystine (70 g/kg protein), while having lower levels of lysine (18 g/kg protein).

Very little research has been done on modelling of feather growth in ostriches and other birds. A large part of the protein requirements and an even larger part of the requirements of sulphur-containing amino acids is for growth of feathers, so the problem of predicting growth of feathers needs attention. A provisional solution of determining feather loss in turkeys has been dealt by assuming a rate of feather loss which is proportional to feather weight of 0.01/day (Emmans, 1989).

The growth of feather protein and body protein are not allometrically related as feathers and the rest of the body mature at different rates, but as the bird matures the proportion of feather protein to body protein changes (Emmans and Fisher, 1986; Emmans, 1989; Kritzinger, 2011). Thus predictions for feather growth cannot be made from body protein growth. It would be beneficial for the industry to describe feather growth, because when amino acid requirements are known, they may aid in least-cost diet formulations as amino acids are a very expensive nutrient in feeds.

In this thesis, research on feathers was conducted for optimisation of profitability. This research was done to investigate the effect of dietary protein and energy on feather quality. It has been speculated that if feathers are harvested at six months of age, the ostriches tend to grow faster, due to a higher feed intake. Of the ingested feed, not all the nutrients are utilised as heat and the rest of the nutrients might be utilised for growth. The feed intake is probably higher due to the heat loss that is caused by a lack of insulation of the bird after feather harvesting. In this study the effect of feather harvesting on different production parameters was studied.

Meat

From the first exports of ostrich fillets to Switzerland in 1977, the demand for ostrich meat in the European countries has grown steadily. In recent years, ostrich meat has become more popular as consumers become more health conscious and ostrich meat is believed to be a healthier alternative to red meat. Ostrich meat contains less fat than beef and lamb as the fat deposits of ostrich are limited to sub-peritoneal and subcutaneous layers, which are easily removed (Sales and Horbanczuk, 1998). Another advantage of ostrich meat is the higher levels of poly-unsaturated fatty acids (PUFA); higher than in both beef and chicken, and an

advantageous ratio of PUFA: mono-unsaturated fatty acids (MUFA): saturated fatty acids (SFA), which is approximately 1:1:1 (Sales and Horbanczuk, 1998).

Anatomic position of muscles of the ostrich

Most of the ostrich meat is sold as complete muscles, with most of the animal's meat on the legs with a smaller proportion of meat on the neck and back (Sales, 1999). Two thirds of the ostrich's meat is from the following muscles: *Muscularis 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* (Sales, 1999), the other third is made up of trimmings. The whole carcass of the ostrich consists of 23 muscles which are commercially sold as steaks (Kritzinger, 2011). The anatomical positions of the muscles are presented in Figures 2.3, 2.4, 2.5, 2.6 and 2.7. The muscle numbers in Table 2.6 are correlated with the numbers for the muscles in Figures 2.3, 2.4, 2.5 and 2.6.

Table 2.6. *Anatomical names, commercial names and marketing application of ostrich muscles (Mellett, 1985, 1992, 1994; 1996; Kritzinger, 2011)*

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

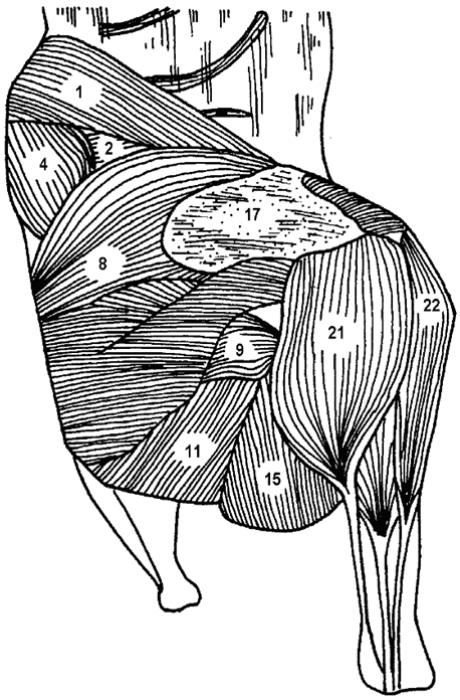


Figure 2.3. *Outer layer of muscles of the pelvic limb (Mellett, 1985; 1992; 1994; 1996).*

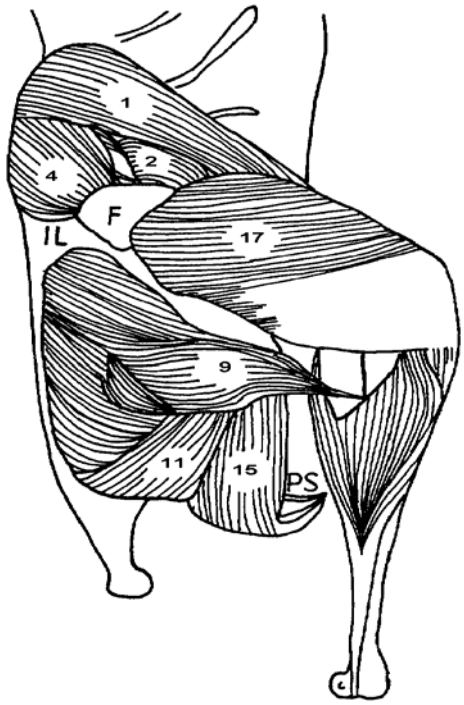


Figure 2.4. *The second layer of muscles of the pelvic limb (Mellett, 1985; 1992; 1994; 1996).*

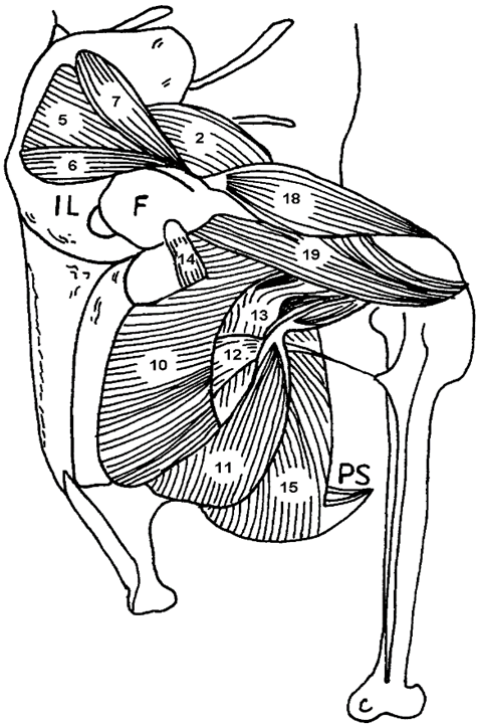


Figure 2.5. *Third and fourth layers of muscles of the pelvic limb (Mellett, 1985; 1992; 1994; 1996).*

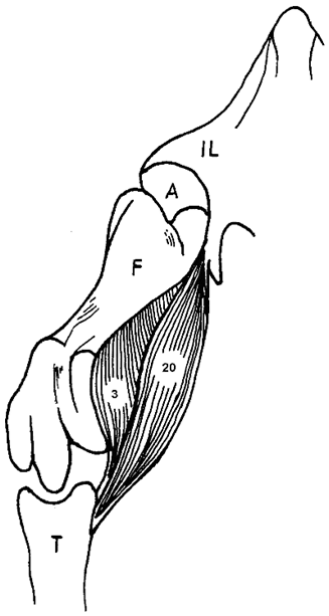
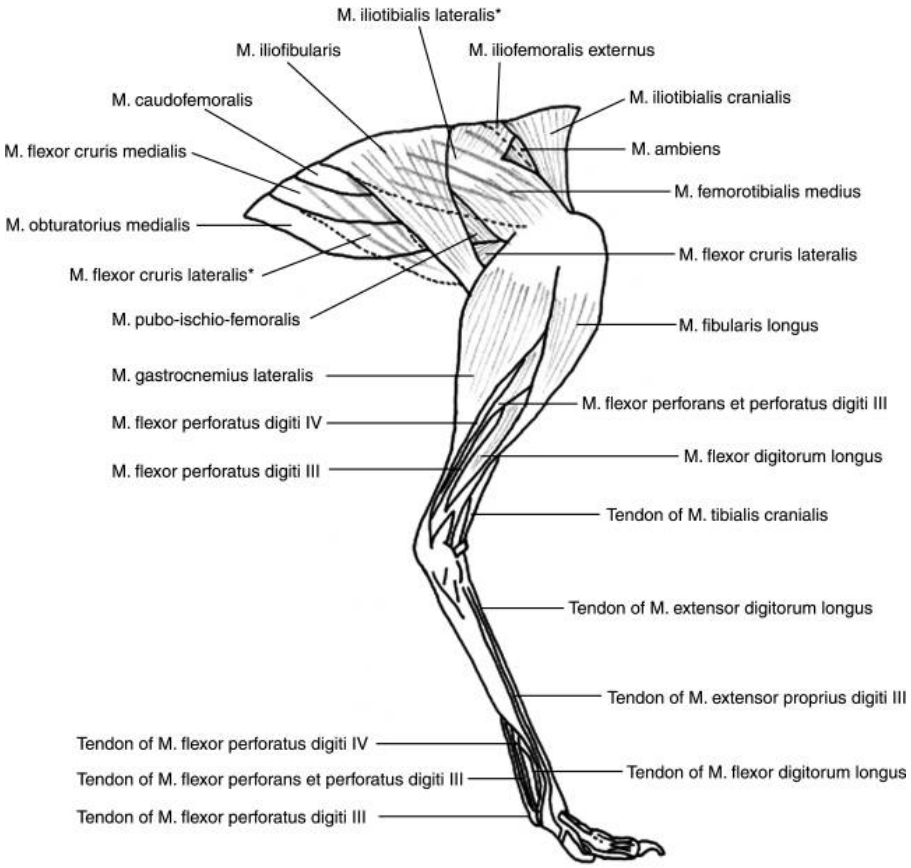


Figure 2.6. *Medial muscles of the upper leg (Mellett, 1985; 1992; 1994; 1996).*



*M. iliotibialis lateralis and M. flexor cruris lateralis are transparent so that deeper muscles can be visualised

Figure 2.7. *Lateral view of the anatomy of the pelvic limb of the ostrich (Smith et al., 2006).*

This study will focus on the effect of dietary energy and protein on individual commercially important muscles (Table 2.6).

2.7 MODELLING

A mathematical model is a set of equations or a single equation that represent a system's behaviour (Thornley and France, 2007). Models are a way of simplifying reality; they produce representations of reality that can be used by a scientist to compare with quantitative predictions (France and Kebreab, 2008). Mathematical modelling is used for application of real world problems and processes such as animal nutrition (Gous *et al.*, 2006). Models are used by scientists to represent parts of the real world and to convey an understanding to others how they work and to reduce a mass of observations to equations which have powerful

predictive value (Morris, 2006). According to Morris (2006), mechanistic models are quantitative models that aim to represent the underlying mechanisms that produce results.

Every aspect of biology consists of different organisational levels (Thornley and France, 2007; France and Kebreab, 2008; Kritzinger, 2011). The biological diversity is due to the different levels of organisation (France and Kebreab, 2008). Every level can be viewed as a system, and is built on an underlying system (Gous *et al.*, 2006). When the underlying levels are combined, the next level in the hierarchy is created (Thornley and France, 2007). For the field of animal science, the organisational levels are shown in Table 2.7 and the levels can be continued in both directions (France and Kebreab, 2008).

Table 2.7 *Levels of organisation to construct hierarchy for biological systems (adapted from France and Kebreab, 2008)*

Level	Description of level
$i + 3$	Collection of organisms (herd, flock)
$i + 2$	Organism (animal)
$i + 1$	Organ (heart, liver, kidneys)
i	Tissue
$i - 1$	Cell
$i - 2$	Organelle
$i - 3$	Macromolecule

Three categories of models will be overviewed: teleonomic modelling, which is usually aimed at higher levels, empirical modelling, which is aimed at a single level, and mechanistic modelling which looks downwards at lower levels (France and Kebreab, 2008).

Teleonomic models are formulated in terms of goals and are apparently goal directed. The word 'apparently' is used because the true existence of goal seeking behaviour is denied by science (Thornley and France, 2007). In Table 2.7, the responses at level i are referred to the constraints provided at the level $i + 1$ (France and Kebreab, 2008). By means of evolutionary pressures, the higher level constraints can select lower level mechanisms which can possibly lead to behaviour at level i that is goal directed. Although its role may expand, teleonomic modelling plays a minimal role in biological modelling. Despite that Thornley and France (2007) found some application of teleonomic models in plant and crop modelling,

it has not been applied to problems in animal physiology and animal nutrition (France and Kebreab, 2008).

Empirical models are used to quantify relationships from experimental data and they are based at a single level as discussed in Table 2.7 (Heafner, 1996; France and Dijkstra, 2006). The aim of this type of model is to describe responses of a system without constraints of scientific principles and content; it only uses pure mathematical and statistical equations (Thornley and France, 2007). This may be the best model to use, depending on the objective of the study. This type of model is regularly curve-fitting and as it is predominantly prediction orientated, the direct biological meaning usually cannot be attributed to the parameters of the equation (France and Dijkstra, 2006). The equation could prove to be very useful if the model fits the data well (Haefner, 1996). The range of the predictive ability of the model is limited as the model is particular to the conditions under which the data were collected (France and Kebreab, 2008).

Mechanistic models give an understanding, cause and explanation of the modelled data (Thornley and France, 2007). This can only be achieved if the model is constructed on at least two levels of hierarchy (Table 2.7). To construct a mechanistic model, the structure of the system needs to be taken into account (France and Dijkstra, 2006). The system then needs to be divided into its key components and then the behaviour of the whole system can be analysed in terms of the individual components and their interaction with each other (France and Kebreab, 2008).

The traditional philosophy and reductionist method of the chemical and physical sciences are followed with mechanistic modelling (France and Dijkstra, 2006). A mechanistic model is always incomplete and must be open to modification and extension without limit. This kind of model can represent what is known about the system and its components and the model is ever expanding (Thornley and France, 2007). It is essential to apply models in the correct way, models that are applied in the wrong way can be misleading as the output of quantitative models are typically numbers, and it would be difficult to find the source of the errors (Kritzinger, 2011).

Model evaluation

When evaluating a model, all methods of critique are included (Thornley and France, 2007). Evaluation is not a process with only one objective (France and Kebreab, 2008). A model must go through the process of hypothesis evaluation, because a model can be perceived as a

mathematically expressed hypothesis (France and Dijkstra, 2006). As stated earlier, the mechanistic model is a model that is always incomplete and this model has the potential to execute certain commands very well while other commands are executed badly or not at all.

The objective of the modeller must be the starting place for evaluation of a model which includes the questioning of the modelling objectives, from there on, progress can be made to a wider evaluation process (Thornley and France, 2007; France and Kebreab, 2008). The level of predicted outcomes on the upper level and the levels of assumptions on the lower level must be evaluated (Thornley and France, 2007). At the assumptions level, the parameters should be determined by investigations, however this is not always possible and calibration of parameters is often needed (Thornley and France, 2007). The following properties of the model may be considered by the wider evaluation, namely the quantitative and qualitative accuracy and applicability of predictions, elegance, generality, plausibility and simplicity (Thornley and France, 2007). Some of these properties stand alone, while others are dependent on the relationship between the model and other matters. An example would be when the applicability is dependent on the application being considered (Thornley and France, 2007).

Animal growth

The simulation of growth can aid in predicting performance as well as the subsequent effects on production of the ostrich over a range of conditions with a high accuracy (Ferguson, 2006). In the ostrich industry, limiting factors can be identified: for example the quality and the quantity of meat can be predicted, the nutrient requirements can be predicted, the consequences of genetic selection can be predicted and more effective management and financial decisions can be made (Ferguson, 2006).

According to Emmans and Fisher (1986) and Ferguson (2006), a model is a theory that is evolving and this needs to play a greater role in animal nutrition. The theory has been applied to a number of modelling applications and is essentially driven by an accurate description of the animal in a state of being, health status, the environment in which the animal exists, and the type and quantity of feed given to the animal. The combination of these factors will aid in predicting growth and supply a framework for predictions (Ferguson, 2006). In this theory, the key assumptions are that predictions are for the average individual and more feed is offered than what is consumed. Maintenance of the heat balance, stocking density and health status may be growth constraints.

The current state and genetic potential of the animal will define the potential growth rate as the animal will always attempt to reach its potential growth rate (Ferguson, 2006). If the genotype is accurately described, the potential growth rate of the animal can be predicted. The potential growth rate however, will not be met if the nutritional and environmental conditions are inadequate (Ferguson, 2006). Accordingly, the following equation can be used to determine protein growth over time:

$$P_t = Pm \times e^{-e \ln(-\ln u_0)-(Bxt)} \quad \text{kg/day} \qquad (1)$$

With P_t = weight of body protein at time t (kg)

Pm = weight of mature body protein (kg)

e = 2.718, the base of natural logs

u_0 = degree of maturity at birth (Pt_0/Pm)

B = rate of maturing constant (day^{-1})

t = age (days)

The following equation is used to determine rate of potential protein deposition:

$$pPD = B \times P_t \times \ln(Pm/P_t) \quad \text{(g/day)} \qquad (2)$$

The maximum potential protein growth can be determined by the next equation:

$$pPDmax = B \times 1/e \times Pm \quad \text{(g/day)} \qquad (3)$$

Equations 1, 2 and 3 indicate that growth will depend on its current state and B as well as Pm. If the environment is cool enough for the animal to lose the excess heat produced, and if the animal can ingest subsequent levels of energy and first limiting amino acids, the potential protein deposition will be realised, otherwise the actual protein deposition will be lower than the potential deposition (Ferguson, 2006).

Growth curves and growth functions

When plotting a growth curve with live weight against age, animals with no feeding restrictions would have a sigmoidal growth curve, consisting of three different parts: the initial self-accelerating phase, the intermediate linear phase and a self-decelerating phase fading out as maturity is reached (Wilson, 1977; López, 2008).

The most correct model for poultry or ostrich growth will include all knowledge about the metabolism, which constituent of growth of the bird and all the phenomena observed

during growth must be reproduced. However to produce a model like this would take infinite time and resources and it would not be manageable (Wilson, 1977).

In most farm animals, the inflection point is reached just after puberty when the growth rate is at a maximum (Wilson, 1977). Weight gain per unit of time, the growth rate, varies with age (López, 2008) and this is fundamental to commercial success (Wilson, 1977). Initially, during the self-accelerating phase it will increase and reach a maximum at the intermediate phase, and finally in the last phase, the growth rate decreases until it reaches the asymptotic body weight at maturity (López, 2008). This growth curve is applicable under assumed optimal conditions and the curve will have this S-shape if all environmental effects stay optimal (López, 2008).

Different breeds will have different growth curves (Wilson, 1977). If the growth curves are smooth and they are close to each other with a similar sigmoidal shape, they can be represented by a single mathematical equation (Wilson, 1977). One difficulty in describing growth is separating short term deviations with the long term curve. According to López (2008), a growth function is normally an analytical function and can be written as an equation to connect body weight (W) to time (t), in the general form, where f denotes a functional relationship:

$$W = f(t) \tag{4}$$

By integrating some of these mathematical functions, certain equations have been derived, for example, changes in growth rate over time:

$$\frac{dW}{dt} = f'(t) \tag{5}$$

The use of growth functions is empirical and the form of the equation is chosen providing a fit, closer to the data observed. Ideally the underlying biological and physiological processes and constraints must be represented in a growth function (López, 2008). In an example of this kind of function, it can be expressed as follows: Rate is a function of state form where g denotes a function of W as a state variable:

$$\frac{dW}{dt} = g(W) \tag{6}$$

This kind of equation is preferred as it is biologically plausible and the parameters may be meaningful as a mechanistic description of growth (López, 2008). This is not the case in some equations where growth rate is purely an empirical function of time.

Growth rate cannot be represented by such a single differential equation, because growth is a complex process consisting of many biological processes. There are growth functions which are derived from such equations where growth rate is a function □ of both *W* and *t:*

$$\frac{dW}{dt} = \text{Œ}(W, t) \tag{7}$$

The scientific interpretability is decreased and the model is made more empirical because the differential equations are explicitly time dependant (López, 2008). According to Wilson (1977), if the growth of a strain of poultry is linear, if equal increments of weight gain and time are observed, the following equation could describe growth:

$$W = at + W_0 \tag{8}$$

Where W = live weight at time *t,* weight at hatch = W_0 and a = growth rate.

The Gompertz equation is a growth function that describes the sigmoidal growth curve well:

$$W = a.\exp\left(-\exp(-b(t - c^*))\right) \quad \text{kg} \tag{9}$$

Where W = live weight at time t. In this equation 'exp' means 'e to the power of'. The final weigh = a, b = weight rate for maturing parameter, time for weight = t and c^* = Max growth rate when $W = a/e$ where e = 2.718 (the base of natural logarithms). With the Gompertz growth curve, the assumption is made that the substrate is non-limiting and that the growth is proportional to dry weight (Thornley and France, 2007). The rate, b can be seen in different ways, when $t = c^*$ then $W = a/e$ and the growth rate is at a maximum given by:

$$(\mathrm{d}W/\mathrm{d}t)_{\max} = \mathrm{b}.\, a/e \quad \text{kg/day} \tag{10}$$

The value of b can be seen as given by $(\mathrm{d}W/\mathrm{d}t)_{\max}$ (e/a)/day (Emmans, 1989).

According to Henderson *et al.* (2006), there is another form of the Gompertz growth function: if it is assumed that growth rate of an animal decreases with size, the rate of change for any measure of size or weight, *l*, can be described by:

$$\frac{d \log l}{dt} = K(\log L_\infty - \log l) \tag{11}$$

Where K = growth rate, L_∞ is the asymptotic length where growth is equal to zero, this has the same form as Von Bertalanffy's equation, the only difference is that log replaces length. When this is integrated, the next equation arises:

$$l_t = L_\infty e^{e^{-k(t-I)}} \tag{12}$$

Age is represented by t and age at the inflection point is represented by I (Henderson *et al*., 2006).

Von Bertalanffy's equation was derived in 1938 from physiological studies and is used mostly in fisheries studies (Thornley and France, 2007). When assuming that growth rate of an animal decreases as size increases, the change in length can be described by the following:

$$\frac{dl}{dt} = K(L_\infty - l) \tag{13}$$

In this equation, t is time, l is length or any other measure of size, K is the growth rate and L_∞ is the asymptotic length where growth is equal to zero (Henderson *et al.,* 2006). If this is integrated, the following equation is produced:

$$l_t = L_\infty(1 - e^{-K(t-t_0)}) \tag{14}$$

The parameter t_0 is defined as the age at which the animal would have zero size. However the simplest form of this equation is:

$$L't = r_B(L_\infty - L(t)) \tag{15}$$

Where $L't$ indicates length over time, r_B is the growth rate, $L(t)$ indicates length at a certain time and again L_∞ is the asymptotic length where growth is equal to zero (Henderson *et al.,* 2006).

The point of inflection for this equation is given by:

$$\frac{dW}{dt} = \mu W^b - \lambda W \tag{16}$$

The Verhulst model is also known as the logistic model. It was first proposed by Pierre Verhulst and is the simplest of the S-shaped curves (Thornley and France, 2007). When assuming growth rate to decrease with size, growth rate can be described by:

$$\frac{dl}{dt} = l(k - \delta) \tag{17}$$

In this equation t represents time, l represents size, K represents the growth rate, and δ represents the rate at which growth rate declines with size (Henderson *et al.,* 2006). After integrating, the following equation arises:

$$l_t = \frac{L_\infty}{1 + e^{-K(t-I)}} \tag{18}$$

In this equation, I is the age at the inflection point and L_∞ is the upper asymptote. In a logistic equation with three parameters, there is a lower asymptote that is equal to zero (Henderson *et al.,* 2006). The inflection point on the y-axis is at the point represented by the following equation:

$$I_y = L_\infty/2 \tag{19}$$

This formula declares that the inflection point is always at 50% of L_∞. However, this is not correct for all growth processes (Henderson *et al.,* 2006). This curve is symmetrical about the inflection point (Henderson *et al.,* 2006; Thornley and France, 2007).

The general logistic curve is also referred to as the Richard's curve. It is used to fit a range of S-shaped growth models (Thornley and France, 2007). An additional parameter was added to the logistic equation to deal with asymmetrical growth curves:

$$l_t = L_\infty[1 + (\delta - 1)e^{-k(t-\gamma)}]^{1/(1-\delta)} \tag{20}$$

In this equation, l = weight, $\delta \neq 1$ and t = time, and the four parameters: $L\infty$ = upper asymptote, k = growth rate, □ = inflection point on x-axis and δ is the parameter that determines the inflection point on the y-axis (Henderson *et al.,* 2006).

The next equation determines the y-ordinate of the inflection point:

$$L_\infty/\delta/(1 - \delta) \tag{21}$$

The normalised growth rate on average is determined by the next equation:

$$k/2(\delta + 1)$$

(22)

The curve of Richard requires one more parameter to generate asymmetry; this can be avoided by using the Gompertz model as it can generate an asymmetrical curve with only three parameters (Henderson *et al.,* 2006).

The following equation describes the Weibull growth model:

$$l_t = L_\infty - (L_\infty - \beta)e^{(-(kt)^\delta}$$

(23)

Where time = t and l = size, and the four parameters: β = lower asymptote, $L\infty$ = upper asymptote, k = growth rate, and δ is the parameter controlling the x-ordinate for the inflection point, this inflection point on the x-axis is found at:

$$(\frac{1}{k})(\frac{\delta - 1}{\delta})^{1/\delta}$$

(24)

When δ = 1, the Weibull turns into an exponential growth curve (Henderson *et al.,* 2006).

The following equation describes the exponential growth model:

$$l_t = L_\infty - (L_\infty - \beta)e^{(-(kt))}$$

(25)

In this equation, l = size, t = time and the three parameters: β = lower asymptote, L_∞= upper asymptote, k = growth rate (Henderson *et al.,* 2006; Thornley and France, 2007).

2.8 PREDICTING NUTRIENT REQUIREMENTS AND GROWTH

As stated earlier, a model is a theory that is evolving and this needs to play a greater role in animal nutrition (Emmans and Fisher, 1986; Ferguson, 2006). In chickens and pigs, nutrient requirements cannot be defined very accurately due to three reasons (Morris, 2006). Firstly, the response of animals to increasing inputs of a limiting factor is curvilinear thus an optimum input can be determined. This should not be labelled as the requirement. The second reason is that the response curve will shift with changes in the potential outputs in the group of animals. Thirdly, the optimum on the curve will shift when cost and value of input and output are taken into consideration. Thus, considering the inputs until prices have been defined, the optimum dose cannot be calculated (Morris, 2006).

The largest expense in an ostrich production unit is feeding costs, so if one can lower the feed cost, the production unit can be made more profitable (Kritzinger, 2011). Thus it is

important for the nutrient requirements of the animal to be known. Feed intake, growth and genetics are factors that need to be taken into account before predictions for nutrient requirements of ostriches can be made (Kritzinger, 2011). Allometric equations are used for growth predictions. Before these predictions can be done, the growth potential of different parts of the body and feather proteins need to be characterised (Gous and Brand, 2008). The body size and chemical composition changes during growth, and thus the nutrient requirements change too, therefore when using mathematical models these also need to be taken into account (Kritzinger, 2011).

Little is known about the exact nutrient requirements of ostriches when compared to other domesticated monogastric animals such as poultry and pigs (Brand and Gous, 2006a; Olivier, 2010). In Europe, the recommended protein levels for ostriches vary between 14.6 – 22% for the starter diet, 15 – 21.8% for the grower diet, 12 – 17.8% for maintenance diets and 16 – 22% for breeder diets. The energy value of feed for commercial diets of the ostrich varies between 7.9 and 10.6 MJ ME/kg feed. These figures emphasise the lack of knowledge in ostrich nutrition (Brand and Gous, 2006b). Research by Brand *et al*. (2006c) led to the derivation of equations for predicting TME values for ostriches which can be calculated from known TME values for poultry and pigs.

TME ostrich (MJ/kg) = 9.936 + 0.326 × TME poultry ($P \leq 0.01$; $R^2 = 79.6$; SE xy = 0.54) (Brand *et al*., 2006c)

(26)

TME ostrich (MJ/kg) = 6.743 + 0.638 × ME pig ($P \leq 0.01$; $R^2 = 67.7\%$; SE xy = 0.67) (Brand *et al*., 2006c)

(27)

As little is known on the specific nutritional requirements of ostriches, particularly as pertaining to the growth and development of the muscle (meat), skin and feathers, different levels of protein and energy will be fed to ostriches in this investigation so as to help develop predictive models which will aid in a more scientific approach to the feeding of growing birds. At the same time, the impact of various management strategies (such as feather clipping) will also be evaluated.

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Chapter 3

The growth response of ostrich (*Struthio camelus* var. *domesticus*) chicks fed diets with three different dietary protein and amino acid levels

Abstract

1. The ostrich industry has certain challenges to overcome in order to farm profitably. Feeding costs are the largest expense in an ostrich production system and protein is one of the more expensive components of the diet. This study evaluated the growth response of ostrich chicks on diets containing different levels of protein (amino acids). The diets were formulated to contain three levels of protein (one diet with 20% less protein than the conventional level, L; one diet with the conventional level of protein, M; and one diet with 20% more protein than the conventional level, H) for each of the phase diets. The phase diets that were fed were pre-starter, starter, grower and finisher.

2. This study includes the analysis of ostrich body weight (BW) by modelling growth with linear polynomial and nonlinear functions for all the data not separated for treatments. In total, 3378 BW recordings of 90 animals were collected weekly from hatch (d0) to 281 days of age.

3. Seven nonlinear growth models and three linear polynomial models were fitted to the data. The growth functions were compared by using Akaike's information criterion (AIC). For the nonlinear models, the Bridges and Janoschek models had the lowest AIC values for the H treatment, while the Richards curve had the lowest value for M and the Von Bertalanffy for the L treatment.

4. For the linear polynomial models, the linear polynomial of the third degree had the lowest AIC value for all three treatments thus making it the most suitable model for the data; therefore the predictions of this model were used to interpret the growth data. Significant differences were found between treatments for growth data.

5. The results from this study can aid in describing the growth of ostriches subjected to assumed optimum feeding conditions. This information can also be used in research when modelling the nutrient requirements of growing birds.

3.1. INTRODUCTION

Ostrich farming is an intensive industry and feed costs comprise 70 – 80% of the overall expenses in a typical intensive ostrich production system (Brand *et al.*, 2006). As the nutrient requirements for poultry and ratites changes constantly, this requires the diet to be altered in

accordance with the stage of production and growth of the bird (Swart, 1988). The environment in which the animal is reared should also not be a limiting factor in achieving maximum growth (Du Preez *et al*., 1992; Ramos *et al.*, 2013). In ostriches a range of diets are used, namely pre-starter, starter, grower, finisher and breeder rations (Brand *et al*., 2003a; Brand and Gous, 2006; Brand and Olivier, 2011). The diets are changed in accordance with the nutritional needs of the ostrich to obtain optimal growth and to utilise the feed to an economical maximum (Polat *et al*., 2003).

One of the many advantages of using prediction models is that they are dynamic and can constantly be changed for more accurate predictions. The use of a large enough dataset results in more accurate predictions. Thus the more data entered into the model, the more accurate the predictions will be. The data obtained in this study for the three levels of protein fed was used to fit three different growth curves. This is of value to producers as protein is a very expensive raw material in feed. By modelling data, the optimum protein requirements of the ostrich can be determined. Thus nutrients, in this case, protein will be neither over- nor undersupplied. Results from this study may aid in formulating least-cost diets for ostriches.

From early times, scientists have attempted to describe and predict growth. When evaluating the amount of growth functions and the amount of work done on models, it becomes clear that growth is a very important characteristic of an animal (Ramos *et al.*, 2013). Linear polynomial models and different nonlinear models were fitted to the data. The nonlinear functions were chosen because they have desirable properties, for example they can describe continuous growth, inflection points, asymptotes, sigmoid forms and parameters with biological interpretations (Ramos *et al.*, 2013). Over the years, there has been an interest in determining what the effect of different feeding intensities or nutritional standards would be (Cilliers *et al*., 1995) and data from this study may aid in describing such effects. Growth data from the study was used to apply different nonlinear functions and linear polynomial models to describe the growth of ostriches and to compare the models to find a best fit model for growing ostriches.

This study evaluates the growth response of ostrich chicks that were fed diets containing three different levels of protein and associated amino acids levels.

3.2. MATERIALS AND METHODS

Ethical clearance number: R11/41. The study was conducted at the Kromme Rhee experimental farm of the Department of Agriculture near Stellenbosch in South Africa ($18^{o}50'$E, $33^{o}51'$S and altitude 177m).

Experimental protocols

In this investigation, 90 birds, divided into 18 groups with 5 birds per group, were used. Six groups of birds per treatment were used as replicates. Each group per treatment consumed either a high protein (H), a medium protein (M) or a low protein (L) diet. The different protein values of the diets are depicted by Table 3.1. Complete growth data were available for the 90 birds. During the slaughter ostriches' lifetime, they are normally fed four diets (pre-starter: 0 – 8 weeks of age, starter: 8 – 18 weeks of age, grower: 18 – 26 weeks of age and finisher: 26 – 42 weeks of age). A prediction model developed by Brand and Gous, (2006) was used to predict the protein and amino acid composition for the medium protein ration for these stages. The low protein diets were formulated to have 20% less protein and amino acids than values predicted by the model while the high protein diets were formulated to have 20% more protein and amino acids than the values predicted by the model. All the birds were weighed once a week, on the same day every week for 41 weeks. For each treatment, the water and feed supply was *ad libitum.*

A range of applicable nonlinear models were applied to the ostrich growth data namely Gompertz, Brody, Von Bertalanffy, Logistic, Bridges and Janoschek. Linear polynomial models with third to the fifth order were also fitted to the growth data of the ostriches (Table 3.2).

Table 3.1. *Protein andamino acid composition of diets used in the growth study (high - H, medium-M and low - L) for each phase (Brand, 2012)*

Amino Acid (g/kg)	Pre-starter			Starter			Grower			Finisher		
	0 – 2.5 months			2.5 – 4.5 months			4.5 – 6 months			6 – 9 months		
Treatment	L	M	H	L	M	H	L	M	H	L	M	H
Crude Protein	168.00	202.80	234.80	131.60	159.80	180.10	132.00	159.90	175.00	119.80	127.90	146.10
Lysine	7.90	10.90	14.90	7.00	7.90	11.00	6.50	6.60	9.40	5.20	5.90	8.20
Methionine	1.00	1.30	1.70	0.90	0.60	0.70	0.60	0.40	0.50	0.50	0.50	1.00
Arginine	6.50	8.60	11.40	5.40	5.70	7.80	4.50	4.90	6.50	5.10	5.60	6.20
Threonine	5.00	6.40	8.60	4.50	4.90	6.30	4.30	4.40	5.60	4.00	4.10	4.80
Aspartate	11.80	16.00	21.00	10.90	13.50	17.40	12.10	12.40	16.30	9.8	10.30	12.90
Glutamate	28.30	34.60	44.50	27.00	24.30	31.90	18.70	19.70	24.80	20.10	21.30	23.70
Serine	6.40	8.20	11.60	6.00	6.50	8.40	5.70	5.80	7.50	5.10	5.40	6.80
Histidine	2.90	4.10	5.40	2.90	3.10	4.00	2.50	2.70	3.30	2.40	2.70	3.00
Glycine	5.80	7.50	10.60	4.30	4.50	5.90	4.10	4.00	5.40	4.50	4.90	5.40
Alanine	7.10	8.60	11.40	6.70	6.30	7.80	5.80	5.60	6.60	5.10	5.30	6.00
Tyrosine	5.20	6.60	8.50	5.20	5.00	6.50	4.60	4.60	5.60	3.90	4.10	4.80
Valine	7.20	9.00	11.50	6.70	7.00	8.80	6.30	6.30	7.70	6.00	6.10	7.30
Phenylalanine	6.50	8.10	10.60	6.50	6.50	8.40	5.70	5.70	7.10	4.80	5.00	6.00
Isoleucine	5.50	7.00	9.40	5.00	5.30	6.90	4.50	4.70	5.90	3.80	4.00	5.00
Leucine	12.00	14.30	18.30	12.30	11.20	13.90	9.90	9.80	11.40	7.60	7.80	9.20

Table 3.2. *Growth functions considered for the modelling of ostrich growth data*

Model	Equation	No. of parameters	Reference
Gompertz	$\boldsymbol{W = a.\exp\left(-\exp(-b(t - c^{*})\right))}$	3	Thornley & France (2007)
Brody	$W = a \times (1 - b \times e^{(-c \times t)})$	3	Fitzhugh (1967)
Von Bertalanffy	$W = [(\frac{a}{b} - \frac{a}{b - W_0^{\frac{1}{3}}}) \times e^{\frac{1}{3} \times b \times t}]^3$	3	Thornley & France (2007)
Logistic	$W = \frac{a}{(1 + b \times e^{(-c \times t)})}$	3	Fekedulegn *et al*. (1999)
Bridges	$W = W_0 + a \times (1 - e^{(-m \times t^p)})$	4	Wellock *et al*. (2004)
Janoschek	$W = a - (a - W_0) \times e^{(-c \times t^m)}$	4	Wellock *et al*. (2004)
Richards	$W = \frac{a}{(1 + b \times e^{(-c \times t)})^{\frac{1}{m}}}$	3	Fekedulegn *et al*. (1999)
Linear polynomials 3 and 4 degree	$W = d_0 + \sum_{i=1}^{r} d_i \times t^i$	3 – 5	Hadeler (1974)

W = BW; W_0 = initial BW in kg; a = mature BW in kg; t = age in days; b, c and m = parameter specific for the function; d_0 = intercept; d_i = regression coefficients, r = degree of polynomial.

Similar to the study by Köhn *et al*. (2007), outliers were detected and removed, using influence diagnostics suggested by Belsley *et al*. (1980). By using this method, the influence of the observations on the parameter estimates was measured. If the observations have a significant influence on the parameter estimates, they are referred to as influential observations. The method of Belsley *et al.* (1980) is incorporated into the statistical REG procedure (SAS Inst. Inc., Cary, NC) by using the INFLUENCE option in the MODEL statement. The Studentised residual was used for analysing the influence of each weight record and was calculated as follows:

$$\text{RSTUDENT} = \frac{r_i}{s_i\sqrt{(1 - h_i)}}$$

Where $r_i = y_i - \hat{y}_i$; s_i^2 is the error variance estimated without the i^{th} observation; and h_i is the hat matrix, which is the i^{th} diagonal of the projection matrix for the predictor space. Belsley *et al*. (1980) suggest paying special attention to all observations with RSTUDENT larger than an absolute value of 2. All records lying outside the 99% confidence interval [-1.96; 1.96] were discarded. Thus a total amount of 222 body weight records were discarded. The total

amount of body weight records that was used to fit the data was 3 378 for the group of 90 birds that were used for the growth analysis.

3.3. RESULTS

Nonlinear models: The results for the growth prediction when comparing the nonlinear models using AIC (Akaike's information criterion) (Köhn *et al*., 2007) values are depicted in Table 3.3. The lower the AIC value, the better the model fits the data. The high protein treatment had the lowest AIC value for both the Bridges and Janoschek models which had equal AIC values. These two models are flexible concerning their inflection points. These two models are usually only used to describe post-natal growth of individuals (Köhn *et al*., 2007). The medium protein treatment had the lowest AIC value for the Richards model whilst the low protein treatment had the lowest AIC value for the Von Bertalanffy model. The Richards function has a flexible inflection point, making it suitable for growth modelling. The Von Bertalanffy model has an inflection point that lies at 30% of the mature body weight (Köhn *et al*., 2007). See Table 3.4 for the parameters of the different nonlinear models. The predicted values for each of the models are depicted in Figure 3.1. As each of the different treatments had a different model which predicted the ostrich growth more accurately, linear polynomial models were also fitted in an attempt to find a single best fit model.

Table 3.3. *Akaike's information criterion (AIC)*[1] *for nonlinear models for the different diets (high - H, medium – M and low - L)*

Model	Treatment		
Nonlinear	L	M	H
Gompertz	8384.7	8197.9	7290.9
Richards	8370.4	**8177.2**	7225.7
Logistic	8461.6	8270.3	7479.9
Von Bertalanffy	**8354.0**	8181.2	7240.6
Brody	8454.1	8233.3	7361.2
Bridges	8361.7	8183.8	**7222.6**
Janoschek	8358.8	8182.9	**7222.6**

[1]The lowest values for AIC are printed in boldface in each column.

Table 3.4. *Parameter values for the different nonlinear models*

Parameter*			
	Gompertz		
	L	M	H
a	98.295446	104.669879	100.958148
b	0.019831	0.012643	0.014047
c	125.563671	121.288372	104.529288
	Richards		
B_0	135.900000	124.700000	123.100000
B_1	-1.065300	-1.092100	-1.096600
B_2	0.005740	0.006780	0.007090
B_3	-0.568600	-0.586000	-0.638300
	Logistic		
a	91.660000	94.151000	92.914000
b	21.270000	20.025700	17.918000
W_0	0.020500	0.021300	0.023000
	Von Bertalanffy		
a	0.118200	0.130300	0.152800
b	0.024100	0.026700	0.032200
W_0	1.842300	1.762200	1.561100
	Brody		
a	710.900000	309.500000	174.100000
b	1.012900	1.034800	1.074500
c	0.000538	0.001440	0.003160
	Bridges		
a	-358.900000	-285.500000	-188.300000
W_0	359.700000	286.200000	189.300000
m	42.165600	48.730000	78.707200
p	-0.604700	-0.669400	-0.839000
	Janoschek		
a	0.841000	0.674400	1.068200
W_0	359.700000	286.200000	189.300000
m	42.165000	48.729300	78.707200
p	-0.604700	-0.669400	0.839000

*a = mature BW, kg; W_0 = initial bodyweight, kg; b = biological constant; c = maturing index; m = shape parameter determining the position of the inflection of the curve point

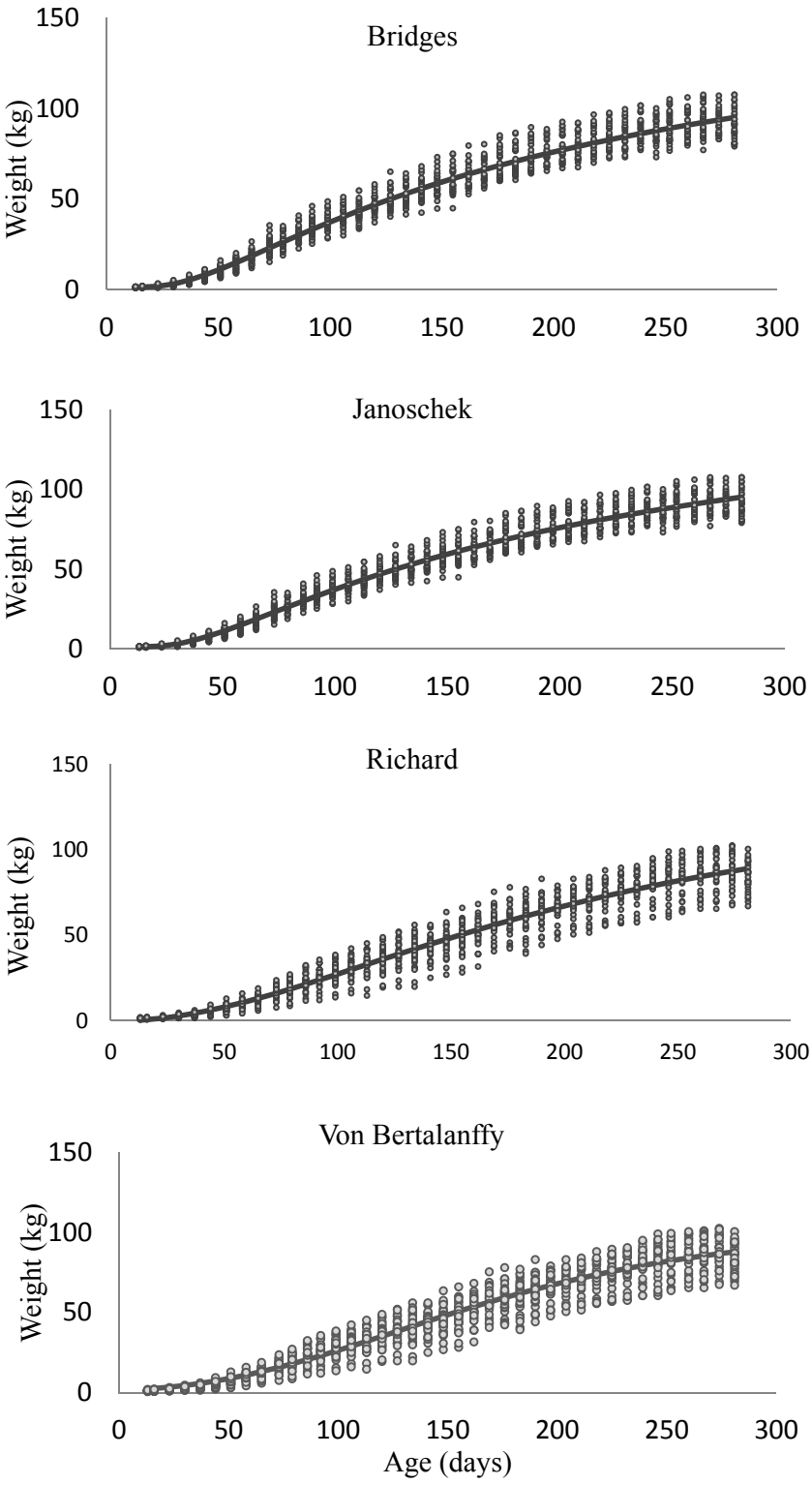

Figure 3.1. *Growth curves for the ostriches as predicted by the Bridges and Janoschek (High protein), Richards (Medium protein) and Von Bertalanffy (Low protein) functions.*

Linear polynomial models: The linear polynomial of the third order had the best fit for the growth data for the high, medium and low treatments (Table 3.5). The least square means (LSMeans) of the linear polynomial of the third order is depicted in Figure 3.2.

Table 3.5. *Values of Akaike's information criterion (AIC)[1] for linear polynomial models for the different diets (high - H, medium - M and low - L)*

Model	Treatment		
Linear linear polynomial	L	M	H
Linear polynomial, third order	**8394.8**	**8223.2**	**7309.5**
Linear polynomial, fourth order	8430.4	8258.2	7329.8
Linear polynomial, fifth order	8460.6	8288.1	7358.8

[1]The lowest values for AIC are printed in boldface in each column.

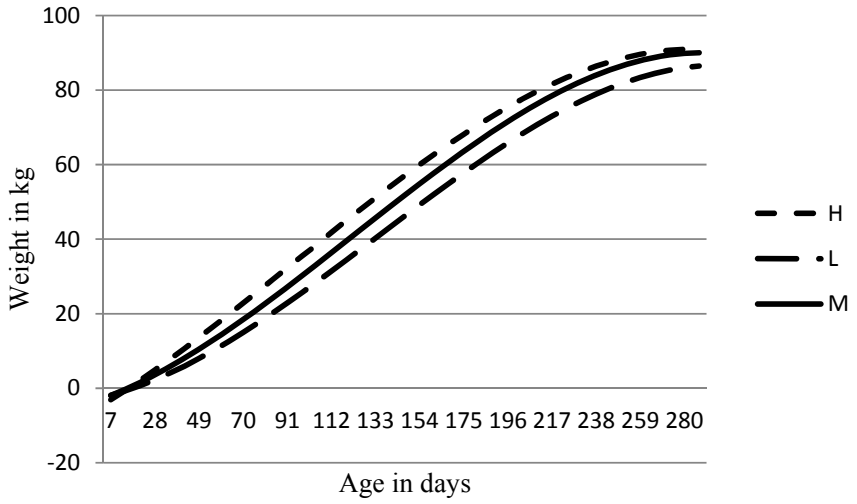

Figure 3.2. *LS Means for the linear polynomial of the third order for the different dietary treatments fed to ostriches, day 1 = day of hatch. Equation for H: $y = -0.0014x^3 + 0.0577x^2 + 2.4047x - 5.5398$; equation for M: $y = -0.0019x^3 + 0.0982x^2 + 1.3937x - 3.4303$; equation for L: $y = -0.0019x^3 + 0.1087x^2 + 0.8876x - 2.87$.*

Fixed effects had an influence up to the linear polynomial of the third order (Table 3.6)

Table 3.6. *Type 1 test for fixed effects with linear polynomial models*

Effect	Numerator degrees of freedom	Denominator degrees of freedom	F-Statistic	Pr>F
Treatment	2	13.6	6.12	0.0127
Age	1	3349	79803	<0.0001
Age^2	1	3349	552.29	<0.0001
Age^3	1	3349	453.88	<0.0001
Age × Treatment	2	3349	11.6	<0.0001
Age^2 × Treatment	2	3349	64.71	<0.0001
Age^3 × Treatment	2	3349	3.22	0.04

The model that fitted the data best was the linear polynomial of the third order; the growth data were interpreted using the LSMeans values for growth of the ostrich chicks.

High versus low: Concerning the LS Means, from day one to day 42 there were no significant differences between the high and low treatments for weight gain. From day 49 to day 273 there were significant differences. From day 280 to day 287 there were again no significant differences between the high and low treatments (Table 3.7a and Table 3.7b).

High versus medium: For the LSMeans, from day one to day 77 there were no significant differences between the high and medium treatments for weight gain. From day 84 to day 161 there were significant differences. There were again no significant differences between the high and medium treatment between day 168 and day 287 (Table 3.7a and Table 3.7b).

Medium versus low: For LSMeans, from day one to day 98 there were no significant differences between the medium and low treatments for weight gain. From day 105 to day 252 there were significant differences. While there were no significant differences from day 259 to day 287 between the medium and low treatment (Table 3.7a and Table 3.7b).

Table 3.8 shows the different coefficients of parameters for the linear polynomial to the third order for the three treatments. The d_0 (intercept) of the curves for the H and L treatments differed from each other ($P < 0.05$) but not from the M treatment ($P > 0.05$). The d_1 value of the curves for the H and L treatments differed from each other ($P < 0.05$) but not

from the M treatment ($P > 0.05$). The d_2 and d_3 values for the curves were not influenced by the treatment ($P > 0.05$).

Table 3.7a. *Least Squares Means (weight in kg) predicted by the linear polynomial of the third order for the three treatments high protein (H), low protein (L) and medium protein (M)from age 7 to age154*

Age in days	L	M	H
7	-1.87[a]	-1.94[a]	-3.09[a]
14	-0.67[a]	-0.26[a]	-0.52[a]
21	0.72[a]	1.58[a]	2.15[a]
28	2.30[a]	3.60[a]	4.91[a]
35	4.05[a]	5.76[a]	7.75[a]
42	5.93[a]	8.07[a]	10.66[a]
49	8.03[a]	10.50[ab]	13.64[b]
56	10.23[a]	13.05[ab]	16.67[b]
63	12.55[a]	15.71[ab]	19.74[b]
70	15.00[a]	18.46[ab]	22.85[b]
77	17.54[a]	21.30[ab]	26.00[b]
84	20.18[a]	24.21[a]	29.16[b]
91	22.90[a]	27.18[a]	32.33[b]
98	25.70[a]	30.20[a]	35.51[b]
105	28.55[a]	33.27[b]	38.48[c]
112	31.45[a]	36.36[b]	41.84[c]
119	34.38[a]	39.47[b]	44.97[c]
126	37.35[a]	42.59[b]	48.07[c]
133	40.32[a]	45.69[b]	51.13[c]
140	43.30[a]	48.79[b]	54.15[c]
147	46.27[a]	51.85[b]	57.10[c]
154	49.22[a]	54.88[b]	60.00[c]

[a - c] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 3.7b. *Least Squares Means (weight in kg) predicted by the linear polynomial of the third order for the three treatments high protein (H), low protein (L) and medium protein (M) from age 161 to age 287*

Age in days	L	M	H
161	52.14[a]	57.85[b]	62.81[c]
168	55.01[a]	60.77[a]	65.55[a]
175	57.84[a]	63.61[b]	68.19[a]
182	60.59[a]	66.36[b]	70.73[a]
189	63.28[a]	69.02[b]	73.16[a]
196	65.87[a]	71.58[b]	75.48[a]
203	68.36[a]	74.02[b]	77.67[a]
210	70.75[a]	76.33[b]	79.72[a]
217	73.01[a]	78.50[b]	81.63[a]
224	75.14[a]	80.51[b]	83.39[a]
231	77.13[a]	82.37[b]	84.99[a]
238	78.96[a]	84.05[b]	86.42[a]
245	80.62[a]	85.55[b]	87.67[a]
252	82.11[a]	86.85[b]	88.74[a]
259	83.41[a]	87.94[ab]	89.61[b]
266	84.50[a]	88.81[ab]	90.27[b]
273	85.39[a]	89.46[ab]	90.73[b]
280	86.05[a]	89.86[ab]	90.96[b]
287	86.48[a]	90.01[ab]	90.97[b]

[a - c] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 3.8. *Regression coefficients ± standard error of different model parameters for the linear polynomial of the third order for the three treatments high protein (H), low protein (L) and medium protein (M)*

Coefficient of parameter	L	M	H
d_0	-1.7791[a] ± 0.8006	-2.8970[ab] ± 0.8006	-5.559[b] ± 0.8770
d_1	0.8002[a] ± 0.3113	1.3099[ab] ± 0.3113	2.4069[b] ± 0.3410
d_2	0.1067 ± 0.0175	0.0987 ± 0.0175	0.0579 ± 0.0192
d_3	-0.0018 ± 0.0003	-0.0018 ± 0.0003	-0.0014 ± 0.0003

[a - c] Rows means with different superscripts differ significantly ($P \leq 0.05$).

3.4. DISCUSSION

Production efficiency can be optimised by modelling data and determining the optimum level of nutrients in the feeds (Tompić *et al*., 2011; Kritzinger, 2011). This will ensure that nutrients in the feed are not over- or undersupplied. This may have an economic advantage because with the optimum concentration of nutrients in a feed, the optimum growth will be acquired. A result of the popularity of modelling is the large amount of growth models that have been developed (Wilson, 1977; Emmans, 1989; Ferguson, 2006; France and Dijkstra, 2006; Henderson *et al*., 2006; López, 2008; France and Kebreab, 2008). Whilst modelling ostrich growth has been researched before (Ramos *et al.*, 2013), this study focussed on a broad scope of models. Another aim was to model data of different treatments to get a better understanding of what effect varying nutrients, in this case, protein levels in diets would have on growth.

Although different nonlinear models fitted the data of the different treatments better, a single model was desired, thus it was found that a linear polynomial model to the third order had the best overall fit. Similar results were found by Tompić *et al*. (2011) in a study on chickens although Ramos *et al.* (2013) found that the logistic model had the best fit to ostrich data from their trial. In previous studies concerning growth modelling in ostriches, the Gompertz growth curve was used (Du Preez *et al*., 1992; Cilliers *et al*., 1995). One of the advantages non-parametric approaches have is that as the data become more complex, the model changes. Thus the model can be modified to accommodate the dataset.

Evaluating the third degree linear polynomial, it was evident that there were significant differences during the growth phases and towards the end of the trial and the curves converged to a mutual point where the treatments did not have an effect on growth after 280 days (Table 3.7a and Table 3.7b). Therefore it may be advantageous to feed birds at the L treatment until 49 days and then the M treatment until 77 days. From day 77 onwards the H level may be fed until 168 days of age and then the M level until 259. The low level may then be fed from this age onwards until day 287 (which is typically the age/weight when birds are slaughtered) (Table 3.9).

Table 3.9. *Recommendations for the diets that need to be fed from the results in this study*

CP,%	Protein level, L, M, H	Up to age, months
16.8 (17)	L	1.8
20.2 (20)	M	2.6
18 (18)	H	5.6
12.7-15.9 (13-16)	M	8.6
11.98 (12)	L	9.6

All the models that were fitted showed that the growth was relatively linear from hatch until approximately 250 days of age (Figure 3.1 and Figure 3.2). For linear polynomial models the time at which the inflection point occurs is determined by the following equation: $t_i = -B_2 / 3(B_3)$ (Tompić *et al*., 2011). According to this equation the inflection point for the L treatment was at 138 days of age, for the M treatment 128 days of age and 96.5 days of age for the H treatment. This is the point at which growth is at a maximum. From 189 days of age it is evident that the average daily gain (ADG) start to decrease and gradually the curve flattens as the bird matures. The curves of the three treatments started to converge to a mutual point from round about 210 days of age. From that age, the curves gradually approached a mutual point thus at this age the treatment had less of an effect than on an earlier age.

By using the best fitting model, in this instance the linear polynomial to the third order, growth of ostriches can be modelled, thus providing a useful tool to determine needs in terms of feed and space. Models may also be an important tool when it comes to formulations of least-cost diets, which will have an economic advantage for ostrich producers.

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Chapter 4

The effect of dietary bulk density on the feed intake of slaughter ostriches (*Struthio camelus* var. *domesticus*)

Abstract

1. Intake in most animal species is constrained by feeds high in fibre or low in bulk density. Currently, the extent to which ostrich feed intake is restricted due to the bulk density of the feed remains unknown. However, it has been established that ostriches have the ability to digest fibrous plant materials and convert these to volatile fatty acids as a result of microbial fermentation in the hindgut.

2. When formulating least-cost diets it is important to determine the bulk capacity and fibre levels of the feed to avoid formulating a feed that might be too bulky thereby constraining intake and reducing growth rate. In this study, a range of diets was formulated for the five growth stages of ostriches (pre-starter, starter, grower, finisher and maintenance) according to their nutrient requirements.

3. The diets were diluted with wheat straw. Three dilution levels (0%, 10% and 20%) were used for the pre-starter and starter phases, five dilution levels (0%, 15%, 30%, 45% and 60%) were used for the grower and the finisher phases, and five levels (0%, 20%, 40%, 60% and 80%) were used for the maintenance phase. Weekly intake data were collected throughout each phase.

4. Feed bulk restricted intake by 21% and 52% at the 10% and 20% dilution level, respectively, in the pre-starter phase, whereas intake was not restricted during the starter phase. Intake was constrained by 39% and 42% at the 45% and 60% dilution levels in the

grower phase, respectively, and by 17% and 39% at the 45% and 60% dilution levels in the finisher phase, respectively. Feed bulk restricted intake by 60% and 69% for the 60% and 80% dilution levels, respectively, in the maintenance phase.

5. Defining the bulk density that will constrain feed intake, as established in this study, will aid in least-cost feed formulations, feed intake modelling and growth predictions.

4.1. INTRODUCTION

Ostriches are single-stomached animals with very long digestive tracts which have developed the ability to digest fibre. The retention of plant fibres in the elongated hindgut (in particular the caeca) allows for its degradation by gut microflora (Glatz *et al.,* 2003). The ability of ostriches to utilise energy from fibrous food materials can be regarded as a positive characteristic in terms of reducing the cost of feeding since some of the fibre may be used as a substitute for a portion of the concentrate in the ostrich diet (Strydom, 2010). The capacity of ostriches to digest bulky, fibrous feeds increases as the bird matures (Swart, 1988) due to the increase in the overall size of the colon, as well as its increased size in relation to the rest of the digestive tract (Bezuidenhout, 1986). Fibrous ingredients are therefore commonly used in ostrich feed, raising concerns regarding the upper limit that should be placed on the amount of such ingredients to be included in the feed, whether these limits will be similar for all fibrous ingredients, and what the consequences would be on voluntary food intake.

The theory of Emmans (1981), upon which the prediction of voluntary feed intake in animals may be based, assumes that an animal will attempt to grow to its genetic potential, and thus eat accordingly to reach such potential within the constraints of gut capacity, environmental conditions, social stressors and general health (Emmans, 1989; Ferguson, 2006; Gous and Brand, 2008). The prediction of the amount of a given feed needed by a given bird to achieve its potential (the desired food intake, DFI) is relatively straightforward, but this is not the case when considering those factors associated with the genotype, the feed and the environment, which may constrain food intake below the desired food intake (Emmans and Fisher, 1986; Emmans, 1989; 1995). Two of the more important constraints that have been identified are the amount of heat the animal can lose to its immediate environment (Ferguson, 2006), and the gut capacity when dealing with low density feeds (Kyriazakis and Emmans, 1995; Tsaras *et al*., 1998; Whittemore *et al*., 2003; Ferguson, 2006). The indigestible components of the diet and the size of the animal are factors that are known to limit the volume of feed ingested (Emmans, 1986; Ferguson, 2006), and the

measure of the bulkiness of a feed that most accurately correlates with gut capacity has been reported to be its water holding capacity (WHC) (Tsaras *et al*., 1998).

It can thus be anticipated that food intake will increase with the increase in the concentration of fibre that is included in the feed. However, it is also expected that gut capacity would limit the excessive inclusion of fibre in such feeds. Predicting the consequence of fibre inclusion on food intake is therefore critical if feeds for growing ostriches are to be optimised. Low bulk density could also interfere with rate of passage in the digestion tract, resulting in more nutrients reaching the hind gut. These nutrients may then be converted by means of microbial fermentation to volatile fatty acids as a predecessor of glucose which is energetically a less economic route to energy than enzymatic digestion in the fore gut (Swart, 1988).

The aim of this study was to produce data that could be used to predict the feed intake of ostriches given feeds of increasing fibre content at different stages of growth. The outcome of such work is likely to provide significant benefits when formulating feeds for growing ostriches in the future. In addition, any savings that can be achieved in feed costs through the inclusion of higher levels of inexpensive fibre sources will contribute substantially to the overall profitability of the ostrich industry.

4.2. MATERIALS AND METHODS

Ethical clearance number: R11/41. The trial was conducted at Kromme Rhee experimental farm, Stellenbosch. Separate studies using new birds from the standard commercial flock were conducted for each phase of the growth cycle (pre-starter 0 – 8 weeks of age, starter 8 – 18 weeks of age, grower 18 – 26 weeks of age, finisher 26 – 42 weeks of age and maintenance 18 – 20 months of age). During each phase a basal feed was diluted serially with increasing levels of milled wheat straw to constitute the treatments. For the pre-starter and starter phases, 120 birds were placed in six pens (25 m × 25 m and 20 birds per pen) and three dilution levels (0%, 10% and 20%) were used, with two replications of each treatment. For the grower and the finisher phases, 150 birds were placed in ten pens (15 birds per pen), there being five treatments (0%, 15%, 30%, 45% and 60%) and two replications of each. For the maintenance phase, 100 birds were allocated to ten pens (10 birds per pen) and each of five dilutions (0%, 20%, 40%, 60% and 80%) was fed to the birds in two pens. The wheat straw was finely milled (8 mm sieve), mixed with the basal feed and pelleted using a commercial pellet binder. Feed was offered *ad libitum* and water was freely available.

Birds were weighed at two-weekly intervals throughout the pre-starter and starter phases, at four-week intervals throughout the grower and finisher phases and after eight weeks for the maintenance phase. Feed intake was determined for each pen by weighing the feed that remained in the feeding troughs on the days when birds were weighed. Randomly selected samples of each phase-specific feed were analysed using the methods of the Association of Official Analytical Chemists (AOAC, 2002) for crude protein (method 976.05), metabolisable energy (ME), fat (method 920.39), moisture (method 934.01), crude fibre (method 962.09), as well as those for acid digestible fibre (ADF) (Goering and van Soest, 1970), neutral detergent fibre (NDF) (Robertson and van Soest, 1981), lignin (Goering and van Soest, 1970), *in vitro* organic matter digestibility (IVOMD) (Tilley and Terry, 1963) and the water holding capacity of the feed (WHC) (Robertson and Eastwood, 1981) (Table 4.1).

The data were analysed statistically in a manner similar to that used in the study on broiler breeders by Sharifi *et al.* (2010). Feed intake data for the pre-starter, starter, grower, finisher and maintenance periods were analysed using analysis of variance (ANOVA) with the general linear models (GLM) procedure of SAS version 9.1 (SAS, 2000) according to the following model:

$$y_{ijkl} = \mu + T_i + W_j + e_{ijkl}$$

Where y is the dependent variable; μ is the general mean; T is the main effect of treatment; W is the main effect of repetitions and e_{ijkl} is the random error. Least squares means were estimated by applying the LSMEANS procedure of SAS. Significant differences between least squares means were tested using a t-test procedure by including the PDIFF option in the LSMEANS statement (Sharifi *et al.,* 2010). *P*-values < 0.05 were considered to be statistically significant.

Table 4.1. *The composition of the respective diets (g.kg^{-1}) with dilution levels (1 – 3 for pre-starter and starter and 1 – 5 for grower, finisher and maintenance) on an as is basis according to AOAC standards*

Component	Pre-Starter			Starter			Grower					Finisher					Maintenance				
Treatment	0%	10%	20%	0%	10%	20%	0%	15%	30%	45%	60%	0%	15%	30%	45%	60%	0%	20%	40%	60%	80%
Dry matter (g/kg)	930	930	930	920	910	920	910	910	920	930	930	930	930	930	930	940	930	940	940	940	930
Energy (MJ/kg feed)*	14.5	13.1	10.2	13.6	12.2	10.8	12.5	10.6	8.8	6.9	5.0	11.5	9.8	8.0	6.3	4.6	10.5	8.4	6.3	4.2	2.1
Crude Protein (g/kg)	195	179	163	173	158	142	139	140	111	96	78	143	123	106	97	71	126	118	89	71	61
Fat (g/kg)	88	90	72	64	66	58	41	36	32	28	21	25	25	22	21	19	23	18	14	12	14
Ash (g/kg)	92	77	86	103	93	84	65	72	55	62	53	89	72	67	66	60	88	78	68	61	51
Lignin (g/kg)	22	25	28	36	59	38	35	47	46	46	57	43	40	63	58	60	30	69	34	78	64
Crude Fibre (g/kg)	51	84	124	94	120	153	88	147	158	240	303	153	174	245	247	317	183	259	336	349	364
ADF (g/kg)	63	104	149	109	152	177	113	180	199	298	365	175	205	291	288	413	217	320	377	409	410
NDF (g/kg)	121	174	271	295	293	299	194	296	320	478	569	268	300	424	454	598	309	524	431	519	286
IVOMD (%)	85.8	77.8	71.4	79.6	75.5	76.7	73.4	74.8	75.4	65.9	62.1	80.1	75.7	76.4	69.1	64.3	79.7	73.0	61.3	58.1	56.2
WHC (g water/g feed)	2.4	2.7	3.6	2.4	3.0	3.1	2.6	3.6	3.4	4.6	5.1	3.0	3.6	3.8	4.4	5.4	3.8	4.7	5.2	4.9	5.8

Abbreviations: ADF = acid detergent fibre; NDF = neutral detergent fibre; IVOMD = *in vitro* organic matter digestibility; WHC = water holding capacity of the feed.

*Calculated according to formulations.

4.3. RESULTS

The least square means (±SE) and significance levels between dietary treatments for the average daily feed intake per ostrich for each of the growth phases are summarised in Table 4.2.

Table 4.2. *Least squares means and standard error of the mean (SEM) for mean daily feed intake (kg/bird d) for each of the phases for the different treatments*

Treatment	Pre-Starter	Starter	Grower	Finisher	Maintenance
0%	0.32	0.52	1.46	1.99	2.72
10%	0.25	0.66	-	-	-
15%	-	-	1.66	2.18	-
20%	0.15	0.67	-	-	2.12
30%	-	-	1.63	2.09	-
40%	-	-	-	-	2.14
45%	-	-	0.89	1.66	-
60%	-	-	0.85	1.21	1.09
80%	-	-	-	-	0.84
SEM	0.02	0.07	0.09	0.06	0.14

The daily intake per bird in the pre-starter phase dropped significantly ($P < 0.05$) as the level of straw increased (Table 4.2). Feed intake was 0.32 kg/bird/day for the control diet, 0.25 kg/bird day for the 10% and 0.15 kg/bird/day for the 20% dilution. The average daily gain (ADG) was significantly reduced at the 20% dilution level (Table 4.3). However, in the starter phase no differences ($P > 0.05$) in food intake (Table 4.2) were evident between treatments, although the means increased slightly as the fibre content increased.

Food intake in the grower phase was not constrained until the fibre content exceeded 30% of the complete feed, after which intake was only 61% and 58% of the undiluted feed on the two highest rates of dilution. This resulted in a significantly lower ADG in these two dilution treatments (Table 4.3). Food intake in the finisher phase first increased at the 15% dilution and then decreased to the same level as the undiluted feed at the 30% dilution and then to 83% and 61% of the intake on the undiluted feed on the two highest dilutions (Table 4.2). Although ADG was the same on the undiluted and the two lowest dilutions, it was significantly ($P < 0.05$) lower on the two feeds with the greatest amounts of fibre (Table 4.3).

Table 4.3. *Least squares means and standard error of the mean (SEM) for average daily gain (g/bird d) in each four phases of growth for the different treatments*

Treatment	Pre-Starter	Starter	Grower	Finisher	Maintenance
0%	130	130	190	140	80
10%	110	190	-	-	-
15%	-	-	180	130	20
20%	80	150	-	-	-
30%	-	-	140	120	30
40%	-	-	-	-	-
45%	-	-	90	90	-130
60%	-	-	60	50	-
80%	-	-	-	-	-170
SEM	10	50	20	10	130

Results for the maintenance phase showed that the average daily intake per bird decreased significantly ($P < 0.05$) from the 0% to the 20% dilution level, but there were no differences between average daily intake per bird between the 20% and 40% dilution levels (Table 4.2). This lower intake per bird per day might still be considered acceptable even though it was lower than that observed at the 0 dilution level. However, the intake was 60% lower at the 60% dilution level and 69% lower when the dilution level was increased to 80%. The bulk capacity of mature ostriches thus appears to be reached at dilution level of *ca*. 40%. The ADG had a decrease as the dilution levels increased; only means are shown in Table 4.3 as repetitions were not sufficient for statistical analysis.

Mortality occurred in all of the phases for the different treatments. Data were statistically analysed using a logistic regression in XLSTAT and it was observed that treatment did not cause greater mortality rates in the pre-starter, starter, finisher and maintenance phases ($P > 0.05$). Nevertheless, treatment was found to have an influence on mortality in the grower phase ($P < 0.05$). This situation may have been due to the differences in dilution levels fed to the animals. In the pre-starter and starter phases, the feeds were diluted only by 20%, whereas in the grower stage the feed was diluted by 60%. The increase in dilution level from the starter to the grower phase clearly was too large. When evaluating the treatments in the grower phase, the 0% dilution level is the control treatment. The 15% and 30% dilution levels did not differ ($P > 0.05$) from the control in terms of mortality, but

the 45% and 60% dilution levels differed from the control ($P < 0.05$). It would thus be recommended, when taking mortalities into account, that the 30% fibre dilution level be the maximum for the grower phase.

For almost all of the phases there was a decrease in intake from the lowest level of dilution (Figure 4.1). It was expected that there would be an increase in feed intake and then from a certain inflection point, a decrease. In Figure 4.1, starter rep 2 and grower rep 1 had an initial increase and grower rep 2 had a decrease from the 20% dilution level. The rest of the phases had only decreases from the first dilution levels and thus the assumption could be made that gut capacity was constraining feed intake in all the diluted feeds.

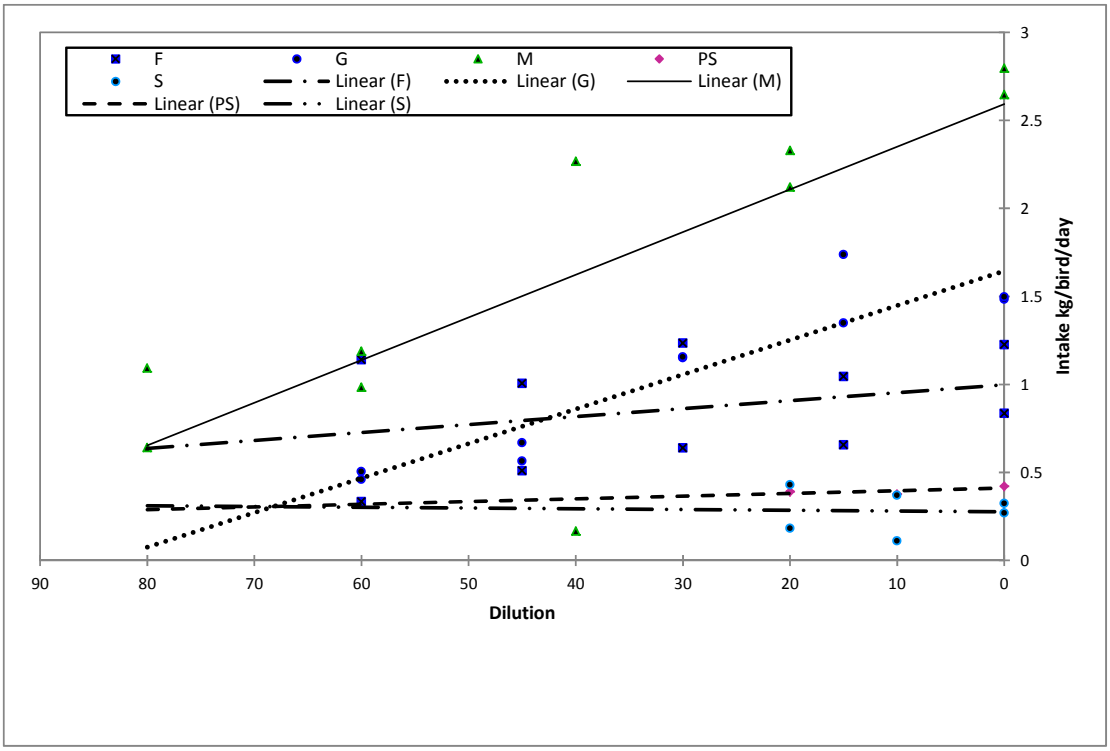

Figure 4.1. *Feed intake (kg feed/bird/day) for pre-starter: y = -0.0015x + 0.4111, R² = 0.4578; starter: y = 0.0004x + 0.2765, R² = 0.0011; grower: y = -0.0196x + 1.6449, R² = 0.8673; finisher: y = -0.0045x + 0.9987, R² = 0.1031 and maintenance y = -0.0242x + 2.5922, R² = 0.6225 and replications for different dilution levels.*

4.4. DISCUSSION

The main objective of this study was to evaluate the feed intake of ostriches fed diets with increasing fibre inclusion levels to determine the bulk capacity of the ostrich at certain stages. It is important to know the bulk capacity of ostriches for feed intake predictions. In this trial

it was important to describe the bulkiness of a feed because when a feed is formulated that is too bulky, the feed intake that is predicted by the growth model will be reduced and thus the growth rate will decrease.

The extreme dilution levels in this study were formulated to determine maximum inclusion levels. The study, however, was not done to evaluate fibre as a replacement of starch for energy, and for this reason not much attention was given to production parameters.

Also, in this study, diet formulations for the pre-starter and starter phases were not diluted with as much fibre as in the later phases based on the assumption that young birds would still be developing the ability to digest fibre during these phases. It was assumed that in the grower, finisher and maintenance phases the ostriches would be able to digest higher levels of fibre without any detrimental effects since they were at the ages of 18 weeks for grower, 26 weeks for finisher and 42 weeks for maintenance at the initiation of each phase.

In the pre-starter phase, the results of lower intake with higher levels of fibre were anticipated since it is known that ostriches up to the age of 10 weeks do not digest fibrous plant material (cellulose and hemi-cellulose) as effectively as older birds (Bezuidenhout, 1986; Cilliers and Angel, 1999), and for the same reason the lower ADG at the 20% treatment diet was expected. In commercial ostrich diets, wheat straw is not included in the pre-starter phase since the animals are not yet able to digest fibre effectively. It appears that the birds in this growth phase will eat as much as possible without being regulated by their "eating to fulfil limiting nutrients" response (Ferguson, 2006). This can probably be attributed to the fact that growing birds will utilise as much of the available nutrients as possible for growth to increase their chance of survival. It can therefore be reasoned that feed intake was restricted by increasing the bulkiness of the feed.

For the starter phase, as the fibre dilution level increased, intake increased simultaneously to meet the energy requirements, since the diluted feed had a lower energy content. It is known that birds prefer high density (energy and protein rich) diets and eat to fulfil the requirement of the first limiting nutrient (Ferguson, 2006). The lowest average intake of the 0% dilution treatment was expected as there were no capacity restrictions and it can be assumed that the nutrient requirements were met. The increased intakes with the increased dilution levels were expected as birds in this phases were older than 10 weeks of age. The basic rules for intake regulation are still applicable. In other words, an increased intake is anticipated with higher dilution levels to a certain point, then the bulk capacity of the ostrich will be reached and the intake will decrease. This is due to the physical size/limitation of the digestive tract. However this was not determined for the start phase as

the highest dilution level of 20% was not sufficiently high to determine the dilution percentage at which the intake would begin to be restricted. Further research is thus required in order to elucidate the level at which intake will become significantly lowered by increasing the dilution levels from 15% to 30%, 45% and even 60%.

In the grower phase, intake was drastically affected at dilution levels higher than 30%. In this phase, the obtained results were expected, in that the intake increased as the birds eat to fulfil their energy requirements, but at a certain stage the feed becomes too bulky and intake is negatively influenced. Similar results were obtained for the ADG's, although the ADG's for all the treatments were positive, growth was lower for the treatments from 30% and upwards.

In the finisher phase, it can be reasoned that the intake may have increased to accommodate the 15% dilution level and decreased slightly as the dilution level was increased to 30%. For dilution levels higher than 30%, feed intake decreases further. The results are thus as expected for this phase, because intake increases as the animals eat to fulfil their requirements for the limiting nutrient in the feed, but at a certain stage the feed gets too bulky (the bulk capacity of the bird is reached) and intake and growth declines.

In the maintenance phase, the feed intake decreases significantly ($P < 0.05$) when the dilution is higher than the 40% level. The ADG values were expected as the birds are mature at the age of ± 580 days. Due to too few repetitions of weighing the birds, larger variance and thus larger standard errors were obtained, thus obscuring potential treatment differences – this aspect warrants further research.

The bulk capacity of mature ostriches appears to be reached at dilution levels of *ca*. 45%. Furthermore, concerning the ADG's, although the growth of the birds in all treatments was positive, the treatments 45% and 60% were significantly lower than the rest of the treatments.

In general it was expected that feed intake would increase as bulk density increased up to an inflection point from which the intake would decline as the maximum gut capacity was reached. The reason being that as the diet is diluted; the bird would eat more as the dilution level increases to fulfil the needs for the first limiting factor. From the point that the maximum gut capacity is reached, feed intake would decline. For all the phases, the general trend for intake was to decrease as the bulk density increased.

In an attempt to obtain a model to predict intake from known factors the body weight of the bird was measured at different stages and the AME, CP, Fat, Ash, Lignin, Fibre, ADF, NDF, IVOMD and WHC of the feeds used were also measured. A step-wise regression

indicated that the most important nutritional factors that constrain feed intake (gut capacity) were body weight, fibre and NDF. The maximum amount of food that an ostrich can consume is a function of the said parameters. The final model was: Intake kg/bird day = 0.2488 + 2.464 E - 02*Weight - 8.528 E - 02*Fibre % + 0.036 * NDF % (Table 4.4).

Table 4.4. *Estimates of parameters for the model determined by the step-wise regression*

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	0.248	0.148	1.670	0.097	-0.045	0.541
Weight	0.025	0.002	13.745	< 0.0001	0.021	0.028
Energy (MJ/kg feed)	0.000	0.000				
Crude Protein %	0.000	0.000				
Fat %	0.000	0.000				
Ash %	0.000	0.000				
Lignin %	0.000	0.000				
Fiber %	-0.085	0.013	-6.560	< 0.0001	-0.111	-0.060
ADF %	0.000	0.000				
NDF %	0.036	0.008	4.814	< 0.0001	0.021	0.051
IVOMD %	0.000	0.000				
Water holding capacity (WHC)	0.000	0.000				

These results contradict findings of previous studies (Tsaras *et al*., 1998) which found that WHC was one of the most important factors concerning feed intake in pigs. When analysing data and fitting a step-wise regression, certain parameters may not be included in the model due to high correlations between parameters.

Historical data were used to determine the goodness of fit for the model to different data, so as to determine whether the model is useful. The dataset that was used to test the model had a better R^2 (0.72) than the initial data (0.56) (Figure 4.2). The Pearson correlation for the test data was strong positive (Table 4.5). This model may thus be used to predict intake values for the test dataset.

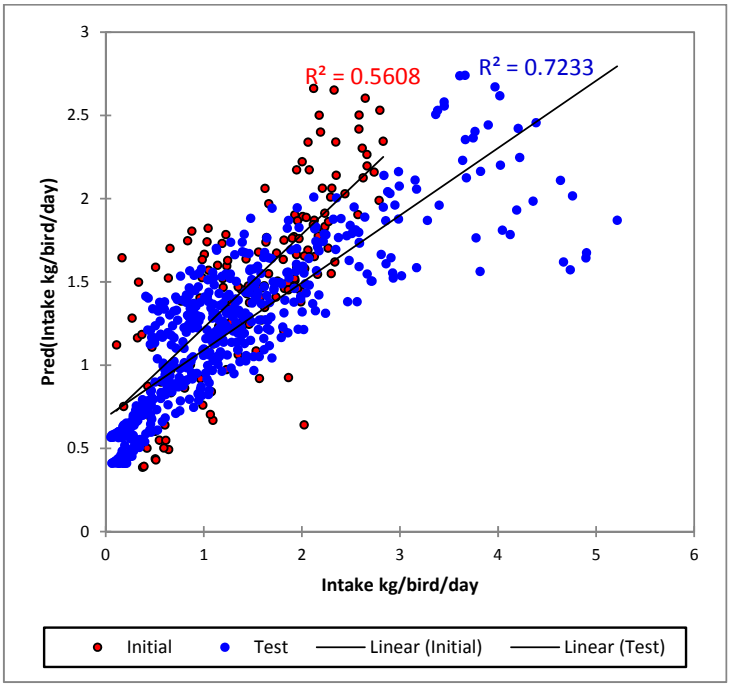

Figure 4.2. *Scatterplot for the initial and test datasets for intake predictions.*

Table 4.5. *Correlation matrix (Pearson) for the test data*

Variables	Intake kg/bird/day	Predicted intake (Intake kg/bird/day)
Intake kg/bird/day	1	0.850
Predicted intake(Intake kg/bird/day)	0.850	1

Results from this study show that as the digestive tract of the ostrich develops throughout the growth cycle, the ability of the birds to digest and tolerate high levels of fibrous material in their diets also increases. The bulk capacity of the birds also increases as the bird matures. The bulk capacity and intake regulation limits in the ostrich will aid with least-cost modelling as ostrich intake parameters with regards to bulk capacity were defined in this study. Simplified intake predictions and defined bulk capacity levels for ostriches will improve the practical applications of least-cost simulation modelling.

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Chapter 5

The effect of dietary protein concentrations on production parameters of ostrich chicks (*Struthio camelus* var. *domesticus*)

Abstract

1. The effect of three different dietary protein (with a specific associated amino acid content) concentrations on certain production parameters in growing ostriches were investigated. Measured parameters included feed intake, cumulative feed conversion ratio (FCR), and growth rate. Basic abattoir weight, *post mortem* measurements of the commercial cuts of meat, and measurements on the feathers were also conducted.

2. The crude protein and amino acid requirements of ostrich chicks for the different production phases (pre-starter, starter, grower and finisher) were predicted by a growth and optimisation model developed by Gous and Brand (2011).

3. Three basic diets were formulated to be 20% lower and 20% above predicted levels for lysine, sulphur-containing amino acids, threonine, tryptophan and arginine (named diets with a low, medium or high protein content). The three diets were fed to the ostriches during each of the four production phases from hatching up to slaughtering. Feed and water were available *ad libitum.*

4. Significant differences were found for the final live weight of birds at slaughter (350 days old), cold carcass weight, thigh weight as well as for most of the weighed muscles. Concerning the growth and feed related parameters, only average daily gain (ADG) was influenced by dietary treatment ($P < 0.05$). No significant differences were found for any of the measured parameters on the feathers. Results indicated that birds on the diet with the medium protein performed optimally. No further increase in production levels were observed in the diet with the highest level of protein (and associated amino acids).

5. This study showed that feeding diets with a higher protein and amino acid content than that predicted by the model developed by Gous and Brand (2011) was not able to further increase performance levels of growing ostriches.

5.1. INTRODUCTION

Feed costs comprise the largest component of all expenses in an intensive ostrich production system (Brand and Gous, 2006). Ostrich producers struggle to realise a profit due to many challenges in the industry. In an attempt to decrease expenses, research was done on the

nutrition of the ostrich. The focus of this research was to optimise the prediction of nutrient requirements in order to avoid over or under supplying certain nutrients (Kritzinger, 2011). Our study was done to evaluate the growth response of ostrich chicks which were fed diets containing three different levels of protein and amino acids.

In poultry and ratites, nutrient requirements constantly change, which means that the diet needs to be altered in accordance with the stage of production and growth (Swart, 1988). As implemented in poultry, the following diets are used in ostriches: pre-starter, starter, grower, finisher and breeder rations (Brand *et al*., 2003; Brand and Gous, 2006; Brand and Olivier, 2011). This study concentrated on pre-starter, starter, grower and finisher diets. The diets are adapted in accordance with the needs of the ostrich to obtain an optimal growth and to utilise the feed to an economical maximum (Polat *et al*., 2003). Revenue from ostriches is generated from skin, feathers and meat (Gous and Brand, 2008). In this study, the effect of dietary protein on production parameters, as well as on meat and feather parameters, was investigated.

5.2. MATERIALS AND METHODS

Ethical clearance number: R11/41. This trial was conducted at Kromme Rhee experimental farm in the Western Cape (18°50'E, 33°51'S and altitude 177 m). In this trial, 180 birds, divided in 18 groups with 10 birds per group, were used. Each group had one of the three treatments, thus six groups per treatment. During slaughter ostriches' lifetime, they are fed four diets (pre-starter, starter, grower and finisher). In this trial the ostriches were fed accordingly but in three treatments namely high, medium and low (Table 5.1). The amino acids for the feeds of this trial were balanced for ostrich chicks at the different phases (Table 5.2). Diet compositions are presented in Table 5.3 – Table 5.6.

Table 5.1. *Proximate analysis (as is basis) of experimental feeds containing three levels of protein (Low: L, Medium: M and High H) fed to ostriches during the pre-starter (0 – 2 months), starter (2 – 4 months), grower (4 – 6 months) and finisher (6 – 10 months) phases*

Ingredient	Pre-starter			Starter			Grower			Finisher		
	L	M	H	L	M	H	L	M	H	L	M	H
Energy MJ/kg feed*	14.5	14.5	14.5	13.5	13.5	13.5	11.5	11.5	11.5	10.7	10.7	10.7
Dry matter (g/kg)	922	923	929	917	917	921	903	915	928	910	909	909
Ash (g/kg)	8.79	9.53	10.2	7.89	8.19	8.76	7.94	7.55	8.23	13.2	11.3	11.7
Crude protein (g/kg)	168.0	202.8	234.8	131.6	159.8	180.1	132	150.9	175.0	119.8	127.9	146.1
Fibre (g/kg)	29.5	33.7	29.5	64.5	86.0	74.0	119	128	136	130	134	122
Fat (g/kg)	54.3	52.6	68.2	21.7	39.7	29.8	17.4	48.0	27.4	21.8	23.3	21.9
ADF (g/kg)	56.8	73.1	61.4	106	125	119	184	175	189	220	211	181
NDF (g/kg)	179	223	130	180	215	194	255	240	271	323	322	313
Ca (g/kg)	14.5	14.8	14.9	13.1	13.8	13.2	12.6	11.6	13.1	12.2	12.5	14.1
P (g/kg)	12.0	12.7	13.5	6.3	6.9	7.3	7.2	7.3	8.1	11.0	11.5	10.8

Abbreviations: ADF = acid detergent fibre; NDF = neutral detergent fibre.

*As formulated.

Table 5.2. *The amino acid composition of the feeds (g/kg, as is basis)) containing three levels of protein (Low: L, Medium: M and High H) fed to ostriches during the pre-starter (0 – 2 months), starter (2 – 4 months), grower (4 – 6 months) and finisher (6 – 10 months) phases*

Amino Acid (g/kg)	Pre-starter			Starter			Grower			Finisher		
	0 – 2.5 months			2.5 – 4.5 months			4.5 – 6 months			6 – 9 months		
Treatment	L	M	H	L	M	H	L	M	H	L	M	H
Lysine	7.90	10.9	14.9	7.00	7.90	11.0	6.50	6.60	9.40	5.20	5.90	8.20
Methionine	1.00	1.30	1.70	0.90	0.60	0.70	0.60	0.40	0.50	0.50	0.50	1.00
Arginine	6.50	8.60	11.40	5.40	5.70	7.80	4.50	4.90	6.50	5.10	5.60	6.20
Threonine	5.00	6.40	8.60	4.50	4.90	6.30	4.30	4.40	5.60	4.00	4.10	4.80
Aspartate	11.8	16.0	21.0	10.9	13.5	17.4	12.1	12.4	16.3	9.8	10.3	12.9
Glutamate	28.3	34.6	44.5	27.0	24.3	31.9	18.7	19.7	24.8	20.1	21.3	23.7
Serine	6.40	8.20	11.6	6.00	6.50	8.40	5.70	5.80	7.50	5.10	5.40	6.80
Histidine	2.90	4.10	5.40	2.90	3.10	4.00	2.50	2.70	3.30	2.40	2.70	3.00
Glycine	5.80	7.50	10.6	4.30	4.50	5.90	4.10	4.00	5.40	4.50	4.90	5.40
Alanine	7.10	8.60	11.40	6.70	6.30	7.80	5.80	5.60	6.60	5.10	5.30	6.00
Tyrosine	5.20	6.60	8.50	5.20	5.00	6.50	4.60	4.60	5.60	3.90	4.10	4.80
Valine	7.20	9.00	11.50	6.70	7.00	8.80	6.30	6.30	7.70	6.00	6.10	7.30
Phenylalanine	6.50	8.10	10.60	6.50	6.50	8.40	5.70	5.70	7.10	4.80	5.00	6.00
Isoleucine	5.50	7.00	9.40	5.00	5.30	6.90	4.50	4.70	5.90	3.80	4.00	5.00
Leucine	12.0	14.3	18.3	12.3	11.2	13.9	9.90	9.80	11.4	7.60	7.80	9.20

Table 5.3. *Ingredient and nutrient composition (as fed basis) of experimental pre-starter diets (kg/ton) (Brand, 2012)*

Ingredients (kg)	L	M	H
Maize meal	600.0	550.0	500.0
Soybean oilcake	105.4	180.3	255.1
Fishmeal	50.0	75.0	100.0
Full fat soya	50.0	31.1	12.1
Lucerne meal	50.0	50.0	50.0
Wheat bran	43.7	21.6	0.0
Plant oil	47.1	43.9	40.6
Monocalcium phosphate	24.0	23.5	22.9
Limestone	13.0	7.9	2.7
Salt	10.0	10.0	10.0
Synthetic lysine	1.8	1.7	1.6
Vitamin and mineral premix*	5.0	5.0	5.0

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 5.4. *Ingredient and nutrient composition (as fed basis) of experimental starter diets (kg/ton) (Brand, 2012)*

Ingredients (kg)	L	M	H
Maize meal	634.6	565.7	495.5
Soybean oilcake	100.0	165.0	231.0
Lucerne meal	100.0	100.0	100.0
Wheat bran	100.0	100.0	100.0
Plant oil	15.5	20.0	25.0
Monocalcium phosphate	10.6	9.6	8.5
Limestone	22.0	22.0	22.0
Salt	10.0	10.0	10.0
Synthetic lysine	2.3	2.7	3.0
Vitamin and mineral premix*	5.0	5.0	5.0

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 5.5. *Ingredient and nutrient composition (as fed basis) of experimental grower diets (kg/ton) (Brand, 2012)*

Ingredients (kg)	L	M	H
Maize meal	451.0	413.0	374.0
Soybean oilcake	37.9	89.4	140.9
Molasses powder	25.0	25.0	25.0
Lucerne	444.9	431.78	419.7
Monocalcium phosphate	18.3	17.1	15.9
Limestone	6.0	6.6	7.2
Salt	10.0	10.0	10.0
Synthetic lysine	1.25	1.32	1.38
Synthetic methionine	0.68	0.80	0.91
Vitamin and mineral premix*	5.0	5.0	5.0

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 5.6. *Ingredient and nutrient composition (as fed basis) of experimental finisher diets (kg/ton) (Brand, 2012)*

Ingredients (kg)	L	M	H
Maize meal	200.0	200.0	200.0
Soybean oilcake	0.0	25.0	50.0
Molasses powder	50.0	50.0	50.0
Lucerne	250.0	250.0	250.0
Wheat bran	306.0	280.0	253.9
Oat hulls	100.0	100.0	100.0
Bentonite	50.0	50.0	50.0
Monocalcium phosphate	20.4	19.8	19.3
Limestone	10.7	10.8	11.0
Salt	10.0	10.0	10.0
Synthetic lysine	0.3	1.0	1.6
Synthetic methionine	0.6	1.4	2.2
Vitamin and mineral premix*	2.0	2.0	2.0

*Refer to ANNEXURE A, Table A for the composition of the premix.

The prediction model developed by Gous and Brand (2008) was used to predict the protein and amino acid for the medium protein ratio for every diet. The low protein diet was formulated to have 20% less protein than what the model predicted for each diet, and the high protein diet was formulated to have 20% more protein than what the model predicted for each diet, while the energy was kept constant, therefore only protein and amino acids differed between treatments. For each treatment, the feed was available *ad libitum* and feed intake was determined by weekly weighing the feed offered (and refusals) to the birds.

A high percentage of mortalities occurred in the first six weeks due to ambient temperature fluctuations. There were 90 mortalities, and 90 animals survived throughout the trial. An initial statistical analysis did not show any relationship between diet and mortality; thus the experiment was continued as described.

At 11.5 months of age the ostriches were weighed to determine live weight and then slaughtered at Ostriswell abattoir in Swellendam. Standard slaughtering procedures were used as described by Hoffman (2012). The organs, fat and certain bones of every bird were weighed to determine the effect of protein on these weights. The weighed parameters included the following: heart, liver, lungs, kidneys, empty stomach, fat plate and the chest bone. The feathers were removed and kept separately per bird and sent to the feather department of Klein Karoo International Ltd (responsible for production, processing and exports of ostrich products) at Oudtshoorn for drying prior to classification and weighing. The carcasses were placed in a cold room to cool overnight and the cold carcass weights were recorded the following day. The dressing percentages were calculated by using the cold carcass weight, deviding it by the live weigth and multiply it by 100. The following morning the carcasses were weighed to determine the cold carcass weight. The carcass includes the thighs, neck and chest of the bird (all internal organs, feathers, skin, head and feet were removed).

The carcasses were transported to the deboning facility at Klein Karoo International Ltd in Oudtshoorn. The cold carcasses were deboned, and the neck, tibia, femur, the whole thigh and the patella were weighed. The weights of a single leg's components were weighed, which were then doubled to obtain the weight for both sides.

The meat was weighed per commercial cut for one thigh of the ostrich; the values were multiplied by two to obtain the total weight of the ostrich carcass as almost all of the meat is from the thigh of the ostrich. The commercial cuts that were measured included: fan fillet *Muscularis iliofibularis*, rump steak *M. iliotibialis lateralis*, moon steak *M. femorotibialis medius*, triangle steak *M. flexor cruris lateralis*, big drum *M. gastrocnemius*,

flat drum *M. gastrocnemius*, drum steak *M. gastrocnemius*, tenderloin *M. obturatorius medialis*, eye fillet *M. iliofemoralis*, tornedo *M. ambiens*, long fillet *M. ambiens*, oyster fillet *M. iliofemoralis externus*, small steak *M. flexor cruris medialis*, minute 1 *M. femorotibialis externus*, minute 2 *M. femorotibialis externus*, small drum *M. fibularis longus* and the tender steak *M. pubio-ischio-femoralis* (Kritzinger, 2011; Anon, 2013).

The big drum (*M. gastrocnemius*) muscles were collected and analysed further in the meat laboratory at Stellenbosch where the dorsal part of the muscle was removed and minced. The minced part was freeze-dried with a Virtis benchtop K and ground with a Knifetec 1095 Sample Mill (Tecator, Box 70, S-263 21 Hoganäs, Sweden) using a 1 mm sieve, and then analysed for chemical composition. The crude protein (CP) was measured by a FP-428 Nitrogen and Protein Determinator (Leco Corporation, 3000 Lakeview Avenue, St Joseph, MI 49085-2396). Lipid (petroleum ether extraction) was measured according to AOAC (2002) (Method number 7.061). Dry matter (DM) was determined by drying a sample (*ca*. 1.0 g) at 100 °C to a constant mass and ash content by placing the sample in a furnace at 500 °C overnight (AOAC, 2002) (Method numbers 7.003 and 7.009, respectively).

The feathers were dried for 47.5 hours at 50 °C and then for 30 minute at 70 °C, at Klein Karoo International Ltd in Oudtshoorn and then separated and classified into the economically important types of feathers per bird. The weight of the different classes of feathers was noted. The different classes of feathers included: “wings”, “drab dry points”, “drab silver floss”, “drab bloods”, “young bird floss”, “chick blondene floss”, “chick body short”, “chick body floss”, “tail feathers” and “worthless feathers”. The shafts of ten randomly selected wing feathers were measured at the base (point of skin entry) using a digital calliper. The average diameter of the ten feathers was calculated and used for statistical analysis.

The data were analysed using the GLM Procedure of SAS statistical software version 9.1 (SAS, 2000). Treatment was used as the main effect (classification variable). Tests for homoscedasticity were done using Levene’s test. Homoscedastic data were analysed and interpreted using one way anovas, and hetroscedastic data were analysed and interpreted using the Welch anova. Additionally, to discover the different trends due to the different levels of protein, the data were further analysed using REG Procedures in SAS statistical software version 9.1 (SAS, 2000). In the article by Gous (2010) it is explained why this approach was followed. There were only three protein levels that were tested in the trial, thus it was assumed that all regressions that were fitted in the statistical analysis were linear regressions. The regressions were fitted with the level of protein on the x-axis and the

measured parameter on the y-axis. The regression analysis was designed to determine whether the slope of the regression was significant, and therefore the constant term is not discussed.

5.3. RESULTS

Treatment had an effect ($P < 0.05$) on the following parameters: live weight, cold carcass weight, thigh weight, weight of femur and tibia, and the weight of the heart (Table 5.7). This was expected as the treatments had different levels of protein and amino acids (Table 5.1 and 5.2), which is one of the key components of a well-balanced diet. For these parameters, there were significant differences between treatments H and L ($P < 0.05$) and L and M ($P < 0.05$), although there were no differences between the H and M treatments ($P > 0.05$). No differences were found between treatments for the proximate analysis of the meat ($P > 0.05$).

Table 5.7. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of dietary protein concentrations on the organs, slaughter and carcass weights and proximate analysis of meat for slaughter ostriches*

Parameter	Dietary Protein Concentrations		
	L	M	H
Live Weight (kg)	89.97[a] ± 2.71	98.80[b] ± 2.56	102.07[b] ± 1.06
Cold Carcass Weight (kg)	41.22[a] ± 0.92	45.13[b] ± 1.14	45.14[b] ± 0.77
Dressing Percentage %	46.25 ± 0.65	45.86 ± 0.64	44.40 ± 0.54
Thigh Weight (kg)	30.97[a] ± 0.96	35.29[b] ± 1.15	35.21[b] ± 0.77
Neck (kg)	2.01 ± 0.07	1.95 ± 0.06	1.91 ± 0.05
Heart (kg)	0.72[a] ± 0.03	0.77[b] ± 0.02	0.82[b] ± 0.02
Liver (kg)	1.39 ± 0.08	1.33 ± 0.08	1.34 ± 0.10
Lungs (kg)	0.79 ± 0.02	0.88 ± 0.02	0.82 ± 0.04
Kidneys (kg)	0.52 ± 0.02	0.51 ± 0.02	0.51 ± 0.03
Empty Stomach (kg)	0.85 ± 0.03	0.78 ± 0.03	0.85 ± 0.03
Fat Plate (kg)	3.36 ± 0.41	3.71 ± 0.33	3.01 ± 0.29
Chest Bone (kg)	0.64 ± 0.04	0.68 ± 0.03	0.63 ± 0.02
Tibia (kg)	3.13[a] ± 0.08	3.51[b] ± 0.12	3.41 [b] ± 0.09
Femur (kg)	1.43[a] ± 0.03	1.59[b] ± 0.05	1.54[b] ± 0.04
Patella (kg)	0.47 ± 0.02	0.52 ± 0.02	0.67 ± 0.16
Chemical composition of *M. gastrocnemius*:			
DM %	22.09 ± 0.35	20.94 ± 0.35	22.26 ± 0.39
Protein %	19.82 ± 0.31	18.87 ± 0.35	19.98 ± 0.35
Fat %	0.83 ± 0.07	0.62 ± 0.08	0.74 ± 0.08
Ash %	1.05 ± 0.02	1.00 ± 0.03	1.02 ± 0.03

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

It becomes clear that treatment had an effect ($P < 0.05$) on the weight of the following commercial steaks: tenderloin, small steak, fan fillet, rump steak, moon steak, big drum, flat drum, eye fillet, tornedo, long fillet, oyster fillet, small drum, minute 1 and the tender steak (Table 5.8). This was also expected as the carcass and thigh weights differed between the treatments and there is a positive relationship between the carcass weight and the weight of the muscles as well as between the thigh weight and the weight of the muscles. For the weight of the following muscles: fan fillet, rump steak, moon steak, big drum, tenderloin, eye

fillet, small drum, tendersteak, flat drum and minute 1 steak, there were differences between treatments H and L ($P < 0.05$) and L and M ($P < 0.05$) although there were no differences between the H and M treatments ($P > 0.05$). When treatments were compared with each other, the weight of the tornedo steak differed significantly between the H and L treatments but not between the H and M treatments ($P > 0.05$) or the M and L treatments ($P > 0.05$). Also, the weight of the small steak differed significantly between the M and L treatments but no differences were noted between the H and M treatments ($P > 0.05$) nor the H and L treatments ($P > 0.05$). The weight of the long fillet also differed significantly between treatments H and L, whilst there were no differences between treatments H and M ($P > 0.05$) or M and L ($P > 0.05$) for the long fillet weight. Similarly, the weight of the oyster fillet differed significantly between the M and L treatments whilst there were no differences for oyster fillet weight between H and M treatments ($P > 0.05$) or H and L treatments ($P > 0.05$).

Table 5.8. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of dietary protein concentrations on the weights of different commercial steaks of slaughter ostriches*

Steak Weight (kg)	Dietary Protein Concentrations		
	L	M	H
Fan Fillet	2.86[a] ± 0.10	3.32[b] ± 0.10	3.37[b] ± 0.09
Rump Steak	2.48[a] ± 0.10	2.84[b] ± 0.10	2.89[b] ± 0.08
Moon Steak	1.57[a] ± 0.07	1.86[b] ±0.07	1.85[b] ± 0.06
Triangle Steak	0.72 ± 0.06	0.80 ± 0.05	0.77 ± 0.02
Big Drum	1.89[a] ± 0.09	2.20[b] ± 0.09	2.23[b] ± 0.07
Flat Drum	1.33[a] ± 0.06	1.62[b] ± 0.06	1.53[b] ± 0.05
Drum Steak	1.13 ± 0.06	1.23 ± 0.05	1.27 ± 0.04
Tenderloin	0.97[a] ± 0.04	1.16[b] ± 0.04	1.15[b] ± 0.03
Eye Fillet	0.73[a] ± 0.03	0.90[b] ± 0.03	0.86[b] ± 0.03
Tornedo	0.42[a] ± 0.01	0.47[ab] ± 0.02	0.53[b] ± 0.03
Long Fillet	0.88[a] ± 0.05	1.02[ab] ± 0.05	1.06[b] ± 0.04
Oyster Fillet	0.93[a] ± 0.04	0.63[b] ± 0.02	1.06[ab] ± 0.04
Small Steak	0.29[a] ± 0.01	0.35[b] ± 0.02	0.33[ab] ± 0.01
Small Drum	0.53[a] ± 0.02	0.63[b] ± 0.02	0.62[b] ± 0.02
Tender Steak	0.62[a] ± 0.02	0.71 [b] ± 0.02	0.71[b] ± 0.02
Minute 1	0.23[a] ± 0.01	0.26[b] ± 0.01	0.26[b] ± 0.01
Minute 2	0.33 ± 0.02	0.37 ± 0.02	0.38 ± 0.01

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Treatment did not have any effect on any of the measured feather parameters (Table 5.9).

Table 5.9. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of dietary protein concentrations on feather parameters of slaughter ostriches*

Feather Parameter (kg)	Dietary Protein Concentrations		
	L	M	H
Shaft Thickness, mm	5.32 ± 0.08	5.33 ± 0.08	5.34 ± 0.07
Wing feathers	0.13 ± 0.01	0.12 ± 0.01	0.11 ± 0.01
Drab Dry Points	0.11 ± 0.01	0.14 ± 0.02	0.13 ± 0.01
Drab Silver Floss	0.15 ± 0.01	0.18 ± 0.01	0.18 ± 0.01
Young Bird Floss	0.19 ± 0.01	0.19 ± 0.01	0.17 ± 0.01
Chick Blondene Floss	0.11 ± 0.01	0.11 ± 0.01	0.11 ± 0.01
Chick Body Short	0.17 ± 0.01	0.20 ± 0.02	0.18 ± 0.02
Chick Body Floss	0.16 ± 0.02	0.16 ± 0.02	0.13 ± 0.03
Tail Feathers	0.10 ± 0.00	0.10 ± 0.00	0.13 ± 0.03

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

The ADG was calculated over the total period using a linear regression model. The diet had an influence ($P < 0.05$) on the ADG for the starter and grower phases. The maximum ADG for the starter phase was 480.2 g/bird/day for the H treatment, then the M treatment with 428.1 g/bird/day, and the lowest was for the L treatment with 388.75 g/bird/day. In the grower phase, the maximum ADG was also for the H treatment (432.63 g/bird/day), but this did not differ ($P > 0.05$) from the M treatment (400.52 g/bird/day) however; it did differ significantly ($P < 0.05$) from the L treatment (368.89 g/bird/day). Treatment had no effect ($P > 0.05$) on the cumulative feed conversion ratio (FCR) nor feed intake ($P > 0.05$) for any of the four phases (Table 5.10). The protein efficiency factor was significantly lower for the H treatment than the L and M treatments.

Table 5.10. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of different dietary concentrations on production parameters of slaughter ostriches for the different phases (pre-starter, starter, grower and finisher)*

Phase*	Production Parameter	Dietary Protein Concentrations		
		L	M	H
Pre-Starter	Average daily gain ADG	226.8 ± 4.01	219.5 ± 3.84	225.5 ± 4.37
Starter	ADG	388.8^{a} ± 9.58	428.1^{b} ± 10.1	480.2^{c} ± 10.03
Grower	ADG	368.9^{a} ± 10.86	400.5^{ab} ± 11.27	432.6^{b} ± 12.30
Finisher	ADG	230.6 ± 6.43	236.4 ± 6.51	231.2 ± 6.82
All	Mean ADG	338.8^{a} ± 8.95	360.6^{ab} ± 8.78	376.6^{b} ± 10.13
Pre-Starter	Daily Feed Intake (DFI)	0.73 ± 0.12	0.73 ± 0.12	0.82 ± 0.13
Starter	DFI	1.07 ± 0.04	1.16 ± 0.04	1.21 ± 0.04
Grower	DFI	1.68 ± 0.06	1.72 ± 0.06	1.85 ± 0.07
Finisher	DFI	2.25 ± 0.08	2.23 ± 0.08	2.34 ± 0.09
All	Mean DFI	1.63^{a} ± 0.03	1.67^{ab} ± 0.03	1.76^{b} ± 0.03
Pre-Starter	Cumulative FCR	3.25 ± 0.43	3.48 ± 0.40	3.01 ± 0.43
Starter	Cumulative FCR	2.36 ± 0.08	2.57 ± 0.07	2.28 ± 0.08
Grower	Cumulative FCR	3.27 ± 0.09	3.15 ± 0.09	2.97 ± 0.10
Finisher	Cumulative FCR	4.37 ± 0.10	4.25 ± 0.10	4.41 ± 0.10
All	Mean Cumulative FCR	3.81 ± 0.20	3.57 ± 0.20	3.26 ± 0.20
Pre-Starter	Mean weight end of phase	19.47^{a} ± 0.79	23.25^{b} ± 0.83	26.80^{c} ± 0.83
Starter	Mean weight end of phase	47.9 ± 1.14	46.5 ± 1.08	49.4 ± 1.20
Grower	Mean weight end of phase	81.1^{a} ± 1.08	81.6^{a} ± 1.07	76.2^{b} ± 1.17
Finisher	Mean weight end of phase	96.8 ± 1.63	99.7 ± 1.67	96.9 ± 1.71
Pre-starter	Protein efficiency ratio	2.83 ± 0.34	2.70 ± 0.34	2.70 ± 0.37
Starter	Protein efficiency ratio	2.86 ± 0.56	1.53 ± 0.56	1.61 ± 0.61
Grower	Protein efficiency ratio	1.38^{a} ± 0.06	1.18^{a} ± 0.06	0.87^{b} ± 0.07
Finisher	Protein efficiency ratio	0.51 ± 0.06	0.51 ± 0.06	0.38 ± 0.07

$^{a\text{ - }b}$ Column means with different superscripts differ significantly ($P \leq 0.05$).

*****Phase: Pre-Starter 0 – 80 days, Starter 81 – 147 days, Grower 148 – 227 days, Finisher 228 – 350 days.

The following is an interpretation of the data analysed by the regressions: The B_0 or constant term was not interpreted as the regression analysis was only done to calculate the slope of the different parameters. Only the B_1 or slope values were interpreted. Although the R^2 values for all the measured parameters were small, the *P*-values for the slope were still interpreted and

discussed (Table 5.11). The B_1 values for the following parameters were significantly higher than zero: live weight before slaughter, cold carcass weight and thigh weight ($P < 0.05$). The B_1 value for the dressing percentage was significantly lower than zero ($P < 0.05$). Except for the heart, none of the B_1 values for the regression for organs or tissue weighed at slaughter were significantly different than zero ($P > 0.05$). The B_1 value of the heart was significantly higher than zero (Table 5.11).

Table 5.11. *Regression coefficients ± standard error (SE) along with P-values and R^2 for the slaughter parameters*

Slaughter parameter	$B_0 \pm$ SE	*P*-value	$B_1 \pm$ SE	*P*-value	R^2
Live weight before slaughter	34.0 ± 18.8	0.0743	0.481 ± 0.142	0.001	0.14
Cold carcass weight	24.2 ± 7.25	0.0013	0.152 ± 0.055	0.007	0.09
Dressing percentage	56.0 ± 4.80	<0.0001	-0.078 ± 0.036	0.036	0.06
Thigh weight	13.9 ± 7.36	0.0627	0.154 ± 0.056	0.007	0.09
Heart	0.22 ± 0.22	0.3102	0.004 ± 0.002	0.012	0.08
Liver	1.24 ± 0.70	0.0819	0.001 ± 0.005	0.889	0.00
Lungs	0.83 ± 0.24	0.0008	0.0001 ± 0.002	0.966	0.00
Kidneys	0.49 ± 0.19	0.0096	0.0001 ± 0.001	0.921	0.00
Stomach	0.89 ± 0.25	0.0005	-0.0004 ± 0.0019	0.827	0.00
Fat	3.87 ± 2.49	0.1239	-0.005 ± 0.019	0.774	0.00
Chest bone	0.60 ± 0.24	0.0139	0.0004 ± 0.002	0.841	0.00

In Table 5.12 the B_1 values of most of the commercial steaks as well as the total weight of the steaks in the thigh were higher than zero ($P < 0.05$). However the B_1 values of the triangle steak, flat drum, and small steak were not significantly different from zero ($P > 0.05$). Also, the B_1 values for the tibia, femur, patella and neck were not different from zero ($P > 0.05$). The B_1 values for the proximate analysis of the meat (DM, ash, protein and fat) did not differ from zero ($P > 0.05$) (Table 5.12).

Table 5.12. *Regression coefficients ± standard error (SE) along with P-values and R^2 for the different steaks and proximate analysis of the meat*

Steaks weight (kg)	B_0 ± SE	*P*-value	B_1 ± SE	*P*-value	R^2
Total steaks in thigh	5.208 ± 4.870	0.2883	0.112 ± 0.037	0.0032	0.11
Fan fillet	0.823 ± 0.773	0.2906	0.018 ± 0.006	0.0028	0.12
Rump steak	0.610 ± 0.756	0.4223	0.016 ± 0.006	0.0055	0.10
Moon steak	0.377 ± 0.514	0.4663	0.011 ± 0.004	0.0082	0.09
Triangle steak	0.447 ± 0.357	0.2147	0.002 ± 0.003	0.3672	0.01
Big drum	0.665 ± 0.630	0.2948	0.011 ± 0.005	0.0214	0.07
Flat drum	0.620 ± 0.444	0.1639	0.007 ± 0.003	0.0511	0.05
Drum steak	0.354 ± 0.384	0.3594	0.007 ± 0.003	0.0271	0.07
Tenderloin	0.200 ± 0.328	0.5427	0.007 ± 0.002	0.0079	0.09
Eye fillet	0.188 ± 0.247	0.4493	0.005 ± 0.002	0.0127	0.08
Tornedo	-0.163 ± 0.186	0.3835	0.005 ± 0.001	0.0009	0.14
Long fillet	0.006 ± 0.344	0.8561	0.007 ± 0.003	0.0085	0.09
Oyster fillet	0.241 ± 0.291	0.4109	0.006 ± 0.002	0.0094	0.09
Small steak	0.122 ± 0.116	0.2966	0.002 ± 0.001	0.0903	0.04
Small drum	0.228 ± 0.185	0.2211	0.003 ± 0.001	0.0483	0.05
Tender steak	0.256 ± 0.186	0.1717	0.003 ± 0.001	0.0219	0.07
Minute 1	0.092 ± 0.066	0.1669	0.001 ± 0.001	0.0199	0.07
Minute 2	0.082 ± 0.120	0.4926	0.002 ± 0.001	0.0219	0.07
Tibia	2.120 ± 0.775	0.0076	0.010 ± 0.006	0.1020	0.04
Femur	1.030 ± 0.309	0.0013	0.004 ± 0.002	0.1022	0.04
Patella	-0.595 ± 0.735	0.4211	0.009 ± 0.006	0.1199	0.03
Neck	2.362 ± 0.450	<0.0001	-0.003 ± 0.003	0.3748	0.01
DM	19.974 ± 2.758	<0.0001	0.014 ± 0.021	0.5119	0.01
Protein	17.987 ± 2.431	<0.0001	0.012 ± 0.019	0.5147	0.01
Fat	1.033 ± 0.523	0.0542	-0.002 ± 0.004	0.5771	0.01
Ash	1.119 ± 0.181	<0.0001	-0.001 ± 0.001	0.6086	0.01

None of the B_1 values of any of the measured feather parameters were significantly different from zero ($P > 0.05$) (Table 5.13).

Table 5.13. *Regression coefficients ± standard error (SE) along with P-values and R^2 for the feather parameters*

Feather parameters	$B_0 \pm$ SE	*P*-value	$B_1 \pm$ SE	*P*-value	R^2
Total feathers dry	0.417 ± 0.159	0.0102	0.00181 ± 0.00121	0.1362	2.59
Total valuable feathers	0.634 ± 0.156	0.0001	-0.00037 ± 0.00118	0.7542	0.12
Wing feathers	0.206 ± 0.061	0.0011	-0.00685 ± 0.00046	0.1434	0.03
Tail feathers	0.059 ± 0.056	0.2954	-0.00029 ± 0.00042	0.4947	0.55
Average shaft thickness	5.202 ± 0.530	<0.0001	0.00098 ± 0.00403	0.8090	0.00
Drab dry points	-0.055 ± 0.093	0.5521	0.00086 ± 0.00071	0.2258	0.02
Drab silver floss	0.084 ± 0.118	0.4801	0.00002 ± 0.00089	0.9849	0.00
Young bird floss	-0.115 ± 0.114	0.3145	0.00135 ± 0.00086	0.1216	0.03
Chick blondene floss	0.002 ± 0.073	0.9807	0.00041 ± 0.00055	0.4636	0.01
Chick body short	0.297 ± 0.118	0.0136	-0.00104 ± 0.00089	0.2504	0.02
Chick body floss	0.157 ± 0.078	0.0494	-0.00099 ± 0.00059	0.1000	0.03

In Table 5.14, the B_1 value of the ADG for the pre-starter and starter were higher than zero ($P < 0.05$), although the B_1 value of the ADG for the finisher phase was significantly lower than zero. The B_1values of the ADG for the grower phase and ADG value overall did not differ from zero ($P > 0.05$). None of the B_1 values for the FCR were significantly different from zero ($P > 0.05$). Similarly, none of the B_1 values for the feed intake differed ($P > 0.05$) from zero. However, the B_1 values for the weight at the end of the pre-starter, starter and grower phases were significantly higher than zero (Table 5.14).

Table 5.14. *Regression coefficients ± standard error (SE) along with P-values and R^2 for the production parameters*

Production parameter	B_0 ± SE	*P*-value	B_1 ± SE	*P*-value	R^2
ADG pre-starter	-0.288 ± 0.081	0.0006	0.004 ± 0.001	<0.0001	0.32
ADG starter	-0.001 ± 0.121	0.9362	0.003 ± 0.001	0.0004	0.13
ADG grower	0.592 ± 0.120	<0.0001	-0.001 ± 0.001	0.1133	0.28
ADG finisher	0.500 ± 0.081	<0.0001	-0.002 ± 0.001	0.0014	0.11
ADG overall	0.198 ± 0.081	0.0147	0.001 ± 0.001	0.1274	0.01
Feed intake pre-starter	0.254 ± 0.773	0.7467	0.004 ± 0.006	0.5226	0.03
Feed intake Starter	0.501 ± 0.451	0.2845	0.005 ± 0.003	0.1717	0.12
Feed intake Grower	0.900 ± 0.753	0.2508	0.006 ± 0.006	0.2793	0.08
Feed intake Finisher	1.775 ± 0.741	0.0301	0.004 ± 0.006	0.5131	0.03
Feed intake overall	0.858 ± 0.937	0.3635	0.005 ± 0.007	0.5078	0.01
FCR Pre-starter	10.665 ± 6.623	0.1281	-0.053 ± 0.051	0.3083	0.06
FCR Starter	4.732 ± 2.167	0.0452	-0.017 ± 0.017	0.3267	0.06
FCR Grower	4.614 ± 1.884	0.0271	-0.011 ± 0.014	0.4452	0.04
FCR Finisher	4.760 ± 3.106	0.1462	-0.002 ± 0.024	0.9452	0.00
FCR overall	6.193 ± 2.207	0.0066	-0.021 ± 0.0169	0.2223	0.02
Weight end of pre-starter	-17.351 ± 11.130	0.1398	0.305 ± 0.085	0.0027	0.46
Weight end of starter	-20.272 ± 21.462	0.3598	0.515 ± 0.164	0.0068	0.40
Weight end of grower	22.752 ± 23.447	0.3472	0.425 ± 0.179	0.0314	0.27
Weight end of finisher	55.241 ± 23.601	0.0335	0.318 ± 0.180	0.0979	0.17

*****Phase: Pre-Starter 0 – 80 days, Starter 81 – 147 days, Grower 148 – 227 days, Finisher 228 – 350 days.

5.4. DISCUSSION

Although H and L differed for cold carcass weight, there were no differences between the H and M diets; this is economically the most important factor as the ostrich producer is paid per kilogram cold carcass weight. For the different meat cuts, most differed between the H and L treatments, the M and L treatments also differed but the H and M treatments did not differ. The level of protein in the diet had no effect on feather yield and quality in neither the regression nor the ANOVA interpretation. From these results it may be concluded that the M diet contained the optimum level of protein for all the phases and no positive results were found when a higher level of protein, which is more expensive, were fed. The regression

analysis suggested that none of the organs or tissue weighed at the day of slaughter except for the heart, was influenced by the dietary protein concentration. The heart increased in weight as the protein in the diet was increased. The live weight before slaughter, cold carcass weight and thigh weight were influenced in a similar manner. The total weight of steaks in the thigh as well as most of the commercial steaks (except triangle steak, flat drum and small steak) increased in weight as the dietary protein concentration increased.

This study had a wide range of protein concentrations in the diets for the pre-starter phase namely 168g/kg (L), 202.8 g/kg (M) and 234.8 g/kg (H) with corresponding lysine levels of 7.9 g/kg, 10.9 g/kg and 14.9 g/kg respectively. According to the one way anovas, there were no differences for the ADG, FCR and feed intake in this phase. The ADG result is similar to studies by Gandini *et al*. (1986) who found that protein ranging from 160.0 g/kg to 180.0 g/kg will result in growth in the pre-starter phase. However the regression analysis suggests that the slope of the regression for the ADG for this phase was significantly higher than zero. This means that as the protein content of the feed increased, the ADG increased as well for this phase. Similar as in the ANOVAS, the regression analysis suggested that the B_1 values for FCR and feed intake in this phase was not significantly different from zero. The slope for the regression of "weight at the end of the pre-starter phase" was significantly higher than zero. This means that as the protein content of the feed increased, the weight of the birds at the end of the phase increased as well for this phase. This result was confirmed by the ANOVAS for this parameter.

In the starter phase there were no significant differences for feed intake or cumulative FCR, this was backed up by the regression analysis as the B_1 values for FCR and feed intake in this phase was not significantly different from zero. In this phase phase the protein levels in the diets were: 131.6 g/kg (L), 159.8 g/kg (M) and 180.1 g/kg (H), with corresponding lysine levels of 7.0 g/kg, 7.9 g/kg and 11.0 g/kg, respectively. Different results were obtained in a study by Azahan and Noraziah (2011) where three levels of protein were fed to ostriches in the starter phase namely 125.0 g/kg, 175.0 g/kg and 225.0 g/kg. Significant differences were found between the 125.0 g/kg, 175.0 g/kg protein diets for the feed intake and FCR, with a higher intake and a lower FCR for the 175.0 g/kg level of protein. In the starter phase there were significant differences for the ADG, this result is backed up by the regression analysis as the slope of the regression for the ADG for this phase was significantly higher than zero. This means that as the protein content of the feed increased, the ADG increased as well for this phase. The average daily gain was the highest for the high level, lower for the M diet and the lowest for the L diet. Similar results were obtained by Azahan and Noraziah

(2011), where growth increased from the 125.0 g/kg crude protein diet to the 175.0 g/kg crude protein diet. The slope for the regression of weight at the end of the starter phase in this investigation was significantly higher than zero. This means that as the protein content of the feed increased, the weight of the birds at the end of the phase increased as well for the starter phase.

In the grower phase there were no significant differences for the feed intake and the cumulative FCR. The protein content of the diets fed was: 132.0 g/kg (L), 150.9 g/kg (M) and 175.1 g/kg (H) with lysine levels of 6.50 g/kg, 6.60 g/kg and 9.40 g/kg, respectively. Similar results were obtained for the same range of protein in diets by Brand *et al.* (2000, 2004). These results are supported up by the regression analysis as the B_1 values for the FCR and feed intake did not differ significantly from zero. The ANOVA results suggested that there were significant differences concerning the ADG, as it declined significantly as the protein concentration declined. This differs from the results by Brand *et al.* (2000) and Brand *et al.* (2004). This also differs from results obtained by Glatz *et al*. (2008) which found an optimum growth rate for a diet with a protein concentration of 126 g/kg; the range of protein in the diets in their study was: 126 g/kg, 136 g/kg, 138 g/kg and 143 g/kg. However, the regression analysis of this investigartion suggests that the B_1 values for the ADG were not significantly different from zero, this is similar to results by Brand *et al*. (2000) and Brand *et al*. (2004) but different to the results by Glatz *et al*. (2008). Weight at the end of the grower phase increased as the protein concentration increased.

In the finisher phase no differences were found for cumulative FCR, feed intake or ADG. The result for the FCR and feed intake is backed up by the regression analysis as B_1 values of the FCR and feed intake was not significant different from zero. The protein levels fed in the finisher phase were: 119.8 g/kg (L), 127.9 g/kg (M) and 146.1 g/kg (H) with corresponding lysine levels of 5.2 g/kg, 5.9 g/kg and 8.2 g/kg, respectively. Similar results were obtained by Brand *et al.* (2000) in an earlier study where diets containing the following protein concentrations were fed to ostriches during the finisher phases: 130.0 g/kg, 150.0 g/kg and 170.0 g/kg. The same results were obtained in a second study by Brand *et al.* (2004), where the protein in the diets were 80.0 g/kg, 100.0 g/kg, 120.0 g/kg, 140.0 g/kg and 160.0 g/kg with corresponding lysine concentrations of 3.3 g/kg, 4.1 g/kg , 5.0 g/kg, 5.8 g/kg and 6.6 g/kg, respectively. Concerning the regression analysis, in the finisher phase only the B_1 value for ADG were significantly different (lower) than zero. This means that in the finisher phase as the protein of the feed is increased, a decreased growth rate will occur. Different

results for the ADG were found by Brand *et al*. (2000) and Brand *et al*. (2004) where ADG were not influenced by dietary protein concentration.

It can be observed that for certain diets in the different phases the lysine: arginine ratio was greater than 1:1 although the diets were formulated to have a 1:1 ratio. This may be due to the amino acid profile of the raw materials used in the different diets. This may have had an influence on growth as it has been proved that a higher lysine concentration causes a higher arginine requirement in poultry (Chamruspollerd *et al*., 2002). In future studies attention should be given to the actual vs the formulated amino acid composition of the feeds.

This study showed that when a feed with higher protein than that which the model predicts are fed, no significant improvements in production parameters will be obtained as the ostrich has a biological optimum protein level that it can metabolise. One exception is the starter phase (26 – 47 kg) where chicks on the high protein diet outperformed those on the medium protein diet – this aspects warrants further research so as to try and finalise a maximum protein level. This study also showed that the model predicts protein requirements, amino acid requirements as well as a balanced amino acid profile fairly accurately.

The regression analysis suggested that in the pre-starter and starter phases there was an advantage for growth with higher dietary protein concentrations. This advantage was not present in the grower and finisher phases. Feeding too high levels of protein may possibly have detrimental effects on the ostrich as extra energy is required for the cost of deamination of the excess protein, thus energy is wasted. This was observed in the finisher phase where the ADG declined as the protein concentration was increased. These aspects warrant further research. In future research the trial should be designed such that more protein levels may be fed to the ostriches as a more suitable regression (not simple linear) could then be fitted to the data with better R^2 values. This way an optimum protein level could be determined for each of the different production phases.

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Chapter 6

The effect of dietary energy concentrations on production parameters of ostrich chicks (*Struthio camelus* var. *domesticus*)

Abstract

1. The effects of different dietary energy concentrations on ostrich production parameters were examined in two separate trials. The first trial tracked changes in production parameters from the pre-starter phase through the starter phase and grower phase. The second trial was based on the finisher phase *per se*. In both trials the influence of dietary energy on feed intake, feed conversion ratio (FCR) and growth parameters was investigated. Additionally, basic abattoir weights were recorded, and measurements of the feathers and skin as well as quality measurements on commercial meat cuts, were performed.

2. In both trials, three diets with different levels of dietary energy were fed during each phase where the low, medium and high energy levels for each phase were as follows: 13.5, 14.5 and 15.5 MJ ME/kg feed pre-starter; 12.5, 13.5 and 14.5 MJ ME/kg feed starter; 10.5, 11.5 and 12.5 MJ ME/kg feed grower; and 9.5, 10.5 and 11.5 MJ ME/kg feed finisher. Feed and water were available *ad libitum* in both trials.

3. Overall it was found that the best performance for growth, FCR, skin size and grade, thigh weight, live weight, and carcass weight were obtained on the medium energy diet during the pre-starter, starter and grower phases.

4. During the finisher phase improved growth rate and tanned skin size was found in birds fed the diet with the highest energy level (11.5 MJ ME/kg feed). Carcass weight, growth rate, and certain feather parameters were also significantly influenced by gender.

6.1. INTRODUCTION

Ostrich production is an important part of the South African agricultural sector (Viljoen *et al*., 2004) as the average gross value per annum for ostriches amounted to R324 million over the last 10 years (Anon, 2011). As is the case for many livestock enterprises, feed costs comprise the largest portion of an ostrich production system's expenses (Brand *et al*., 2002). This has been the driving force behind a number of studies that have been conducted on ostrich nutrition with the aim of reducing feed costs and thus making ostrich production more profitable (Swart *et al*., 1993a, Farrel *et al.*, 2000; Glatz *et al*., 2003; Brand *et al*., 2006). The over- or undersupply of nutrients in the diet can have a large influence on profitability by increasing costs or decreasing bird performance. The key focus of these studies is the

optimisation of the use of nutrients in the feed. Although ostriches have the ability to digest fibrous components such as cellulose and hemicellulose (Swart, 1988; Swart *et al*., 1993b, Swart *et al*., 1993c, Brand *et al*., 2002), higher energy concentration feeds are currently being fed to ostriches wasting this natural ability.

One of the most effective methods of determining the precise nutrient requirements of an animal is through the use of simulation models (Emmans and Fisher, 1986; Gous and Brand, 2008). It is important for modelling requirements to know what the feed intake of the animal would be if the feed was available *ad libitum* (Gous and Brand; 2008; Schinckel *et al*., 2012). According to McDonald *et al*. (2002), improved production efficiency is usually obtained when feed intake is increased. In most livestock species it is has been found that an increase in the dietary energy level results in a corresponding decrease in feed intake, and the other way round (Marriott, 2010). However, this rule is only true within bounds; at a certain point the feed will become too bulky and the capacity of the animal will begin to play a role, physically restricting feed intake (Quiniou and Noblet, 2012). A number of studies have been reported on the effect of energy levels in the diets of slaughter ostriches (Cilliers *et al*., 1998; Brand *et al*., 2000; Brand *et al*., 2004a; Brand *et al*., 2004b; Brand *et al*., 2004c; Cloete *et al*., 2006; Glatz *et al*., 2008). One of the primary aims of this study was to determine the response of growth and feed intake along with various production parameters to different dietary energy levels. Despite the fact that similar studies have been done, it was felt that more research was justified due to the current lack of consensus among researchers regarding the nutritional requirements of ostriches (Brand *et al*., 2004a). Previous studies that have been undertaken to investigate this subject include Swart and Kemm, (1985), Salih *et al*. (1998); Brand *et al*. (2000); Brand *et al*. (2004b); Brand *et al*. (2004c); Cloete *et al*. (2006) and Glatz *et al*. (2008). The current study focussed on the qualitative and quantitative measurement of post-slaughter parameters relating to meat, skin and feather production as these are the primary sources of income for the ostrich industry.

6.2. MATERIAL AND METHODS

Ethical clearance number: R11/41. This experiment was done in two separate trials. The first trial considered the pre-starter, starter and grower phases, while the second trial focussed on the finisher phase.

Trial 1

This trial was conducted at Kromme Rhee Experimental Farm in the Western Cape (18°50'E, 33°51'S and altitude 177 m). In this trial 180 birds were used, divided into 18 groups with 10 birds allocated per group. Each group was allocated to one of three test diets; there were thus six groups per diet. The three diets were: high energy (H), medium energy (M) and low energy (L) diets. The M energy diet was formulated to have a dietary energy level similar to that of commercially available feeds. The L energy diet was formulated to have 20% less energy than the medium diet and the H energy diet was formulated to have 20% more energy than the medium diet; for each diet the other nutrients were kept constant so that energy alone differed between treatments. The feathers of half the birds on each diet were clipped at six months of age. The feathers were clipped by cutting the wing white feathers with pruning scissors, 2.5 cm from the base of the feathers (Smit, 1964). No significant interaction between the energy level and feather clipping was found in the results by using a factorial analysis and the feathers clipping results are therefore discussed in chapter 7 of this thesis. Refer to Table 6.1 for the proximate analysis and Table 6.2 for the amino acid compositions of the different diets for the different phases. Refer to Tables 6.3, 6.4, 6.5 and 6.6 for the nutrient composition of the different feeds for the different phases.

Table 6.1. *Nutrient composition (as fed basis) and in vitro organic material digestibility (IVOMD) of experimental pre-starter, starter, grower (Trial 1) and finisher (Trial 2) diets*

Nutrient	Pre-starter			Starter			Grower			Finisher		
	L	M	H	L	M	H	L	M	H	L	M	H
ME MJ/kg feed*	13.5	14.5	15.5	12.5	13.5	14.5	10.5	11.5	12.5	9.5	10.5	11.5
Dry material (g/kg)	910.1	912.5	916.5	893.7	899.3	904.1	892.2	888.9	886.5	929.3	927.9	920.9
Crude protein (g/kg)	188.6	184.0	192.8	180.5	172.0	177.4	149.1	142.7	132.9	139.3	132.4	124.2
Ash (g/kg)	93.4	91.4	86.0	101.3	95.1	96.7	102.4	103.1	91.3	165.2	105.6	98.5
IVOMD (g/kg)	820.2	840.3	855.3	799.3	837.0	851.7	739.6	801.5	853.4	626.5	748.2	832.4
Crude fibre (g/kg)	48.0	42.0	35.0	95.5	68.5	41.0	150.0	119.0	80.0	141.0	130.0	105.0
Fat (g/kg)	29.4	45.7	48.9	29.5	42.9	55.1	22.0	22.7	24.1	19.9	25.2	24.4
ADF (g/kg)	117.3	64.6	68.3	125.3	106.5	85.4	290.6	176.3	128.8	234.9	185.9	150.3
NDF (g/kg)	178.0	148.9	145.5	229.5	187.5	136.8	267.3	265.4	210.1	402.6	306.6	215.3
Calcium (g/kg)	16.0	18.1	21.7	17.6	17.2	15.9	12.8	15.7	16.7	18.9	17.8	19.5
Phosphorus (g/kg)	7.20	7.60	7.60	6.80	7.40	8.10	6.10	6.40	6.80	8.20	7.20	6.20

Abbreviations: ADF = acid detergent fibre; NDF = neutral detergent fibre; IVOMD = *in vitro* organic matter digestibility.

*As formulated.

Table 6.2. *The amino acid composition of the feeds on an as-is basis (g/kg) containing three levels of energy (Low: L, Medium: M and High H) fed to ostriches during the pre-starter (0 – 2 months), starter (2 – 4 months), grower (4 – 8 months) in Trial 1 and Finisher (8 – 11.5 months), in Trial 2 on an as-is basis*

Amino acids	Pre-starter			Starter			Grower			Finisher		
	L	M	H	L	M	H	L	M	H	L	M	H
Lysine	11.20	11.50	11.90	8.80	8.90	8.40	7.70	7.60	8.50	6.60	7.60	8.50
Methionine	1.10	1.40	1.40	0.80	0.80	0.80	0.40	0.50	0.50	0.50	0.90	1.10
Arginine	8.90	8.90	9.40	7.60	7.30	6.90	5.50	5.30	5.90	5.80	6.10	6.50
Threonine	6.50	6.40	6.90	5.60	5.50	5.20	4.80	4.50	4.90	4.00	4.50	5.20
Aspartate	15.30	14.90	16.60	14.10	14.40	13.70	14.60	12.90	13.10	11.10	12.40	14.00
Glutamate	35.80	34.50	37.60	30.40	29.60	27.30	19.40	19.90	23.50	23.10	23.50	23.80
Serine	8.30	8.00	8.80	7.20	7.30	6.70	6.50	6.00	6.50	5.70	6.70	7.80
Histidine	4.00	3.80	4.00	3.40	3.40	3.00	2.60	2.50	3.00	2.50	2.80	3.10
Glycine	8.70	9.10	9.10	7.10	6.70	6.10	4.80	4.50	4.80	4.70	5.10	5.80
Alanine	8.80	8.90	9.40	7.20	7.20	6.90	5.70	5.60	6.30	5.10	6.00	7.10
Tyrosine	6.30	6.40	6.70	5.40	5.60	5.20	4.80	4.60	5.10	4.20	5.00	5.80
Valine	9.10	8.90	9.60	8.00	7.90	7.40	7.00	6.60	7.10	6.20	7.20	8.20
Phenylalanine	7.90	7.80	8.60	6.80	7.10	6.60	6.10	5.80	6.40	5.50	6.30	7.20
Isoleucine	6.70	6.80	7.50	5.90	6.00	5.70	5.10	4.90	5.30	4.60	5.30	6.10
Leucine	13.40	13.20	14.80	10.90	11.50	11.20	9.30	9.40	10.80	8.30	9.90	11.70

Table 6.3. *Ingredient and nutrient composition (as fed basis) of experimental diets in the pre-starter phase (kg/ton) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	M	H
Maize meal	501.7	509.1	517.1
Soybean oilcake	160.0	185.0	210.0
Wheat bran	224.0	151.0	77.0
Fishmeal	75.0	75.0	75.0
Vegetable fat	0.00	40.0	80.0
Limestone	22.0	21.0	20.5
Monocalcium phosphate	0.00	1.90	3.80
Synthetic lysine	2.30	2.00	1.60
Salt	10.0	10.0	10.0
Vitamin and mineral premix*	5.00	5.00	5.00

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 6.4. *Ingredient and nutrient composition (as fed basis) of experimental diets in the starter phase (kg/ton) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	M	H
Maize meal	301.7	425.0	548.3
Soybean oilcake	105.4	146.3	187.3
Wheat bran	390.0	197.0	3.90
Fishmeal	48.8	48.8	48.8
Lucerne	97.6	97.6	97.6
Plant oil	0.00	24.4	48.8
Molasses	24.4	24.4	24.4
Monocalcium phosphate	0.00	7.10	14.2
Limestone	17.4	14.7	12.0
Salt	9.80	9.80	9.80
Vitamin and mineral premix*	4.90	4.90	4.90

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 6.5. *Ingredient and nutrient composition (as fed basis) of experimental diets in the grower phase (kg/ton) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	M	H
Maize meal	253.9	413.1	572.3
Soybean oilcake	76.8	89.4	102.0
Lucerne	610.0	431.7	253.4
Molasses	25.0	25.0	25.0
Monocalcium phosphate	17.1	17.05	17.0
Salt	10.0	10.0	10.0
Limestone	0.00	6.65	13.3
Vitamin and mineral premix*	5.0	5.0	5.0
Synthetic lysine	0.81	1.3	1.82
Synthetic methionine	1.4	0.8	0.23

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 6.6. *Ingredient and nutrient composition (as fed basis) of experimental diets in the finisher phase (kg/ton) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	M	H
Maize meal	100.0	250.0	400.0
Oat hulls	397.0	198.5	0.00
Soybean oilcake	113.3	98.0	82.8
Lucerne	100.0	261.1	422.2
Molasses	50.0	50.0	50.0
Monocalcium phosphate	20.8	19.1	17.3
Salt	10.0	10.0	10.0
Limestone	15.0	10.7	6.42
Wheat bran	191.1	99.0	6.86
Vitamin and mineral premix*	2.00	2.00	2.00
Synthetic methionine	0.78	1.61	2.44

*Refer to ANNEXURE A, Table A for the composition of the premix.

Trial 1 was only completed until the end of the grower phase (eight months of age), due to the birds having to be slaughtered at that time as it was thought that they might be at risk of contracting bird flu.

For each treatment, feed and water were available *ad libitum,* and feed intake was determined by weighing the feed in and weighing back refusals at each point of data collection, intake was therefore determined weekly. The average daily gain (ADG) was determined by fitting a linear regression model to the live weight data and using the gradient as the ADG. During the statistical analysis of the mean weight at the end of each phase, the end weights from the previous phases were included as covariates to avoid any carry-over effects.

At eight months of age, the ostriches were slaughtered at Ostriswell abattoir in Swellendam using standard slaughtering procedures as described by Hoffman (2012). The organs and other tissues of each bird were weighed in order to determine the effect of the dietary energy level. The organs and tissues considered included the gizzard, heart, liver, lungs and kidneys, fat plate and chest bone. The carcasses were then placed in a cold room overnight to cool and the cold carcass weights were recorded the following day. Dressing percentage was calculated as follows: cold carcass weight/live weight*100.

The carcasses were transported to the deboning facility at Klein Karoo International Ltd in Oudtshoorn. There the carcasses were deboned, and the neck, tibia, femur, whole thigh, as well as patella were weighed. The meat was weighed per commercial cut for one of the thighs of each ostrich. The commercial cuts that were weighed included the fan fillet *Muscularis iliofibularis*, rump steak *M. iliotibialis lateralis*, moon steak *M. femorotibialis medius*, triangle steak *M. flexor cruris lateralis*, big drum *M. gastrocnemius*, flat drum *M. gastrocnemius*, drum steak *M. gastrocnemius*, tenderloin *M. obturatorius medialis*, eye fillet *M. iliofemoralis*, tornedo *M. ambiens*, long fillet *M. ambiens*, oyster fillet *M. iliofemoralis externus*, small steak *M. flexor cruris medialis*, minute 1 *M. femorotibialis externus*, minute 2 *M. femorotibialis externus*, small drum *M. fibularis longus* and tender steak *M. pubio-ischio-femoralis* (Kritzinger, 2011; Anon, 2013; Stadelman *et al*., 2013). The pH and the temperature of the big drum and fan fillet were also recorded at deboning.

The big drum (*M. gastrocnemius*) muscles were collected and further analysed in the meat laboratory at Stellenbosch University, where the dorsal part of the muscle was removed and minced. The minced part was freeze-dried with a Virtis benchtop K and ground with a Knifetec 1095 Sample Mill (Tecator, Box 70, S-263 21 Hoganäs, Sweden) using a 1 mm sieve before being analysed for chemical composition. The crude protein (CP) was measured

by a FP-428 Nitrogen and Protein Determinator (Leco Corporation, 3000 Lakeview Avenue, St Joseph, MI 49085-2396). Lipid (petroleum ether extraction) was measured according to AOAC (2002) (Method number 7.061). Dry matter (DM) was determined by drying a sample (*ca*. 1.0 g) at 100 °C to a constant weight and ash content by placing the sample in a furnace at 500 °C overnight (AOAC, 2002) (Method numbers 7.003 and 7.009, respectively).

In addition to the chemical analyses, the following procedures were done on meat samples that were brought back to Stellenbosch:

One large meat sample was taken from the right *M. gastrocnemius* of each carcass and used to determine drip loss, cooking loss, Warner-Bratzler shear force values and colour measurements on the meat of birds in all treatments. These samples were analysed according to the method described by Honikel (1998).

The percentage drip loss was determined by hanging individually weighed samples (sample weight between 50 g and 100 g) in inflated polythene bags for 24 hours at ± 4 °C in a cold room. Care was taken that the samples did not touch the sides of the inflated bags. After 24 hours, the samples were removed and weighed, and the percentage drip loss calculated as the amount of weight lost from the sample during the 24 hours that the sample spent in the polythene bag.

The percentage cooking loss was calculated by weighing the raw meat samples (50 g to 100 g), then placing them in polythene bags in a water bath at a temperature of 80 °C for 50 minutes. The samples were then removed from the water bath, the water drained from the bags and the samples (still in the bags) cooled under running water to ± 20 °C. After cooling, the samples were removed from the bags, patted dry with tissue paper and subsequently weighed. The percentage cooking loss was calculated as the amount of weight lost by each sample during the cooking period.

The cooled meat samples used in the above mentioned cooking-loss procedure were then used to determine tenderness using a Warner-Bratzler device, with a load of 2.000 kN, attached to a Instron (Model 4444) Testing Instrument. Five cylindrical core samples, each with a diameter of 1.27 cm, were cut from each cooked piece of muscle (five pieces from ach bird) at random locations on the cooked piece. Maximum Warner-Bratzler shear force values were recorded by shearing the cylindrical core of cooked muscle perpendicular to the longitudinal orientation of the muscle fibres at a crosshead speed of 200 mm/min. An average shear force value (N) was calculated for each bird. Care was taken to avoid cylindrical core samples that contained visible connective tissue that could influence shear force results. Colour was measured by a colour guide (BYK Gardner, USA); more specifically the CIELab

colour scale (Commission International de L'Eclairage, 1976); as proposed by Honikel (1998). This is commonly used in meat analysis trials to measure meat colour instrumentally. The CIELab colour scale has three parameters, namely *L*, a** and *b*,* with the hue angle and chroma being calculated from these three colour measurements. The *L** value indicates lightness, the *a** value indicates the red-green range and the *b** value indicates the blue-yellow range; the hue angle and chroma values are an indication of colour definition and colour intensity respectively (Honikel, 1998).

The average diameter of ten randomly selected wing feathers per bird was calculated and statistical analysis was done on these averages. The skins were tanned, and the surface areas determined and graded at Klein Karoo International Ltd. The skins were then returned to the laboratory, where a number of quality parameters were measured. These quality parameters included nodule density, nodule size and pin-hole density.

The number of nodules in a 10 cm × 10 cm square was counted at five localities on the skin as indicated in Figure 6.1. Additionally, five nodules per locality were measured in diameter and an average was calculated.

In previous studies (Engelbrecht *et al*., 2009; Engelbrecht *et al*., 2012), a subjective scoring system was used for pin holes, however in this study an objective approach was used. Pin holes at the same five localities were counted in a 5 cm × 5 cm square. The reason for counting at five localities and not only one is due to low genetic correlations between these five localities (Cloete *et al*., 2006).

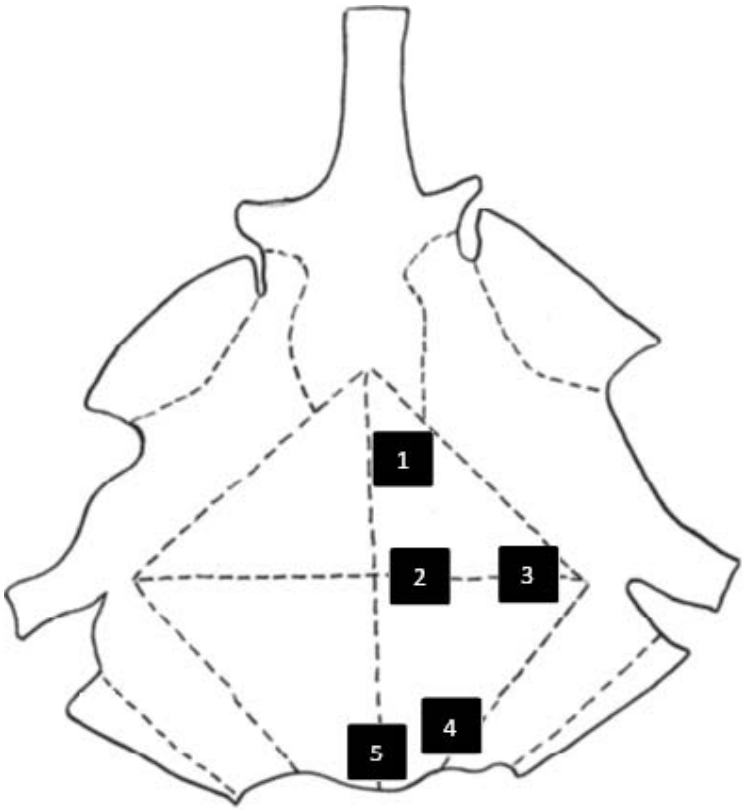

Figure 6.1. *The different localities (numbered 1-5) where nodules and pin holes were counted and measured.*

The data were analysed using the GLM Procedure of SAS statistical software version 9.1 (SAS, 2000). Diet was used as the main effect (classification variable). Tests for homoscedasticity were done using Levene's test. Homoscedastic data were analysed and interpreted using one way ANOVA'S and hetroscedastic data were analysed and interpreted using the Welch ANOVA.

Trial 2

Trial 2 was conducted at the farm *Drie Riviere* in the Prince Albert district, Klein Karoo, Western Cape (22° 3'E, S 33° 11'S and altitude 428, 25 m). In this Trial, 300 eight-month-old ostriches were used. These were divided into six groups (six paddocks) of 50 birds each. The trial tested the three different dietary energy levels described for trial 1 for use in the finisher phase.

For each treatment feed and water was available *ad libitum*. The feed intake was determined by the difference between the weight of the offered feed and the refusals, this was

done monthly. The average daily gain was determined by fitting a linear regression model to the live weight data over time and using the gradient as the ADG. The feathers of half the birds on each diet in this trial were clipped at eight months of age. The feathers were clipped by cutting the wing white feathers with pruning scissors, 2.5 cm from the base of the feathers (Smit, 1964). In the results no significant interaction between the energy level and feathers-clipped or between sex and feathers-clipped was found, thus the feathers-clipped results are discussed in chapter 7 of this thesis.

The birds were slaughtered at an age of 11.5 months at Klein Karoo International abattoir in Oudtshoorn using standard slaughtering procedures as described by Hoffman (2012). Dressing percentage was calculated as follows: cold carcass weight/live weight*100. Basic carcass data were collected and feathers were collected per bird and transported to the feathers department at Klein Karoo International for drying. The feathers were dried for 47.5 hours at 50 °C and then for 30 minutes at 70 °C, after which they were separated/classed into the economically important types of feathers per bird. The different classes of feathers were then weighed, these classes include: “male body short”, “blondene light tipless”, “male bodies long”, “drab body short”, “drab body slope”, “female wing”, “male wing”, “reject wings”, “drab dry points”, “drab silver floss”, “drab bloods” and “young bird floss”. The diameters of the shafts of ten randomly selected wing feathers were measured in millimetres at the base (point of skin entry) using a digital calliper for each bird. The average diameter of the ten feathers was calculated and the statistical analyses were done on this averages using proc GLM in SAS.

The skins in trial 2 were handled similarly to those in trial 1.

6.3. RESULTS

Trial 1

None of the data from Trial 1 indicated any significant interaction between the different treatments, thus allowing treatments to be interpreted individually. The different dietary energy levels influenced the weights of lungs and kidneys, wet feathers, gizzard, fat plate, chest bone, thigh, live weight and carcass weight (Tables 6.7, 6.8, 6.9). The following commercial steak cuts were influenced by the dietary energy level: fan fillet, tenderloin, big drum and moon steak (Table 6.9).

Table 6.7. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of dietary energy concentrations on the organ and tissue weights of slaughter ostriches in Trial 1*

Organ/tissue weight (kg)	Dietary energy concentrations		
	L	M	H
Wet feathers	$0.75^{ab} \pm 0.02$	$0.82^{a} \pm 0.02$	$0.70^{b} \pm 0.02$
Heart	0.56 ± 0.02	0.62 ± 0.02	0.57 ± 0.02
Liver	1.2 ± 0.03	1.21 ± 0.03	1.14 ± 0.03
Lungs and kidneys	$0.92^{a} \pm 0.03$	$1.04^{b} \pm 0.02$	$0.93^{a} \pm 0.03$
Gizzard	$0.38^{a} \pm 0.01$	$0.34^{b} \pm 0.01$	$0.25^{c} \pm 0.01$
Fat plate	$0.86^{a} \pm 0.13$	$1.62^{b} \pm 0.12$	$1.18^{ab} \pm 0.14$
Chest bone	$0.36^{a} \pm 0.02$	$0.44^{b} \pm 0.02$	$0.38^{a} \pm 0.02$
Tibia	2.57 ± 0.05	2.67 ± 0.05	2.54 ± 0.06
Femur	1.21 ± 0.03	1.26 ± 0.02	1.18 ± 0.03
Patella	0.63 ± 0.24	0.26 ± 0.23	0.21 ± 0.27
Neck	1.46 ± 0.03	1.55 ± 0.03	1.44 ± 0.04

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 6.8. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of dietary energy concentrations on the slaughter- and meat quality parameters (M. gastrocnemius) and the proximate analysis of the M. gastrocnemius of slaughtered ostriches in Trial 1*

Parameter	Dietary energy concentrations		
	L	M	H
Production parameters:			
Live weight (kg)	57.1[a] ± 2.27	66.9[b] ± 1.41	57.9[a] ± 2.45
Carcass weight (kg)	27.9[a] ± 1.24	33.3[b] ± 0.77	29.0[a] ± 1.34
Dressing percentage (%)	49.0 ± 1.30	50.0 ± 0.81	49.9 ± 1.40
Meat quality parameters:			
Shear force (N)	41.1 ± 1.80	41.5 ± 1.93	38.9 ± 2.16
Colour: L*	31.6 ± 0.36	32.0 ± 0.39	32.4 ± 0.43
Colour: a*	17.7 ± 0.31	18.1 ± 0.33	18.2 ± 0.37
Colour: b*	8.47 ± 0.22	8.86 ± 0.24	8.9 ± 0.27
Cooking loss (%)	37.6 ± 0.66	38.4 ± 0.71	38.0 ± 0.79
Drip loss (%)	0.61 ± 0.03	0.57 ± 0.03	0.57 ± 0.03
pH big drum	6.04 ± 0.04	6.02 ± 0.04	6.04 ± 0.04
Temperature big drum (°C)	5.64 ± 0.33	5.84 ± 0.31	5.30 ± 0.37
pH fan fillet	6.15 ± 0.04	6.08 ± 0.03	6.09 ± 0.04
Temperature fan fillet (°C)	4.78 ± 0.28	4.76 ± 0.26	4.48 ± 0.31
Proximate analysis:			
DM (g/kg)	217.0 ± 1.60	218.0 ± 1.60	217.0 ± 1.90
Protein (g/kg)	190.0 ± 1.50	189.0 ± 1.50	187.0 ± 1.80
Fat (g/kg)	5.10 ± 0.40	6.20 ± 0.40	6.40 ± 0.50
Ash (g/kg)	10.1 ± 0.10	10.0 ± 0.10	10.1 ± 0.10

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 6.9. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of dietary energy concentrations on different commercial steaks of slaughtered ostriches in Trial 1*

Commercial steaks (kg)	Dietary energy concentrations		
	L	M	H
Carcass weight	27.9[a] ± 1.24	33.3[b] ± 0.77	29.0[a] ± 1.34
Thigh weight	23.5[a] ± 0.65	25.5[ab] ± 0.60	22.8[b] ± 0.72
Total steaks from thigh	12.3 ± 0.38	13.5 ± 0.37	11.8 ± 0.43
Fan fillet	1.90 [a] ± 0.07	2.16[b] ± 0.07	1.86[a] ± 0.08
Rump steak	1.51 ± 0.06	1.68 ± 0.06	1.50 ± 0.07
Moon steak	1.14[ab] ± 0.08	1.38[a]± 0.07	1.09[b] ± 0.08
Triangle steak	0.39 ± 0.02	0.45 ± 0.02	0.41 ± 0.03
Big drum	1.39[ab] ± 0.05	1.52[a] ± 0.04	1.31[b] ± 0.05
Flat drum	1.02 ± 0.03	1.10 ± 0.04	0.96 ± 0.04
Drum steak	0.75 ± 0.03	0.78 ± 0.03	0.69 ± 0.03
Tenderloin	0.58[ab] ± 0.02	0.64[a] ± 0.02	0.55[b] ± 0.02
Eye fillet	0.57 ± 0.02	0.63 ± 0.02	0.58 ± 0.03
Tornedo	0.28 ± 0.01	0.31 ± 0.01	0.28 ± 0.01
Long fillet	0.58 ± 0.03	0.66 ± 0.03	0.58 ± 0.03
Oyster fillet	0.61 ± 0.03	0.68 ± 0.02	0.61 ± 0.03
Small steak	0.22 ± 0.01	0.23 ± 0.01	0.20 ± 0.01
Small drum	0.40 ± 0.02	0.44 ± 0.02	0.39 ± 0.02
Tender steak	0.50[ab] ± 0.02	0.55[a] ± 0.02	0.46[b] ± 0.02
Minute 1	0.17 ± 0.01	0.19 ± 0.01	0.17 ± 0.01

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Of all the measured skin parameters, the number of pin holes at locality 5, average number of nodules, crust size and crust grade were influenced significantly by the energy content of the feed (Table 6.10). The average number of nodules was found to be significantly greater in birds fed the high-energy diet.

Table 6.10. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of different dietary energy concentrations on skin size, grading and measurements of slaughtered ostriches in Trial 1*

Skin parameter	Dietary energy concentrations		
	L	M	H
Crust size ($dm^{2)}$	$121.3^{a} \pm 2.07$	$123.2^{a} \pm 2.18$	$115.2^{b} \pm 2.08$
Crust grade*	$2.10^{a} \pm 0.14$	$2.63^{b} \pm 0.15$	$2.42^{ab} \pm 0.14$
Skin thickness (mm)	1.52 ± 0.12	1.53 ± 0.06	1.39 ± 0.10
Nodule size locality 1 (mm)	3.08 ± 0.12	3.18 ± 0.07	3.03 ± 0.10
Nodule size locality 2 (mm)	3.00 ± 0.13	3.22 ± 0.07	2.99 ± 0.10
Nodule size locality 3 (mm)	3.97 ± 0.09	3.87 ± 0.17	3.92 ± 0.14
Nodule size locality 4 (mm)	4.06 ± 0.09	3.82 ± 0.17	3.88 ± 0.14
Nodule size locality 5 (mm)	3.71 ± 0.07	3.42 ± 0.14	3.53 ± 0.11
Average nodule size (mm)	3.48 ± 0.98	5.93 ± 1.06	3.32 ± 0.97
Number of nodules locality 1	56.4 ± 3.60	56.4 ± 1.91	54.8 ± 2.95
Number of nodules locality 2	63.8 ± 3.89	57.7 ± 2.06	62.1 ± 3.18
Number of nodules locality 3	30.8 ± 1.99	29.7 ± 1.06	30.5 ± 1.63
Number of nodules locality 4	36.0 ± 2.13	35.8 ± 1.13	36.5 ± 1.74
Number of nodules locality 5	62.9 ± 3.56	59.2 ± 1.88	63.2 ± 2.91
Average number of nodules	$47.0^{a} \pm 0.95$	$47.4^{a} \pm 1.03$	$50.9^{b} \pm 0.94$
Number of pin holes locality 1	59.7 ± 10.05	49.3 ± 5.32	43.9 ± 8.23
Number of pin holes locality 2	68.2 ± 9.67	47.2 ± 5.12	45.6 ± 7.92
Number of pin holes locality 3	12.7 ± 3.16	13.5 ± 1.67	9.1 ± 2.58
Number of pin holes locality 4	13.5 ± 3.48	13.3 ± 1.84	13.2 ± 2.85
Number of pin holes locality 5	$89.3^{a} \pm 6.48$	$54.0^{b} \pm 6.48$	$53.9^{b} \pm 10.01$
Average number of pin holes	40.9 ± 3.04	34.9 ± 3.28	32.3 ± 3.00

$^{a - b}$ Rows means with different superscripts differ significantly ($P \leq 0.05$).

*Skins are graded from 1 – 4 with grade 1 as the best.

The average daily gain (ADG) was significantly influenced by the level of energy, favouring the medium diet in the starter and grower phases. Dietary energy content only influenced voluntary feed intake during the starter phase, at which point it was found that intake was highest for the medium energy level. The FCR was also influenced by the diet, with significantly better (lower) values being found for the medium diet than the other two treatments during the pre-starter, starter and grower phases. The mean weight at the end of

the starter and grower phases was significantly affected by the diet, with the highest weight in the starter phase for the medium diet and the highest weights for the grower phase for the L and M diets (Table 6.11).

Table 6.11. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of different dietary energy concentrations on production parameters of slaughtered ostriches in Trial 1*

Phase*	Dietary energy concentrations		
	L	M	H
Average daily gain (g/bird/day):			
Pre-starter	162.0 ± 5.99	174.7 ± 6.05	161.8 ± 6.72
Starter	434.2^{a} ± 6.76	462.5^{b} ± 6.48	430.8^{a} ± 7.44
Grower	281.6^{a} ± 5.85	302.3^{b} ± 5.60	254.7^{c} ± 6.42
Feed intake (kg/bird/day):			
Pre-starter	0.24 ± 0.02	0.29 ± 0.02	0.24 ± 0.02
Starter	0.94^{a} ± 0.04	1.10^{b} ± 0.04	0.85^{a} ± 0.04
Grower	1.84 ± 0.11	1.91 ± 0.11	1.73 ± 0.11
Feed conversion ratio (kg feed/kg weight gain):			
Pre-starter	2.88^{a} ± 0.11	2.06^{b} ± 0.11	2.04^{b} ± 0.10
Starter	3.05^{a} ± 0.14	2.03^{b} ± 0.13	2.20^{b} ± 0.13
Grower	4.05^{a} ± 0.13	3.40^{b} ± 0.10	3.96^{a} ± 0.10
Mean weight at end of phase (kg):			
Pre-starter	8.85 ± 0.39	9.53 ± 0.41	8.69 ± 0.45
Starter	39.9^{a} ± 0.81	44.1^{b} ± 0.85	39.6^{a} ± 0.93
Grower	70.9^{a} ± 1.19	71.5^{a} ± 1.24	66.0^{b} ± 1.33

$^{a - b}$ Rows means with different superscripts differ significantly ($P \leq 0.05$).

*****Phase: Pre-Starter 0 – 81 days, Starter 82 – 147 days, Grower 148 – 240 days.

Trial 2

There were no interactions between treatments, thus the main effects were interpreted separately for trial 2. The ADG was significantly higher for the males (374.2 ± 2.18 g/bird/day) opposed to the females (334.8 ± 2.12 g/bird/day). Live weight, carcass weight and the weight of the total feathers with commercial value were influenced by the sex of the animals, with higher values being found for male birds although sexual maturity was not reached by the time of slaughter (Table 6.12).

Table 6.12. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of sex on production parameters and feather measurements of slaughtered ostriches in Trial 2*

Parameter	Male	Female
Production parameters:		
Live weight	100.7[a] ± 0.80	98.1[b] ± 0.78
ADG (g/bird/day)	347.2[a] ± 2.18	334.8[b] ± 2.12
Cold carcass weight (kg)	43.8[a] ± 0.35	42.9[b] ± 0.34
Dressing %	0.49 ± 0.01	0.48 ± 0.01
Feather parameters:		
Feathers with commercial value (kg)	0.82[a] ± 0.02	0.76[b] ± 0.01
Average shaft thickness (mm)	6.86 ± 0.10	6.69 ± 0.010
Adult wings (kg)	0.13 ± 0.01	0.11 ± 0.01
Chick wings (kg)	0.05 ± 0.01	0.07 ±0.01
Drab body slope (kg)	0.03 ± 0.01	0.04 ± 0.01
Chick body floss (kg)	0.11[a] ± 0.01	0.14[b] ± 0.01
Adult tails butts (kg)	0.08 ± 0.01	0.07 ± 0.01
Drab bloods (kg)	0.28[a] ± 0.01	0.22[b] ± 0.01
Young bird floss (kg)	0.07[a] ± 0.01	0.03[b] ± 0.01

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

The dietary energy level influenced the production parameters live weight and ADG; and the feather parameters: feathers with commercial value, average shaft thickness, “chick body floss”, “drab bloods”, and “young bird floss” (Table 6.13).

Table 6.13. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of different dietary energy concentrations on production parameters and feather measurements of slaughtered ostriches in Trial 2*

Parameter	Dietary energy concentrations		
	L	M	H
Production parameters:			
Live weight	97.6 [a] ± 0.96	98.8[ab] ± 0.96	101.9[b] ± 0.98
Average daily gain (g/bird/day)	336.9[a] ± 2.60	338.0[a] ± 2.62	348.2[b] ± 2.65
Feed intake (kg/bird/day)	3.71 ± 0.08	3.49 ± 0.08	3.37 ± 0.08
Feed conversion ratio (kg feed/kg weight gained)	13.6 ± 0.47	11.6 ± 0.47	12.0 ± 0.47
Cold carcass weight (kg)	43.1 ± 0.43	42.9 ± 0.42	43.7 ± 0.43
Dressing %	0.50 ± 0.01	0.48 ± 0.01	0.48 ± 0.01
Feather parameters:			
Feathers with commercial value (g)	0.75[a] ± 0.01	0.82[b] ± 0.02	0.80[ab] ± 0.02
Average shaft thickness (mm)	6.53[a] ± 0.12	6.74[ab] ± 0.12	7.06[b] ± 0.12
Adult wings (kg)	0.11 ±0.01	0.12 ± 0.01	0.13 ±0.01
Chick wings (kg)	0.05 ± 0.01	0.07 ± 0.01	0.06 ± 0.01
Drab body slope (kg)	0.05 ± 0.01	0.03 ± 0.01	0.04 ± 0.01
Chick body floss (kg)	0.12[a] ± 0.01	0.10[a] ± 0.01	0.16[b] ± 0.01
Adult tails butts (kg)	0.06 ± 0.01	0.08 ± 0.01	0.09 ± 0.01
Drab bloods (kg)	0.22[a] ± 0.02	0.29[b] ± 0.02	0.23[a] ± 0.02
Young bird floss (kg)	0.07[a] ± 0.01	0.07[a] ± 0.01	0.02[b] ± 0.01

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Sex had an influence on the crust grade, nodule size at locality 2 and 3, number of nodules at locality 2 and average number of pin holes (Table 6.14). Birds on the low energy diet were found to have skins with more nodules at locality 1, 2 and 3 and more pinholes at locality 5. Skins from birds on the high energy diet had a significantly ($P \leq 0.05$) larger crust size than skins from other treatments (Table 6.15).

Table 6.14. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of sex on skin size, grading* and measurements of slaughtered ostriches in Trial 2*

Skin parameter	Female	Male
Crust size (dm^2)	142.1 ± 0.40	142.5 ± 0.41
Crust grade*	2.78^a ± 0.08	2.54^b ± 0.09
Skin thickness (mm)	2.50 ± 0.06	2.55 ± 0.07
Nodule size locality 1 (mm)	3.83 ± 0.05	3.83 ±0.05
Nodule size locality 2 (mm)	3.53^a ± 0.04	3.65^b ± 0.04
Nodule size locality 3 (mm)	4.60^a ± 0.05	4.75^b ± 0.05
Nodule size locality 4 (mm)	4.29 ± 0.05	4.29 ± 0.06
Nodule size locality 5 (mm)	4.11 ± 0.06	4.14 ± 0.06
Average nodule size (mm)	4.08 ± 0.03	4.14 ± 0.04
Number of nodules locality 1	49.4 ± 0.75	49.0 ± 0.79
Number of nodules locality 2	57.5^a ± 0.90	54.1^b ± 0.95
Number of nodules locality 3	26.9 ± 0.39	26.4 ± 0.41
Number of nodules locality 4	32.1 ± 0.62	31.7 ± 0.66
Number of nodules locality 5	55.1 ± 0.91	52.2 ± 0.97
Average number of nodules	54.6 ± 1.92	55.4 ± 2.06
Number of pin holes locality 1	67.1 ± 2.76	72.9 ± 2.97
Number of pin holes locality 2	69.4 ± 3.07	68.4 ± 3.29
Number of pin holes locality 3	28.0 ± 1.39	30.0 ± 1.49
Number of pin holes locality 4	31.7 ± 1.83	33.0 ± 1.96
Number of pin holes locality 5	78.4 ± 3.33	78.7 ± 3.57
Average number of pin holes	44.1^a ± 0.45	42.6^b ± 0.48

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

*Skins are graded from 1 – 4 with grade 1 as the best.

Table 6.15. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of different dietary energy concentrations on skin size, grading and measurements of slaughtered ostriches in Trial 2*

Skin parameter	Dietary energy concentrations		
	L	M	H
Crust size (dm^2)	$141.5^{a} \pm 0.49$	$142.0^{ab} \pm 0.50$	$143.4^{b} \pm 0.50$
Crust grade*	2.84 ± 0.10	2.57 ± 0.10	2.56 ± 0.10
Skin thickness (mm)	2.57 ± 0.08	2.54 ± 0.08	2.56 ± 0.08
Nodule size locality 1 (mm)	3.87 ± 0.06	3.79 ± 0.06	3.83 ± 0.06
Nodule size locality 2 (mm)	3.61 ± 0.05	3.57 ± 0.05	3.60 ± 0.05
Nodule size locality 3 (mm)	4.72 ± 0.06	4.62 ± 0.06	4.68 ± 0.06
Nodule size locality 4 (mm)	4.30 ± 0.07	4.33 ± 0.07	4.24 ± 0.07
Nodule size locality 5 (mm)	4.15 ± 0.07	4.05 ± 0.07	4.17 ± 0.07
Average nodule size (mm)	4.13 ± 0.04	4.08 ± 0.04	4.12 ± 0.04
Number of nodules locality 1	$51.2^{a} \pm 0.94$	$49.0^{ab} \pm 0.96$	$47.4^{b} \pm 0.92$
Number of nodules locality 2	$58.1^{a} \pm 1.12$	$54.7^{b} \pm 1.16$	$54.6^{b} \pm 1.11$
Number of nodules locality 3	$26.8^{ab} \pm 0.49$	$27.5^{a} \pm 0.50$	$25.5^{b} \pm 0.48$
Number of nodules locality 4	31.4 ± 0.78	33.0 ± 0.80	31.3 ± 0.76
Number of nodules locality 5	55.8 ± 1.65	54.5 ± 1.61	52.6 ± 1.54
Average number of nodules	59.0 ± 2.42	53.1 ± 2.45	52.9 ± 2.35
Number of pin holes locality 1	75.1 ± 3.51	68.4 ± 3.59	66.5 ± 3.41
Number of pin holes locality 2	75.2 ± 3.89	66.3 ± 3.98	65.2 ± 3.79
Number of pin holes locality 3	28.9 ± 1.77	29.3 ± 1.81	28.8 ± 1.72
Number of pin holes locality 4	33.3 ± 2.32	29.9 ± 2.37	33.8 ± 2.56
Number of pin holes locality 5	$88.3^{a} \pm 4.22$	$71.7^{b} \pm 4.31$	$75.7^{ab} \pm 4.10$
Average number of pin holes	$44.6^{a} \pm 0.56$	$43.7^{a} \pm 0.58$	$42.1^{b} \pm 0.55$

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

*Skins are graded from 1 – 4 with grade 1 as the best.

6.4. DISCUSSION

Overall, the medium diet resulted in higher means for the individual muscle weights, as well as live weight and carcass weight. In terms of the effect of dietary energy levels on organ development, an inverse correlation between energy level and gizzard weight was found. In other words, as the level of energy increased, the weight of the gizzard decreased (Table 6.7). This may be due to the higher fibre levels in the lower energy diet as the gizzard would have functioned more intensely and thus been larger with higher levels of fibre. Contrary to

expectations, the fat plate of chicks on the medium diet had a higher mean weight than that of those on either the lower or higher energy diets. However it must be noted that the birds were only at the grower stage at slaughter and it is possible that the results would have been different had the birds been slaughtered at a later stage.

The results from the second trial, regarding the finisher phase, clearly indicated that the cold weight, ADG and most of the measured feather parameters were higher for male birds. It is not uncommon for male birds at this body weight to start showing secondary sexual characteristics such as different feather plummage. This may suggest that male and female ostriches have different nutrient requirements, especially as they reach sexual maturity; this aspect warrants further research.

Concerning the skin parameters for the birds slaughtered at eight months of age, the crust size was higher for the low and medium energy diets, which was expected due to the better growth of the birds in these groups than those on the higher energy diet. Overall, the crust grade was best (lowest) for the birds on the low energy diet.

The skins of the birds slaughtered at 11 months of age had larger nodules for males at locality 2 and 3; this may be due to the more rapid growth observed in male birds. Furthermore, the crust grade was better for males, which may be due to the skins being larger, as males have a larger body size at the same age. The nodule density was the highest for the low energy diet at locality 1, 2 and 3; which may be due to the birds being smaller and thus having smaller skins with more nodules per area.

Concerning the feather parameters, the average shaft thickness was the highest for the high energy diet, then medium and then low. This was expected as the birds had more energy from feed to utilise for feather growth.

Concerning the production parameters of this study, in the pre-starter phase the ADG, feed intake and final weight at the end of the phase were not influenced by the energy concentration, but the FCR was significantly lower (better) for the M (2.06 ± 0.11 kg feed ingested/kg weight accreted) and H (2.04 ± 0.10 kg feed ingested/kg weight accreted) diets than for the L (2.88 ± 0.11 kg feed ingested/kg weight accreted) diet. The dietary energy levels fed in this phase were L: 13.5 MJ ME/kg feed, M: 14.5 MJ ME/kg feed and H: 15.5 MJ ME/kg feed.

In the starter phase, the ADG, feed intake, FCR and mean weight at the end of the phase were significantly influenced by the diet. The ADG was the highest for the M (462.5 ± 6.48 g/bird/day) diet, the FCR was the lowest for the H (2.20 ± 0.13 kg feed ingested/kg weight accreted) and M (2.03 ± 0.13 kg feed ingested/kg weight accreted) diets and the feed

intake was the highest for the M (1.10 ± 0.04 kg/bird/day) diet. The birds on the M diet had significant higher end weights than the birds on the other treatments. The dietary energy levels fed in this phase were: L: 12.5 MJ ME/kg feed, M: 13.5 MJ ME/kg feed and H: 14.5 MJ ME/kg feed. These results are in contrast to those found for ADG and feed intake by Salih *et al*. (1998) in the starter phase. These authors found that there were no significant differences for feed intake and ADG between diets containing 12 MJ ME/kg feed and 14.5 MJ ME/kg feed. However, similar results to this investigation were found in the same study for the FCR, with no significant differences between diets containing 12 MJ ME/kg feed and 14.5 MJ ME/kg feed.

In the grower phase the ADG, FCR and the mean weight at the end of the phase were influenced by the diet, but not the feed intake. The ADG was the highest for the M (302.3 ± 5.60 g/bird/day) diet while the FCR was the lowest (best) for the M (3.40 ± 0.10 kg feed ingested/kg weight accreted) diet. The L (70.9 ± 1.19 kg) and M (71.5 ± 1.24 kg) diets had significantly higher values than the H (66.01 ± 1.33 kg) treatment for the mean weight at the end of the phase. The dietary energy levels fed in this phase were L: 10.5 MJ ME/kg feed, M: 11.5 MJ ME/kg feed and H: 12.5 MJ ME/kg feed.

This study was a follow-up to a study by Brand *et al.* (2004) which showed an optimum energy level of 12.5 MJ ME/kg feed for the grower phase, when the following diets were fed to the ostriches. 8.5, 10.5 and 12.5 MJ ME/kg feed. However, this study was done on a more narrow range of feeds to obtain more accurate results.

The study by Brand *et al.* (2004) followed an earlier study by Brand *et al.* (2000) where diets containing 9.0, 10.5 and 12 MJ ME/kg were fed to ostriches during the grower and finisher phases and no significant growth differences were noted. There was, however, a higher feed intake as the energy concentration decreased (different to our results). A better (lower) FCR was obtained for the lower energy levels than for the high level, which is in agreement with our results.

Salih *et al*. (1998) found different results for this phase however. With no differences being found for the ADG or FCR when the dietary energy levels were 9 MJ ME/kg feed, 11.5 MJ ME/kg feed and 14 MJ ME/kg feed. However a lower feed intake with the 14 MJ ME/kg feed diet was found.

Different results were also found by Glatz *et al*. (2008), namely that an energy concentration of 10 MJ ME/kg feed resulted in the highest weight gain during the grower phase. The following energy levels were compared in that study: 10 MJ ME/kg feed, 10.7 MJ ME/kg feed and 12.5 MJ ME/kg feed.

In the finisher phase, concerning the production data, only the ADG was influenced by energy levels; with the highest ADG (348 g/day) being recorded for the H treatment. The dietary energy levels fed in this phase were L: 9.5 MJ ME/kg feed, M: 10.5 MJ ME/kg feed and H: 11.5 MJ ME/kg feed. This is in agreement with the results of Swart and Kemm (1985). Additionally it was found that the FCR improved as the dietary energy increased. The levels of dietary energy tested in the study by these authors were: 8.1 MJ DE/kg feed, 9.6 MJ DE/kg feed and 10.7 MJ DE/kg feed.

A study by Brand *et al.* (2004b) also concluded that the optimum level of energy in the finisher phase is 11.5 MJ ME/kg feed, with the lowest intake of 2.79 kg feed/day, the highest ADG of 255 g/day and lowest FCR of 11.7. The levels tested in the study of Brand *et al.* (2004b) were 7.5, 9.5 and 11.5 MJ ME/kg feed. Contradictory to this study, these authors found that tanned skin size was smaller for the groups fed lower energy diets and the number of nodules per dm^2 was correspondingly higher in the groups consuming diets with a lower energy content. In an earlier study by Brand *et al.* (2000), diets containing the following energy values were fed to ostriches during the finisher phase: 9.0 (L), 10.5 (M) and 12 (H) MJ ME/kg feed, but no significant growth differences were observed. In the same study there was, however, a higher feed intake as the energy concentration decreased (2.41, 2.63 and 2.90 kg/bird/day respectively for H, M and L). A better (lower) FCR was obtained for the lower energy levels than for the high level. The skin surface area was significantly higher for the high and medium energy levels than the low treatment (138 dm^2 and 138 dm^2, respectively).

Cloete *et al.* (2006) found that the raw skin weight and skin thickness increased as the energy level of the feed increased. The trial diets that were fed contained the following energy values: 9.0 MJ ME/kg feed, 10.5 MJ ME/kg feed and 12 MJ ME/kg feed, in both the grower and finisher phase, which was much lower than the levels in this study.

In conclusion, the feed intake was not higher for lower energy levels for the pre-starter, starter and grower phases. This may be an indication that the bulk density of the feed was too high for the animal to be able to consume more feed. Overall results confirmed that the medium dietary energy level may be appropriate for chicks during the pre-starter, starter and grower phases. This may be due to the detrimental effect of high starch diets on intestinal health (Viljoen *et al*., 2004). During the finisher phase, birds are able to compensate for lower energy diets by increasing feed intake and the results suggested that the high dietary energy level improved growth rate and tanned skin size.

This study contributes to the limited knowledge of ostrich nutrition. It becomes clear that, in some cases (pre-starter, starter and grower phases), diets with higher energy levels are not optimal.

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Chapter 7

The effect of feather clipping on production parameters of ostrich (*Struthio camelus* var. *domesticus*)

Abstract

1. The effect of clipping of feathers at six to eight months of age on the production parameters of ostrich chicks was investigated. Measured parameters included feed intake, feed conversion ratio (FCR), and growth rate. Carcass measurements and *post mortem* measurements on the harvested feathers were also recorded.
2. The study was conducted in three different trials. In each of the trials the feathers of half the birds were clipped at six to eight months of age.
3. Significant differences were found for the FCR, the average daily gain (ADG) and for the quantity of valuable feathers at slaughter. No differences ($P > 0.05$) were found for any of the measured carcass parameters.
4. Results indicated that the growth rate and FCR were better for the birds whose feathers were clipped at six to eight months of age. Results also showed that the quantity of valuable feathers was significantly higher for the clipped group.
5. This study showed that it may be advantageous for ostrich producers to consider feather clipping at six to eight months of age.

7.1. INTRODUCTION

Revenue from ostriches is generated through the sale of skin, feathers and meat (Gous and Brand, 2008; Sales, 1999). The price of each of these products is highly variable, as is the ratio of these prices to one another (Swart, 1984). The South African ostrich industry was established in the Klein Karoo during the period of 1838 to 1866, at which time feathers were the primary product; in the early 1900s, the export value of feathers was £1,500,000 per annum (Duerden, 1907). During this time ostriches were farmed extensively (Jordaan *et al.,* 2008).

The feather market collapsed in the early 1900s (Swart, 1979), causing a gradual shift in emphasis towards hide production. From the 1960s, ostrich producers started to farm intensively due to higher land prices and thus smaller farms. No other animal species could return the same amount of profit per hectare in this semi-arid area as the ostrich. From the 1990s the emphasis shifted from skin towards meat production while income from feathers amounted to only 7 – 10% of the total revenue (Jordaan *et al*., 2008; Nel, 2010). From 2000,

meat prices increased steeply, partly as a result of the increased awareness of the health benefits of ostrich meat. However, it was more importantly related to the outbreaks of BSE (bovine spongiform encephalopathy) in Europe; and foot and mouth disease in the United Kingdom and Europe (Horbańczuk *et al*., 2008), as this resulted in an increased demand for "safe" red meat. However this boom was short-lived, with outbreaks of bird flu (*Avian influenza* H5N2) in 2003 stopping meat exports. This caused income to decrease by almost 300% for ostrich producers as the meat had to be marketed locally. The industry recovered when the export bans were lifted in 2005, but in 2011 there were once again bird flu outbreaks and the resultant bans were not lifted until the end of 2012. However in 2013 *A. influenza* H7N1 was diagnosed in a flock in the Western Cape, and presently only cooked *Sous vide* meat is allowed to be exported. Feather and skin prices therefore play a vital role in the profitability of ostrich farming (Brand and Cloete, 2009) as a result of the dwindling meat price. The skin price currently amounts to 50% of the total value of the ostrich (Engelbrecht *et al*., 2009, Engelbrecht, 2010).

Feathers of slaughter birds are only harvested *post mortem,* while ripe feathers of adult ostriches are harvested every seven to eight months as the feathers need to mature for up to six months prior to harvest (Nel, 2010, Duerden 1911, Duerden, 1908b). The aim of this study was to determine the effects of feather clipping and harvesting at six to eight months of age on slaughter bird production parameters. The basic guideline for the first feather clipping of young slaughter birds is when the live weight of the bird is at least 60 kg or the bird is at least six months of age (Engelbrecht, 2010; Duerden, 1910; Duerden, 1908a).

Ostrich skin is very sought after in the fashion industry for its distinctive quill pattern (Engelbrecht *et al*., 2009). The skin is supple and durable and has a high price in comparison to other livestock hides (Cooper, 2001). The skin price is determined primarily by size (objective measurement), visible defects and the appearance of feather nodules (subjective approach) (Van Schalkwyk, 2008, Engelbrecht *et al*., 2009, Engelbrecht, 2010). Certain factors affect the grading score and thus value of ostrich feathers and skins. These include: age at slaughter, cleaning (term commonly used in the industry to describe clipping) of feathers at six and a half months of age, genetics, precautions for damage by feather lice, feeding conditions, mechanical damage (housing) and feedlot management (dust, water, pasture condition, etc.).

This study will thus aid in determining the effects of harvesting/clipping of feathers on production parameters such as skin development, skin quality, feather quality, growth and carcass weight.

7.2. MATERIALS AND METHODS

Ethical clearance number: R11/41. Trials were conducted at Kromme Rhee experimental farm, Western Cape, South Africa (18°50'E, 33°51'S and altitude 177 m) (Trial 1 and Trial 3) and at the farm *Drie Riviere* in the Prince Albert district, Klein Karoo, Western Cape (22° 3'E, S 33° 11'S and altitude 428, 25 m) (Trial 2).

Trial 1

In Trial 1, 180 one day old birds were used, divided into 18 groups with 10 birds allocated per group. Each group was allocated to one of three test diets, there were thus six groups per diet. The three diets were: high energy (H), medium energy (M) and low energy (L). The M energy diet was formulated to have a level of dietary energy similar to that of commercially available feeds. The L energy diet was formulated to have 20% less energy than the M diet and the H energy diet was formulated to have 20% more energy than the M diet; for each diet the other nutrients were kept constant so that energy alone differed between treatments. In this trial the feathers of half the birds on each diet were clipped at six months of age. The feathers were clipped by cutting the wing white feathers with pruning scissors, 2.5 cm from the base of the feathers (Smit, 1964). Thus of the 18 groups, nine groups' feathers were clipped while the other groups served as a control group. The results showed no interaction between the dietary energy level and feather clipping, thus the feather clipped results are presented in this chapter. The results arising from different diets are presented in Chapter 6 of this thesis.

On the day of slaughter, the feathers were removed and weighed per bird. It was decided not to do further measurements on the feathers as they were only clipped two months earlier and the data would not be useful at that stage of development. This trial was only completed towards the end of the grower phase, that is, at eight months of age, because the birds had to be slaughtered at that time as it was thought that they might be at risk of contracting bird flu.

For each treatment, feed and water were available *ad libitum,* and feed intake was determined by weighing the feed in and weighing back refusals at each point of data collection, thus intake was determined weekly. The average daily gain was determined by fitting a linear regression model.

At eight months of age, the ostriches were slaughtered at Ostriswell in Swellendam. The organs of each bird were weighed to determine the effect of energy on organ weight. The

organs and other tissues weighed include the gizzard, heart, liver, lungs and kidneys, fat plate and the chest bone. The carcasses were placed in a cold room overnight to cool and the cold carcass weights were recorded the following day.

The carcasses were transported to the deboning facility at Klein Karoo International Ltd in Oudtshoorn. There the carcasses were deboned, and the neck, tibia, femur, the whole thigh, as well as the patella were weighed. The meat was weighed per commercial cut for one thigh of the ostrich. The commercial cuts that were weighed included the fan fillet *Muscularis iliofibularis*, rump steak *M. iliotibialis lateralis*, moon steak *M. femorotibialis medius*, triangle steak *M. flexor cruris lateralis*, big drum *M. gastrocnemius*, flat drum *M. gastrocnemius*, drum steak *M. gastrocnemius*, tenderloin *M. obturatorius medialis*, eye fillet *M. iliofemoralis*, tornedo *M. ambiens*, long fillet *M. ambiens*, oyster fillet *M. iliofemoralis externus*, small steak *M. flexor cruris medialis*, minute 1 *M. femorotibialis externus*, minute 2 *M. femorotibialis externus*, small drum *M. fibularis longus* and tender steak *M. pubio-ischio-femoralis* (Kritzinger, 2011; Anon, 2013; Stadelman *et al*., 2013). The pH and the temperature of the big drum and fan fillet were recorded at deboning.

The data were analysed using the GLM Procedure of SAS statistical software version 9.1 (SAS, 2000). Feather clipping was used as the main effect (classification variable). Tests for homoscedasticity were done using Levene's test. Homoscedastic data were analysed and interpreted using one way ANOVA's and hetroscedastic data were analysed and interpreted using the Welch ANOVA.

The average diameter of ten randomly selected wing feathers was calculated and statistical analysis was done on these averages. The skins were tanned, and the sizes were determined and grading was done at Klein Karoo International Ltd. The skins were then returned to the laboratory, where a number of quality parameters were measured.

The number of nodules in a 10 cm × 10 cm square was counted at five localities on the skin as indicated in Figure 7.1. Additionally, five nodules per locality were measured in diameter and an average was calculated.

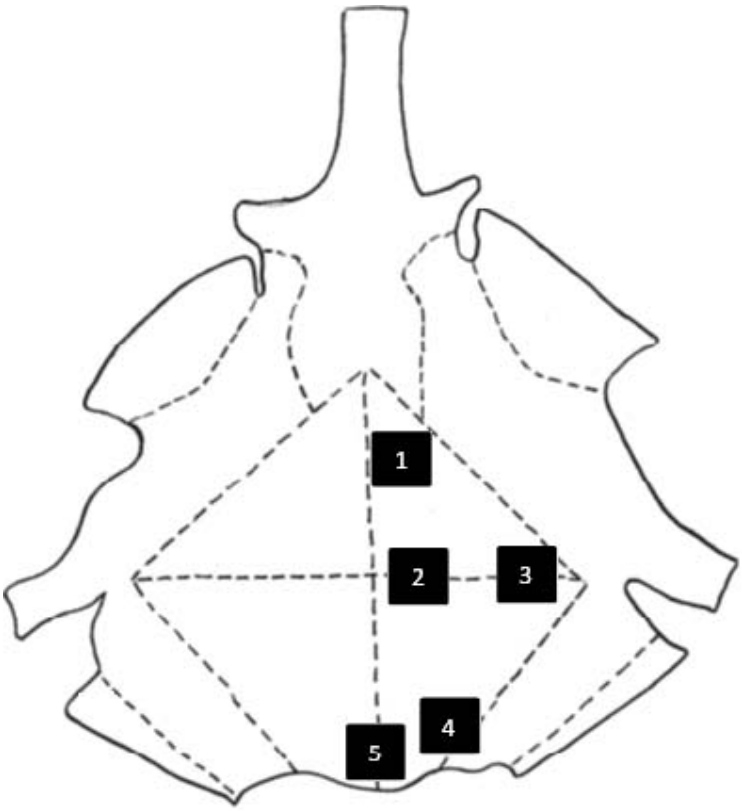

Figure 7.1. *The different localities (numbered 1 – 5) where nodules were counted and measured, and where pin holes were counted.*

In previous studies (Engelbrecht *et al*., 2009; Engelbrecht *et al*., 2012), a subjective scoring system was used for pin holes, however in this study an objective approach was used. Pin holes at the same five localities were counted in a 5 cm × 5 cm square. The reason for counting at five localities and not only one is due to low genetic correlations between these five localities (Cloete *et al*., 2006).

Trail 2

In Trial 2, 300 eight-month-old ostriches were used. These were divided into six groups (six paddocks) of 50 birds each. The trial tested the three different dietary energy levels described for trial 1 for use in the finisher phase. The feathers of half the birds on each diet were clipped at eight months of age in order to determine the effects of feather clipping on production parameters. The feathers were clipped by cutting the wing white feathers with pruning scissors, 2.5 cm from the base of the feathers (Smit, 1964). Thus there were two paddocks per diet, in one paddock the feathers of the birds were clipped, and in the other

paddock the feathers were not clipped. In other words: paddock 1 had L diet and feathers clipped; paddock 2, L diet and feathers not clipped; paddock 3, M diet and feathers clipped; paddock 4, M diet and feathers not clipped; paddock 5, H diet and feathers clipped and paddock 6, H diet and feathers not clipped

In the results there was no interaction between the energy level and feathers clipped and between feathers clipped and sex; the feather clipped results are therefore presented in this chapter. The results arising from different diets are presented in Chapter 6 of this thesis. For each treatment, feed and water was available *ad libitum*. The feed intake was determined by the difference between the weight of the offered feed and the refusals; this was done monthly. The average daily gain was determined by fitting a linear regression model to the live weight data and using the gradient as the ADG. The feathers of half the birds on each diet in this trial were clipped at eight months of age. In the results, no interaction between the energy level and feathers clipped, or between sex and feathers clipped was found, the feathers clipped results are therefore discussed further.

The birds were slaughtered at an age of 11.5 months at Klein Karoo International abattoir in Oudtshoorn. Basic carcass data were collected and feathers were collected per bird and transported to the feathers department at Klein Karoo International for drying. The feathers were dried for 47.5 hours at 50 °C and then for 30 minutes at 70 °C, after which they were separated into the economically important types of feathers per bird. The different types/classes of feathers were weighed. The feather classes include: “male body short”, “blondene light tipless”, “male bodies long”, “drab body short”, “drab body slope”, “female wing”, “male wing”, “reject wings”, “drab dry points”, “drab silver floss”, “drab bloods” and “young bird floss”. The shafts of ten randomly selected wing feathers were measured in millimetres at the base (point of skin entry) using a digital calliper for each bird. The average diameter of the ten feathers was calculated and the statistical analyses were done on the averages using proc GLM in SAS.

The same measurements were made on the skins in trial 2 as in trial 1. Refer to Tables 7.1 and 7.2 for the proximate analysis and amino acid composition of the diets fed in trial 1 and trial 2. Refer to Tables 7.3 – 7.6 for the feed composition of diets fed in trial 1 and trial 2.

Table 7.1. *Nutrient composition (as fed basis) and in vitro organic material digestibility (IVOMD) of experimental pre-starter, starter, grower (Trial 1) and finisher (Trial 2) diets*

Nutrient	Pre-starter			Starter			Grower			Finisher		
	L	S	H	L	S	H	L	S	H	L	S	H
ME MJ/kg feed*	13.5	14.5	15.5	12.5	13.5	14.5	10.5	11.5	12.5	9.5	10.5	11.5
Dry material (g/kg)	910.1	912.5	916.5	893.7	899.3	904.1	892.2	888.9	886.5	929.3	927.9	920.9
Crude protein (g/kg)	188.6	184.0	192.8	180.5	172.0	177.4	149.1	142.7	132.9	139.3	132.4	124.2
Ash (g/kg)	93.4	91.4	86.0	101.3	95.1	96.7	102.4	103.1	91.3	165.2	105.6	98.5
IVOMD (g/kg)	820.2	840.3	855.3	799.3	837.0	851.7	739.6	801.5	853.4	626.5	748.2	832.4
Crude fibre (g/kg)	48.0	42.0	35.0	95.5	68.5	41.0	150.0	119.0	80.0	141.0	130.0	105.0
Fat (g/kg)	29.4	45.7	48.9	29.5	42.9	55.1	22.0	22.7	24.1	19.9	25.2	24.4
ADF (g/kg)	117.3	64.6	68.3	125.3	106.5	85.4	290.6	176.3	128.8	234.9	185.9	150.3
NDF (g/kg)	178.0	148.9	145.5	229.5	187.5	136.8	267.3	265.4	210.1	402.6	306.6	215.3
Calcium (g/kg)	16.0	18.1	21.7	17.6	17.2	15.9	12.8	15.7	16.7	18.9	17.8	19.5
Phosphorus (g/kg)	7.20	7.60	7.60	6.80	7.40	8.10	6.10	6.40	6.80	8.20	7.20	6.20

Abbreviations: ADF = acid detergent fibre; NDF = neutral detergent fibre; IVOMD = *in vitro* organic matter digestibility.

*As formulated.

Table 7.2. *The amino acid composition of the feeds on an as is basis (g/kg) containing three levels of energy (Low: L, Medium : M and High H) fed to ostriches during the pre-starter (0 – 2 months), starter (2 – 4 months), grower (4 – 8 months), Trial 1 and Finisher (8 – 11.5 months), Trial 2 on an as is basis*

Amino acids	Pre-starter			Starter			Grower			Finisher		
	L	S	H	L	S	H	L	S	H	L	S	H
Lysine	11.2	11.5	11.9	8.80	8.90	8.40	7.70	7.60	8.50	6.60	7.60	8.50
Methionine	1.10	1.40	1.40	0.80	0.80	0.80	0.40	0.50	0.50	0.50	0.90	1.10
Arginine	8.90	8.90	9.40	7.60	7.30	6.90	5.50	5.30	5.90	5.80	6.10	6.50
Threonine	6.50	6.40	6.90	5.60	5.50	5.20	4.80	4.50	4.90	4.00	4.50	5.20
Aspartate	15.3	14.9	16.6	14.1	14.4	13.7	14.6	12.9	13.1	11.1	12.4	14.0
Glutamate	35.8	34.5	37.6	30.4	29.6	27.3	19.4	19.9	23.5	23.1	23.5	23.8
Serine	8.30	8.00	8.80	7.20	7.30	6.70	6.50	6.00	6.50	5.70	6.70	7.80
Histidine	4.00	3.80	4.00	3.40	3.40	3.00	2.60	2.50	3.00	2.50	2.80	3.10
Glycine	8.70	9.10	9.10	7.10	6.70	6.10	4.80	4.50	4.80	4.70	5.10	5.80
Alanine	8.80	8.90	9.40	7.20	7.20	6.90	5.70	5.60	6.30	5.10	6.00	7.10
Tyrosine	6.30	6.40	6.70	5.40	5.60	5.20	4.80	4.60	5.10	4.20	5.00	5.80
Valine	9.10	8.90	9.60	8.00	7.90	7.40	7.00	6.60	7.10	6.20	7.20	8.20
Phenylalanine	7.90	7.80	8.60	6.80	7.10	6.60	6.10	5.80	6.40	5.50	6.30	7.20
Isoleucine	6.70	6.80	7.50	5.90	6.00	5.70	5.10	4.90	5.30	4.60	5.30	6.10
Leucine	13.4	13.2	14.8	10.9	11.5	11.2	9.30	9.40	10.8	8.30	9.90	11.7

Table 7.3. *Ingredient and nutrient composition (as fed basis) of experimental diets in the pre-starter phase (kg/ton) (Trial 1) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	S	H
Maize meal	501.7	509.1	517.1
Soybean oilcake	160.0	185.0	210.0
Wheat bran	224.0	151.0	77.0
Fishmeal	75.0	75.0	75.0
Vegetable fat	0.00	40.0	80.0
Limestone	22.0	21.0	20.5
Monocalcium phosphate	0.00	1.90	3.80
Synthetic lysine	2.30	2.00	1.60
Salt	10.0	10.0	10.0
Vitamin and mineral premix*	5.00	5.00	5.00

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 7.4. *Ingredient and nutrient composition (as fed basis) of experimental diets in the starter phase (kg/ton) (Trial 1) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	S	H
Maize meal	301.7	425.0	548.3
Soybean oilcake	105.4	146.3	187.3
Wheat bran	390.0	197.0	3.90
Fishmeal	48.8	48.8	48.8
Lucerne	97.6	97.6	97.6
Plant oil	0.00	24.4	48.8
Molasses	24.4	24.4	24.4
Monocalcium phosphate	0.00	7.10	14.2
Limestone	17.4	14.7	12.0
Salt	9.80	9.80	9.80
Vitamin and mineral premix*	4.90	4.90	4.90

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 7.5. *Ingredient and nutrient composition (as fed basis) of experimental diets in the grower phase (kg/ton) (Trial1) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	S	H
Maize meal	253.9	413.1	572.3
Soybean oilcake	76.8	89.4	102.0
Lucerne	610.0	431.7	253.4
Molasses	25.0	25	25.0
Monocalcium phosphate	17.1	17.05	17.0
Salt	10.0	10	10.0
Limestone	0.00	6.65	13.3
Vitamin and mineral premix*	5.0	5	5.0
Synthetic lysine	0.81	1.3	1.82
Synthetic methionine	1.4	0.8	0.23

*Refer to ANNEXURE A, Table A for the composition of the premix.

Table 7.6. *Ingredient and nutrient composition (as fed basis) of experimental diets in the finisher phase (kg/ton) (Trial 2) (Brand, 2012)*

Ingredients (kg)	Dietary energy concentrations		
	L	S	H
Maize meal	100.0	250.0	400.0
Oat hulls	397.0	198.5	0.00
Soybean oilcake	113.3	98.0	82.8
Lucerne	100.0	261.1	422.2
Molasses	50.0	50.0	50.0
Monocalcium phosphate	20.8	19.1	17.3
Salt	10.0	10.0	10.0
Limestone	15.0	10.7	6.42
Wheat bran	191.1	99.0	6.86
Vitamin and mineral premix*	2.00	2.00	2.00
Synthetic methionine	0.78	1.61	2.44

*Refer to ANNEXURE A, Table A for the composition of the premix.

Trail 3

In Trial 3, 60 eight-month-old South African black ostriches were divided into six paddocks with ten birds per paddock. On day 1 of the trial, when the ostriches were placed out into the paddocks, the feathers of the birds in paddocks 2, 4 and 6 were clipped, whilst the feathers of the birds in paddocks 1, 3 and 5 were not clipped. The feathers were clipped by cutting the wing white feathers with pruning scissors, 2.5 cm from the base of the feathers (Smit, 1964). The "drab floss", "drab body long", "silver floss", "body", "tail" and "floss" feathers were clipped so that no follicles were visible on the thighs and body. The dry shafts were removed two weeks after clipping.

All birds in trial 3 were fed the same medium finisher diet until slaughter at an age of 14 months; refer to Table 7.7 and Table 7.8 for the proximate analysis, diet composition and the amino acid composition, respectively of the diet. The birds were weighed monthly and the feed and water intake was *ad libitum*. The daily feed intake was determined per month by keeping records of the amount of feed fed per paddock. The feed conversion ratio (FCR) and the average daily gain (ADG) were subsequently determined. A single mortality occurred in the clipped group, and thus only 59 birds were slaughtered and included in the data.

Table 7.7. *Ingredient and nutrient composition (kg/ton)(as fed basis) and proximate analysis of the diet (as fed basis) in the finisher phase (Brand, 2012)*

	Dietary composition
Ingredients:	
Maize meal kg	250.0
Soybean oilcake kg	98.0
Lucerne kg	261.1
Molasses kg	50.0
Monocalcium phosphate kg	19.1
Salt kg	10.0
Limestone kg	10.7
Wheat bran kg	99.0
Vitamin and mineral premix kg[1]	2.00
Synthetic methionine kg	1.61
Oat hulls kg	198.5
Proximate analysis:	
DM g/kg	930
Crude Protein g/kg	134
Fat g/kg	25.2
Ash g/kg	114
MJ ME/kg feed*	10.5
Crude Fibre g/kg	130
Ca g/kg	17.8
P g/kg	7.2

*As formulated.

[1]Refer to ANNEXURE A, Table A for the composition of the premix.

Table 7.8. *The amino acid composition of the feeds on an as is basis (g/kg), fed to ostriches during the finisher (6-10 months) phase*

Amino acid	g/kg in feed
Lysine g/kg	6.7
Methionine g/kg	0.7
Arginine g/kg	6.1
Threonine g/kg	4.4
Aspartate g/kg	12.0
Glutamate g/kg	24.3
Serine g/kg	6.0
Histidine g/kg	2.8
Glycine g/kg	5.4
Alanine g/kg	5.8
Tyrosine g/kg	4.4
Valine g/kg	7.0
Phenylalanine g/kg	5.5
Isoleucine g/kg	4.5
Leucine g/kg	8.6

The ostriches were slaughtered at Swartland abattoir in Malmesbury, Western Cape using standard procedures as described by Hoffman (2012). The following parameters were measured: live weight, warm weight of carcass, cold weight of carcass and dressing percentage.

At slaughter, the feathers were removed as described by Mellett (1985). The feathers were weighed (wet feather weight) and kept separately per bird and sent to the feather department of Klein Karoo International Ltd. This company is responsible for the slaughter of ostriches and the processing of the feathers, skins and meat. The feathers were dried for 47.5 hours at 50 °C and then for 30 minute at 70 °C, before being separated into the economically important classes of feathers per bird. The classes of feathers were weighed and quality of the feathers was determined. The different classes of feathers included: “male body short”, “blondene light tipless”, “male body long”, “drab body short”, “drab body slope”, “female wing”, “male wing”, “reject wings”, “drab dry points”, “drab silver floss”, “drab bloods” and “young bird floss” (Table 7.9). The shafts of ten randomly-selected wing feathers per bird were measured in millimetres at the base (point of skin entry) using a digital calliper.

The average diameter of the ten feathers was calculated and the statistical analysis was done on the averages. The skins were tanned, their sizes determined and graded at Klein Karoo International Ltd. The skins were returned to the laboratory where the same measurements were made as in trials 1 and 2.

Feather classes can be described by the following: "wing feathers" (white plumes, first row of prominent plumes at the edge of the wing), "floss" (one row of soft downy feathers under the wing), "long body floss" (2nd and 3rd row of feathers above the wing), "short body floss" (feathers under the wing and front and behind of thigh), "long hard body feathers" (second and third row of shorter feathers on the outer edge of the wing), "sides" (5 – 7 rows in front and behind of thighs) and "tail feathers" (Engelbrecht, 2010; Brand and Cloete, 2009; Duerden, 1909; Sclater, 1906). Refer to Table 7.9 for more detail on feather classes.

Table 7.9. *Description of different feather classes*

Feather Class	Area of body and description
Male Body Short	Male wing and body
Blondene Light Tipless	Female wing
Male Body Long	Wing
Drab Body Short	Wing and body
Drab Body Slope	Wing and body
Female Wing	White plumes first row of prominent plumes at the edge of the wing
Male Wing	White plumes first row of prominent plumes at the edge of the wing
Chick Wings	White plumes first row of prominent plumes at the edge of the wing
Drab Dry Points	Wing and body
Drab Silver Floss	Sides of body and wing
Drab Bloods	Wing and body
Young Bird Floss	Sides of body and wing
Chick Blondene Floss	Wing and body
Chick Body Floss	Wing and body
Female Tails	Body (tail part)
Male Tails	Body (tail part)
Chick Tails	Body (tail part)

The data were analysed using the GLM Procedure of SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC, USA). Feather clipping was used as the main effect (classification variable). Tests for homoscedasticity were done using Levene's test. Homoscedastic data were analysed and interpreted using the one-way ANOVA and hetroscedastic data were analysed and interpreted using the Welch ANOVA.

7.3. RESULTS

Trial 1

The treatment "feathers clipped at 6 months of age" only had an influence on the wet feather weight and the feed conversion ratio (FCR) (Table 7.10, 7.11, 7.12 and 7.13), while it had no effect on the other slaughter parameters. The wet feather weight was: 0.92 ± 0.02 kg (Least Square Mean ± Standard Error) for the unclipped group and 0.59 ± 0.02 kg for the clipped group. The FCR was 2.87 ± 0.07 kg feed ingested/kg weight accreted (Least Square Mean ± Standard Error) for the clipped group and 3.53 ± 0.10 kg feed ingested/kg weight accreted for the unclipped group. "Feathers clipped at 6 months of age" had an influence on the pH of the fan fillet (Table 7.11). For the clipped treatment, pH was 6.16 as opposed to 6.06 for those not clipped ($P < 0.05$).

Table 7.10. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feather harvesting at six months of age on organ and tissue weights of 8-month-old slaughtered ostriches in Trial 1*

Organ/tissue (kg)	Clipped	Not clipped
Wet feather weight	$0.59^{a} \pm 0.02$	$0.92^{b} \pm 0.02$
Heart	0.57 ± 0.01	0.59 ± 0.02
Liver	1.19 ± 0.02	1.17 ± 0.03
Lungs and kidneys	0.94 ± 0.02	0.98 ± 0.02
Gizzard	0.33 ± 0.01	0.32 ± 0.01
Fat pad	1.19 ± 0.10	1.25 ± 0.11
Chest bone	0.38 ± 0.01	0.40 ± 0.01
Tibia	2.57 ± 0.04	2.62 ± 0.04
Femur	1.21 ± 0.02	1.22 ± 0.02
Patella	0.48 ± 0.19	0.24 ± 0.21
Neck	1.48 ± 0.03	1.49 ± 0.03

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 7.11. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feather harvesting at six months of age on the slaughter and meat quality parameters of 8-month-old slaughtered ostriches in Trial 1*

Production/meat quality parameter	Clipped	Not clipped
Live weight (kg)	58.8 ± 2.34	62.4 ± 1.31
ADG (g/bird/day)	308.6 ± 7.80	307.9 ± 9.55
Feed intake (kg/bird/day)	1.12 ± 0.05	1.01 ± 0.06
FCR	$2.87^{a} \pm 0.07$	$3.53^{b} \pm 0.10$
Dressing %	49.3 ± 1.33	50.0 ± 0.75
pH big drum	6.07 ± 0.03	6.00 ± 0.03
Temperature big drum (°C)	5.54 ± 0.26	5.64 ± 0.28
pH fan fillet	$6.16^{a} \pm 0.03$	$6.06^{b} \pm 0.03$
Temperature fan fillet (°C)	4.73 ± 0.22	4.63 ± 0.24

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 7.12. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feather harvesting at six months of age on commercial steaks of 8-month-old slaughtered ostriches in Trial 1*

Commercial steak (kg)	Clipped	Not clipped
Carcass weight (kg)	29.0 ± 1.28	31.1 ± 0.72
Thigh	23.5 ± 0.52	24.2 ± 0.55
Total steaks from thigh	12.3 ± 0.30	12.7 ± 0.35
Fan fillet	1.95 ± 0.06	2.00 ± 0.06
Rump steak	1.54 ± 0.05	1.58 ± 0.05
Moon steak	1.20 ± 0.06	1.21 ± 0.06
Triangle steak	0.42 ± 0.02	0.42 ± 0.02
Big drum	1.38 ± 0.04	1.44 ± 0.04
Flat drum	1.00 ± 0.03	1.06 ±0.03
Drum steak	0.72 ± 0.02	0.75 ± 0.03
Tenderloin	0.58 ± 0.02	0.60 ± 0.02
Eye fillet	0.59 ± 0.02	0.60 ± 0.02
Tornedo	0.29 ± 0.01	0.29 ± 0.01
Long fillet	0.58 ± 0.02	0.64 ± 0.03
Oyster fillet	0.63 ± 0.02	0.63 ± 0.02
Small steak	0.21 ± 0.01	0.22 ± 0.01
Small drum	0.40 ± 0.01	0.43 ± 0.01
Tender steak	0.49 ± 0.01	0.52 ± 0.02
Minute 1 steak	0.18 ± 0.01	0.18 ± 0.01

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 7.13. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feathers clipped at six months of age on skin size, grading and measurements of 8-month-old slaughtered ostriches in Trial 1*

Skin parameter	Clipped	Not clipped
Crust size ($dm^{2)}$	118.3 ± 1.50	121.4 ± 1.92
Crust grade*	2.27 ± 0.10	2.49 ± 0.13
Skin thickness (mm)	1.44 ± 0.11	1.53 ± 0.06
Nodule size locality 1 (mm)	3.1 ± 0.11	3.2 ± 0.06
Nodule size locality 2 (mm)	3.0 ± 0.12	3.2 ± 0.06
Nodule size locality 3 (mm)	3.9 ± 0.16	3.9 ± 0.08
Nodule size locality 4 (mm)	3.8 ± 0.16	4.0 ± 0.08
Nodule size locality 5 (mm)	3.5 ± 0.13	3.6 ± 0.07
Average nodule size (mm)	4.9 ± 0.73	3.6 ± 0.93
Number of nodules locality 1	55.7 ± 3.31	56.2 ± 1.71
Number of nodules locality 2	62.2 ± 3.57	60.2 ± 1.84
Number of nodules locality 3	31.4 ± 1.83	29.3 ± 0.95
Number of nodules locality 4	35.6 ± 1.96	36.7 ± 1.01
Number of nodules locality 5	63.9 ± 3.26	59.7 ± 1.69
Average number of nodules	48.8 ± 0.71	48.1 ± 0.91
Number of pin holes locality 1	55.7 ± 9.23	46.2 ± 4.77
Number of pin holes locality 2	56.5 ± 8.88	50.5 ± 4.59
Number of pin holes locality 3	12.5 ± 2.90	11.0 ± 1.50
Number of pin holes locality 4	13.9 ± 3.19	12.8 ± 1.65
Number of pin holes locality 5	67.1 ± 11.23	64.4 ± 5.80
Average number of pin holes	37.3 ± 2.25	34.8 ± 2.89

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

*Skins are graded from 1 – 4 with grade 1 as the best.

Trial 2

The treatment "feathers clipped at eight months of age" had an effect on the following: "weight of feathers with commercial value", average feather shaft thickness and the weight of the following: "female wings", "chick wings" and "female tails" (Table 7.14).

Table 7.14. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feather harvesting at eight months of age on production parameters and feather measurements of 11.5-month-old slaughtered ostriches in Trial 2*

Parameter	Clipped	Not clipped
Production parameter		
Live weight (kg)	99.3 ± 0.79	99.58 ± 0.79
ADG (g/bird/day)	342.0 ± 2.15	340.0 ± 2.14
Feed intake (kg/bird/day)	3.63 ± 0.08	3.42 ± 0.08
FCR (kg feed/kg weight gain)	13.0 ± 0.52	11.8 ± 0.52
Cold carcass weight (kg)	43.4 ± 0.35	43.2 ± 0.35
Dressing %	0.49 ± 0.01	0.48 ± 0.01
Feather parameter		
Feathers with commercial value (kg)	0.83^{a} ± 0.01	0.75^{b} ± 0.01
Average shaft thickness (mm)	7.43^{a} ± 0.10	6.13^{b} ± 0.10
Female wings (kg)	0.19^{a} ± 0.01	0.05^{b} ± 0.01
Chick wings (kg)	0.02^{a} ± 0.01	0.10^{b} ± 0.01
Drab body slope (kg)	0.04 ±0.01	0.03 ± 0.01
Chick body floss (kg)	0.12 ± 0.01	0.13 ± 0.01
Female tails (kg)	0.09^{a} ± 0.01	0.06^{b} ± 0.01
Drab bloods (kg)	0.25 ± 0.01	0.25 ± 0.01
Young bird floss (kg)	0.06 ± 0.01	0.05 ± 0.01

$^{a - b}$ Rows means with different superscripts differ significantly ($P \leq 0.05$).

Feather clipping at eight months of age had no effect on any of the measured skin parameters (Table 7.15).

Table 7.15. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feathers clipped at eight months of age on skin size, grading and measurements of 11.5-month-old slaughtered ostriches in Trial 2*

Skin parameter	Clipped	Not clipped
Crust size (dm^2)	142.3 ± 0.40	142.2 ± 0.41
Crust grade*	2.70 ± 0.08	2.62 ± 0.08
Skin thickness (mm)	2.53 ± 0.06	2.53 ± 0.06
Nodule size locality 1 (mm)	3.87 ± 0.05	3.80 ± 0.05
Nodule size locality 2 (mm)	3.59 ± 0.04	3.60 ±0.04
Nodule size locality 3 (mm)	4.66 ± 0.05	4.69 ± 0.05
Nodule size locality 4 (mm)	4.31 ± 0.05	4.27 ± 0.06
Nodule size locality 5 (mm)	4.09 ± 0.06	4.16 ± 0.06
Average nodule size (mm)	4.10 ± 0.03	4.11 ± 0.04
Number of nodules locality 1	48.5 ± 0.76	50.0 ± 0.78
Number of nodules locality 2	56.2 ± 0.91	55.5 ± 0.94
Number of nodules locality 3	26.9 ± 0.40	26.4 ± 0.41
Number of nodules locality 4	31.7 ± 0.63	32.1 ± 0.65
Number of nodules locality 5	54.1 ± 0.92	53.2 ± 0.96
Average number of nodules	57.0 ± 1.95	52.89 ± 1.98
Number of pin holes locality 1	73.1 ± 2.84	66.9 ± 2.88
Number of pin holes locality 2	73.1 ± 3.15	64.7 ± 3.20
Number of pin holes locality 3	29.2 ± 1.43	28.8 ± 1.45
Number of pin holes locality 4	31.8 ± 1.88	32.9 ± 1.91
Number of pin holes locality 5	82.1 ± 3.41	75.0 ± 3.47
Average number of pin holes	43.3 ± 0.46	43.5 ± 0.47

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

*Skins are graded from 1 – 4 with grade 1 as the best.

Trial 3

In trial 3 the daily feed intake and FCR were not influenced by feather clipping (Table 7.16). Concerning the production parameters, only the ADG was influenced ($P \leq 0.05$) by the treatment. The ADG for the "feather clipped" treatment was 228.0 see table grams per day, whereas the control group had an ADG of 211.0 grams per day. Thus the treatment group had a growth that was 17.0 grams per day faster than the control group.

Table 7.17 summarises the feather parameters. None of the measured feather parameters were influenced significantly ($P > 0.05$) by the feather clipping. Table 7.18 summarises the skin parameters measured at the five different localities. None of the follicle sizes at any of the localities, nor the number of follicles, the amount of pinholes at any of the localities, nor size, nor grading were influenced by the feather clipping.

Table 7.16. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feathers clipped at eight months of age on production parameters of 14-month-old slaughtered ostriches in Trial 3*

Production parameter	Clipped	Not clipped
Live weight (kg)	115.0 ± 2.79	110.0 ± 2.08
ADG (g/day)	228.0[a] ± 9.08	211.0[b] ± 6.57
Daily feed intake (kg/bird/day)	3.78 ± 0.11	3.80 ± 0.11
FCR	14.1 ± 5.2	19.5 ± 11.3
Cold carcass weight (kg)	52.8 ± 1.00	51.6 ± 0.79
Dressing percentage (%)	46.7 ± 0.61	47.8 ± 0.58

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 7.17. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feathers clipped at eight months of age on feather parameters of 14-month-old slaughtered ostriches in Trial 3*

Feather parameter	Clipped	Not Clipped
Wet feather weight (kg)	1.59 ± 0.06	1.55 ± 0.06
Shaft thickness (mm)	6.23 ± 0.09	6.17 ± 0.12
Male body short (kg)	624.1 ± 28.7	683.0 ± 50.0
Blondene light tipless (kg)	70.0 ± 7.21	48.3 ± 5.57
Drab body short (kg)	642.0 ± 38.3	638.0 ± 29.1
Drab body slope (kg)	106.8 ± 8.34	107.5 ± 7.45
Female wing (kg)	230.1 ± 19.11	199.3 ± 20.43
Male wing (kg)	247.0 ± 26.15	245.9 ± 17.12
Reject wings (kg)	229.2 ± 27.82	213.0 ± 34.43
Drab dry points (kg)	370.8 ± 98.91	443.4 ± 39.73
Drab silver floss (kg)	361.1 ± 36.41	360.1 ± 21.43
Young bird floss (kg)	407.1 ± 29.22	386.4 ± 19.67

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

Table 7.18. *Least Squares Means ± Standard Error (LSM ± SE) for the effect of feathers clipped at eight months of age on skin parameters of 14-month-old slaughtered ostriches in Trial 3*

Skin parameter	Clipped	Not clipped
Crust size dm^2	148.2 ± 1.56	147.9 ± 1.50
Skin grading*	2.56 ± 0.18	2.59 ± 0.18
Follicle size locality 1 mm	3.82 ± 0.09	3.96 ± 0.07
Follicle size locality 2 mm	3.87 ± 0.07	4.00 ± 0.06
Follicle size locality 3 mm	4.57 ± 0.10	4.65 ± 0.08
Follicle size locality 4 mm	4.64 ± 0.10	4.76 ± 0.08
Follicle size locality 5 mm	4.66 ± 0.10	4.76 ± 0.09
Mean follicle size mm	4.31 ± 0.05	4.43 ± 0.05
Number of follicles locality 1	48.1 ± 1.62	45.3 ± 1.36
Number of follicles locality 2	50.6 ± 1.58	50.3 ± 1.32
Number of follicles locality 3	22.6 ± 0.76	22.9 ± 0.64
Number of follicles locality 4	24.2 ± 1.16	25.1 ± 0.97
Number of follicles locality 5	41.3 ± 1.77	42.2 ± 1.49
Mean number of follicles	36.6 ± 0.89	37.2 ± 0.73
Number of pinholes locality 1	41.4 ± 3.87	48.2 ± 3.16
Number of pinholes locality 2	42.5 ± 3.96	48.0 ± 3.14
Number of pinholes locality 3	11.7 ± 1.49	11.6 ± 1.22
Number of pinholes locality 4	17.6 ± 2.48	17.7 ± 2.08
Number of pinholes locality 5	52.2 ± 4.99	58.7 ± 4.03
Mean number of pinholes	35.9 ± 3.04	37.3 ± 2.41

[a - b] Rows means with different superscripts differ significantly ($P \leq 0.05$).

*Skins are graded from 1 – 4 with grade 1 as the best.

7.4. DISCUSSION

In trial 1 the wet feather weights were higher for the unclipped group, as was expected as the feathers had not had time to mature. Feathers need six months (Engelbrecht, 2010) to mature and these feathers had only had two months to grow. The FCR in the unclipped group was significantly better than the opposing group. This is an important production parameter that may have an economic impact on the production unit as less feed was used to produce the same amount of meat.

In trial 2 the "feathers with commercial value", "female wings" and "female tails" had higher means for the clipped treatment. This was expected due to the fact that directly after harvest, the birds started to develop new feathers, whereas the unclipped group started developing these feather-types at a later stage. The same argument is valid for the higher mean for "chick-wing feathers" for the unclipped group as they are chick feathers rather than female feathers. The higher means for the "feathers with commercial value", "female wings" and "female tails" may have an economical implication on the production unit as these are valuable feather types.

Differences were also found between feathers clipped versus unclipped for the average shaft thickness; this was expected because, at slaughter, the feathers on the birds that had been clipped at eight months of age did not have time to fully mature. The shafts of "green feathers" are soft and thick, resulting in the difference in means.

In Trial 3, the higher ADG noted in this investigation is noteworthy as the treatment group did not have a higher daily feed intake than the control group despite growing more rapidly. This indicates that the animals utilised the feed more effectively although the FCR was not influenced significantly by the treatment. This has economical implications for ostrich producers as the birds will be ready for slaughter at an earlier age. In the ostrich industry, there is the common belief that if the feathers of slaughter birds are clipped at 6 – 8 months of age, the growth of the bird will be more rapid (as noted in Trial 3). Scientifically, one can reason that when the feathers are clipped, the insulation of the bird is compromised thus the bird needs a higher feed intake to maintain the body heat. The excess nutrients (energy, protein = amino acids etc.) due to the higher feed intake will cause the bird to grow faster.

None of the feather quality parameters harvested *post mortem* were influenced ($P > 0.05$) by an earlier clipping.

Although the quality and value of the early clipping was not measured in any of the trials and warrants further research, a producer could have additional income from the extra clipped feathers. When the feathers of slaughter ostriches are clipped in the Klein Karoo it is recommended that only the wing feathers are clipped during the cold winter months to avoid the birds from utilising a large amount of energy for thermoregulation. If the feathers are clipped in the warmer months, the following feathers may be removed: "wing feathers", "floss", "long body floss", "short body floss", "long hard body feathers", "sides" and "tail feathers" (Engelbrecht, 2010; Brand and Cloete, 2009). Feather quality is mainly determined by characteristics of the feathers, namely: width, proportion and distribution of the feather,

feather size, feather appearance, length of the shaft and flue quality (density and shine) (Engelbrecht, 2010; Swart and Heydenrych, 1982; Swart 1979; Duerden 1918). The feathers of an ostrich comprise 5% to 10% of the total slaughter income; which could make the difference between profit and loss (Engelbrecht, 2010).

It is heartening to note that the earlier feather-clipping had no influence on the meat yield of the birds in any of the trials. Similarly, none of the measured skin parameters were influenced by the early feather-clipping; one can thus reason that the clipping of feathers at six to eight months of age had no detrimental effect on the meat or skin's commercial value.

Table 7.19. *Comparison of production parameter results by Brand et al. (2004), Trial 1, Trial 2 and Trial 3*

Parameter	Brand *et al. (2004)*		Trial 1		Trial 2		Trial 3	
	Clipped	Not clipped	Clipped	Not clipped	Clipped	Not clipped	Clipped	Not clipped
Feed intake	3.27	3.35	1.12 ± 0.05	1.01 ± 0.06	3.63 ± 0.08	3.42 ± 0.08	3.78 ± 0.11	3.80 ± 0.11
ADG	229	246	308.6 ± 7.80	307.9 ± 9.55	342.0 ± 2.15	340.0 ± 2.14	228.0^{A} ± 9.08	211.0^{B} ± 6.56
FCR	14.6	14.0	2.87^{a} ± 0.07	3.53^{b} ± 0.10	13.0 ± 0.52	11.8 ± 0.52	14.1 ± 5.1	19.5 ± 11.3

Means in each Trial with different superscripts in rows differ significantly ($P \leq 0.05$).

Brand *et al*. (2004) found different results in a similar study (Table 7.19) where the feathers of birds were clipped at six months of age and the birds were slaughtered at 12 months of age. In this earlier study, there was no significant difference for the ADG between the groups. There were however significant differences for the carcass weights and thigh weights, with higher weights for the birds from which the feathers had been harvested/clipped. However, similar as our result in trial 2, the weight of *post mortem* feathers to be sold was significantly heavier in the group where feathers were not harvested. The average nodule size was also significantly higher ($P < 0.05$) for the clipped group than the unclipped group whilst the number of pin holes was significantly greater for the unclipped group. Results from Brand *et al*. (2004), trail 1, trial 2 and trial 3 (Table 7.18) indicate that feed intake are not influenced by feather clipping. From these trials, only the ADG in trial 3 were influenced ($P \leq 0.05$) by feather clipping and concerning the FCR, only the FCR in trial 1 were influenced ($P \leq 0.05$) by feather clipping.

The reason for the differences between the earlier study and this study is not clear. It could be argued that in the earlier study the ostriches had their feathers clipped at a younger age (6 months) when either the feathers were still immature/not ripe and/or that the birds were slaughtered too young (12 months vs. 14 months) and/or other factors may be involved. It is therefore suggested that additional research be conducted to evaluate the effect of feather clipping at different ages combined with slaughtering at different ages.

Overall the results suggest that there are advantages when clipping feathers at six to eight months of age without detrimental effects on skin quality. Another advantage is that there may be more feathers of value at slaughter. Further the birds may grow faster and the FCR may be lower (better) when the feathers are clipped at six to eight months of age. This phenomenon should be investigated further.

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Chapter 8

8.1 GENERAL CONCLUSIONS

Five trials were conducted to determine the effects of different dietary protein levels with corresponding amino acids and energy concentrations on production parameters as well as feather, meat and skin quality parameters of ostriches, while different growth models were evaluated. The effect of bulk density of the feed on feed intake of ostriches to determine the bulk capacity at different ages was also evaluated (Chapter 4). Additionally the effects of feather clipping at 6-8 months of age on production parameters were determined (Chapter 7).

In the first study (Chapter 3) an investigation was done to determine the best fitting model for ostrich growth data obtained in a trial where three different levels of dietary protein were fed. Seven nonlinear growth models and three linear polynomial models were fitted to growth data obtained. The three diets were formulated to have 20% more and 20% less protein than the predicted value (H- high protein diet, M- medium protein diet and L- low protein diet). The growth functions were compared using Akaike's information criterion (AIC). For the nonlinear models, the Bridges and Janoschek models had the lowest AIC values for the H treatment, while the Richards curve had the lowest value for M and the Von Bertalanffy for the L treatment. For the linear polynomial models, the linear polynomial of the third degree had the lowest AIC value for all three treatments thus making it the most suitable model for the data. The results from this study can aid in describing the growth of ostriches subjected to optimum feeding conditions. This information can also be used in research when modelling the nutrient requirements of growing ostriches.

In the second research study (Chapter 4) the effect of dietary bulk density on the feed intake of slaughter ostriches were investigated. The diets were diluted with wheat straw. Three dilution levels (0%, 10% and 20%) were used for the pre-starter and starter phases, five dilution levels (0%, 15%, 30%, 45% and 60%) were used for the grower and the finisher phases, and five levels (0%, 20%, 40%, 60% and 80%) were used for the maintenance phase. Weekly intake data were collected throughout each phase. It was found that feed bulk restricted intake by 21% and 52% at the 10% and 20% dilution level, respectively, in the pre-starter phase, whereas intake was not restricted during the starter phase. Intake was constrained by 39% and 42% at the 45% and 60% dilution levels in the grower phase, respectively, and by 17% and 39% at the 45% and 60% dilution levels in the finisher phase, respectively. Feed bulk restricted intake by 60% and 69% for the 60% and 80% dilution levels, respectively, in the maintenance phase. The bulk capacity and intake regulation limits

in the ostrich will aid with least-cost modelling as ostrich intake parameters with regards to bulk capacity were defined in this study. Simplified intake predictions and defined bulk capacity levels for ostriches will improve the practical applications of least-cost simulation modelling.

In the third study (Chapter 5) the effect of dietary protein concentrations on production parameters of ostrich chicks wre evaluated; three basic diets were formulated to be 20% lower and 20% above predicted levels for lysine, sulphur-containing amino acids, threonine, tryptophan and arginine (named diets with a low, medium or high protein content). The three diets were fed to the ostriches during each of the four production phases from hatching up to slaughtering. Feed and water were available *ad libitum.* Significant differences were found for the final live weight of birds at slaughter (350 days old), cold carcass weight, thigh weight as well as for most of the weighed muscles. Concerning the growth and feed related parameters, only average daily gain (ADG) was influenced by dietary treatment. No significant differences were found for any of the measured parameters on the feathers. Results indicated that birds on the diet with the medium protein performed optimally. One exception is the starter phase (26 – 47 kg) where chicks on the high protein diet outperformed those on the medium protein diet. For the rest of the phases, no further increase in production levels were observed in the diet with the highest level of protein (and associated amino acids). This study showed that feeding diets with a higher protein and amino acid content than that predicted by the model developed by Gous and Brand (2008) was not able to further increase performance levels of growing ostriches.

In the fourth study (Chapter 6), three diets with different levels of dietary energy were fed respectively for each phase (Low, Medium and High for each phase): 13.5, 14.5 and 15.5 MJ ME/kg feed pre-starter; 12.5, 13.5 and 14.5 MJ ME/kg feed starter; 10.5, 11.5 and 12.5 MJ ME/kg feed grower; and 9.5, 10.5 and 11.5 MJ ME/kg feed finisher. Overall dietary levels provided in the pre-starter, starter and grower phases indicated better growth, FCR, skin size and grade, thigh weight, live weight, and carcass weight for the birds fed the medium energy diet. Dietary energy levels provided during the finisher phase indicated that the energy level above the medium level (11.5 MJ ME/kg feed) used improved growth rate and tanned skin size. The gender of the birds also significantly influenced carcass weight, growth rate, and certain feather parameters. Certain feather quality measurements (favouring clipped) and the FCR (lower for the clipped group) were also influenced by feather clipping at 6 – 8 months of age.

In the fifth study (Chapter 7) where feather clipping at six to eight months of age were evaluated, significant differences were found for the feed conversion ratio (FCR), the average daily gain (ADG) and for the quantity of feathers with commercial. No significant differences were found for any of the measured carcass parameters. Results indicated that the growth rate and FCR was better for the birds which had their feathers clipped at six to eight months of age. Results also showed that the quantity of valuable feathers were significantly higher for the clipped group. This study showed that there may be an advantage for ostrich producers concerning the harvesting of feathers at six to eight months of age. The reason for the differences between the earlier study and this study are not clear. It could be argued that in the earlier study the ostriches had their feathers clipped at a younger age (6 months) when either the feathers were still immature/not ripe and/or that the birds were slaughtered too young (12 months vs. 14 months) and/or other factors may be involved. It is therefore suggested that additional research be conducted to evaluate the effect of feather clipping at different ages combined with slaughtering at different ages.

Most of the results obtained in these studies will be incorporated into the mathematical optimisation model of Gous and Brand (2008) for more accurate predictions concerning feed intake and other production parameters.

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ANNEXURE A

Table A. *The premix composition per kg of premix of ostrich diets for pre-starter, starter, grower, finisher and maintenance phases*

Ingredient	Pre-Starter	Starter	Grower	Finisher	Maintenance
Vitamin A (IU)	6000000.00	6000000.00	4000000.00	4000000.00	5333333.33
Vitamin D_3 (IU)	1166666.67	1166666.67	1066666.67	1066666.67	1133333.33
Vitamin E (IU)	23333.33	23333.33	16000.00	16000.00	20000.00
Vitamin K_3 (g)	1.67	1.67	1.00	1.00	1.67
Vitamin B_1 (g)	1.67	1.67	1.00	1.00	1.33
Vitamin B_2 (g)	4.33	4.33	3.00	3.00	5.00
Vitamin B_6 (g)	3.00	3.00	2.00	2.00	2.67
Vitamin B_{12} (mg)	33.33	33.33	33.33	33.33	33.33
Niacin (g)	30.00	30.00	26.67	26.67	26.67
CalPan (g)	7.50	7.50	5.00	5.00	6.67
Folic Acid (g)	0.80	0.80	0.53	0.53	0.53
Biotin (mg)	100.00	100.00	66.67	66.67	66.67
Iodine (g)	0.50	0.50	0.33	0.33	0.33
Cobalt (g)	0.25	0.25	0.17	0.17	0.17
Selenium (g)	0.15	0.15	0.10	0.10	0.10
Choline (g)	266.67	266.67	200.00	200.00	216.67
Manganese (g)	40.00	40.00	50.00	50.00	50.00
Zink (g)	40.00	40.00	26.67	26.67	26.67
Copper (g)	2.67	2.67	2.67	2.67	3.33
Iron (g)	10.00	10.00	13.33	13.33	13.33
Magnesium (g)	13.33	13.33	16.67	16.67	13.33