A study on certain factors that may affect the production and feed intake of breeding ostriches

by
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Declaration

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Date: March 2015

Abstract

A large amount of research has gone into developing growth models for other monogastric animals, incorporating various biological and animal related factors, feed factors, the environment as well as the interaction between these factors. In order to develop a mathematical optimization model for breeding ostriches, all possible factors that can influence feed intake and production needs to be investigated. Therefore this study was conducted to identify and quantify the possible factors that affect feed intake and production of breeding ostriches.

In the first study (Chapter 3), the effect of certain nutrients on feed intake and production of breeding ostriches was evaluated. No specific effect of any one of the tested parameters (additional vitamins, minerals, fatty acids and amino acids) was seen on the production parameters considered. Significant differences were found in the quantity of feed ingested indicating a possibility that breeding ostriches may adjust feed intake to satisfy mineral requirements. The supply of additional vitamins and minerals during the resting period might have an effect on the results.

Therefore, the second study (Chapter 4) determined the effect of the addition of minerals and vitamins during the resting and breeding period on the production of breeding ostriches. The presence of a vitamin and mineral premix during the resting period decreased body condition lost by female breeding ostriches with 31.2% and decreased the presence of DIS eggs with 8.1%. The supply of vitamins and minerals in the breeding period decreased the body condition lost by breeding females with 5.3%. Overall it can be concluded that the presence of a vitamin and mineral premix is essential in resting as well as the breeding period.

The commonly used protein source in the diet of breeding ostriches, soya oilcake (SOC), has become so expensive that an alternative protein source, cottonseed oilcake (CSOC), was investigated for its possible use in the third study (Chapter 5). Cottonseed oilcake as a protein source had no significant effect on most of the production parameters (total number of eggs, DIS eggs, infertile eggs or chick production), but led to a significant decrease in the quantity of chicks hatched. Until more research results are available, it is suggested that producers follow the precautionary approach and not use CSOC to feed breeding ostriches.

With the development of a simulation model for ostriches, the immediate effect of dietary energy content on feed intake as well as its long term effect on breeding ostrich production was determined in the fourth study (Chapter 6). One hundred ostrich breeding pairs were divided into five groups of twenty breeding pairs each for two consecutive breeding seasons and received one of the five experimental diets *ad libitum*. Although previous studies of Brand et al. (2002, 2003) have indicated that production in the current breeding season can be affected by nutrition of previous breeding seasons, no such effect was seen on the production parameters measured (total egg production, DIS eggs, infertile eggs, chick production, breeding female ostrich weight change or feed intake). Breeding ostriches also showed no indication of regulating feed intake according to the energy content of the feed. Literature revealed that breeding ostrich feed intake may be influenced by the bulk density of the feed. Due to lack of differences in production parameters measured, possible future studies can include the effect of low and high levels of basal energy supplied over three or more consecutive breeding seasons.

Egg production is a costly process for female breeding ostriches, requiring high levels of quality feed and often causing loss of body condition. In study five (Chapter 7), the egg laying pattern for breeding ostriches was evaluated. Results from this study indicated that the days until first egg and total days in lay are strongly influenced by the age of the female ostrich. However, due to the egg production of female breeding ostriches being highly variable, and a vast number of factors influencing the production of ostrich eggs, a specific egg laying pattern over the breeding season could not be identified.

This thesis makes a significant contribution towards quantifying the factors affecting production and quality parameters in breeding ostriches. Most of the results obtained in these studies can be incorporated into a mathematical optimization model for more accurate predictions concerning feed intake and other production parameters.

Opsomming

‘n Groot hoeveelheid navorsing het al in die ontwikkeling van groeimodelle vir ander enkelmaagdiere gegaan. Hierdie modelle inkorporeer nie net verskeie biologiese- en dierverwante faktore, voerfaktore en die omgewing nie, maar ook die interaksies wat tussen al die genoemde faktore bestaan. Om so ‘n wiskundige optimeringsmodel vir broeivolstruise te ontwikkel, moet al die faktore wat voerinname en produksie van broeivolstruis-behoeftes beinvloed ondersoek word. Daarom is hierdie studie se doel om die moontlike faktore wat 'n invloed het op voerinname en produksie van broeivolstruise te identifiseer en te kwantifiseer.

In die eerste studie (Hoofstuk 3), is die effek van verskeie voedingstowwe op voerinname en produksie van broeivolstruise geëvalueer. Geen spesifieke effek van enige een van die getoetste parameters (addisionele vitamiene, minerale, vetsure en aminosure) is sigbaar in die reproduksiesyfers van die broeivolstruise nie. Beduidende verskille is wel gevind in die hoeveelheid voer wat ingeneem is en toon ‘n moontlikheid dat broei volstruise hul voerinname aanpas ten opsigte van hul mineraa behoeftes. Die verskaffing van bykomende vitamiene en minerale tydens die rusperiode kon 'n invloed op die resultate hê.

In die tweede studie (Hoofstuk 4) is die effek van die toevoeging van minerale en vitamiene in die rus- en broeiperiode op die produksie van broeivolstruise ondersoek. Die teenwoordigheid van 'n vitamien- en mineraalaanvulling tydens die rusperiode het daartoe gelei dat wyfie-broeivolstruise 31.2% minder gewig verlies ervaar het. Dit het ook gelei tot ‘n 8.1% afname in die aantal dood-in-dop (DIS) eiers tydens die broei seisoen. Wyfie-broeivolstruise het ook 5.3% minder gewig verlies getoon as gevolg van die verskaffing van ‘n vitamien- en mineraalaanvulling tydens die broeiperiode. ‘n Neiging, om groter eiers en kuikens te produseer is wel gevind by wyfie-broeivolstruise wat geen aanvulling ontvang het tydens beide die rus- of broeiperiode nie. Die gevolgtrekking van hierdie studie is dus dat ‘n vitamien- en mineraalaanvulling tydens die rus- sowel as broeiperiode noodsaaklik is.

Soja-oliekoek (SOC), wat hoofsaaklik gebruik word as ‘n proteienbron in broeivolstruisdiete, se skaarsheid en onbekostigbaarheid het daartoe gelei dat ‘n alternatiewe proteien bron, naamlik katoensaadoliekoek (CSOC), se geskiktheid ondersoek is in Hoofstuk 5. Katoensaadoliekoek as 'n bron van proteïen het geen wesenlike uitwerking op die meeste van die produksieparameters (totale aantal eiers, DIS eiers, onvrugbare eiers of kuikenproduksie) nie, maar het gelei tot 'n aansienlike afname in die hoeveelheid kuikens wat uitgebroei het.

Totdat daar meer navorsingsuitslae beskikbaar is, word daar voorgestel dat produsente die voorkomende benadering volg en nie CSOC gebruik in die voeding van broeivolstruise nie.

Vir die ontwikkeling van ‘n simulasiemodel vir broeivolstruise, moet die onmiddelike effek van die voer se energie-inhoud op voerinname, sowel as die langtermyn effek op produksie bepaal word (Hoofstuk 6). Een honderd volstruisbroeipare is in vyf groepe van twintig broeipare elk ingedeel. Elke groep het een van vyf eksperimentele diëte *ad libitum* ontvang tydens twee opeenvolgende broeiseisoene. Hoewel vorige studies van Brand *et al*. (2002, 2003) getoon het dat die produksie in die huidige paarseisoen beinvloed kan word deur voeding wat in die vorige paarseisoen ontvang is, is geen sodanige effek op die produksieparameters gemeet nie (totale eierproduksie, DIS eiers, onvrugbare eiers, kuikenproduksie, wyfie-broeivolstruis gewigsverandering of voerinname). Broeivolstruise het ook geen regulering van voerinname getoon weens die energie-inhoud van die voer nie. Literatuur het aan die lig gebring dat die digtheid van die voer (Bulk density) moontlik die voerinname van broeivolstruise kan beinvloed. Weens die gebrek aan verskille in die produksieparameters gemeet, kan moontlike toekomstige studies die effek van lae en hoë vlakke van basale energie verskaf, oor drie of meer agtereenvolgende paarseisoene insluit.

Eierproduksie, deur wyfie-broeivolstruise, word beskou as ‘n duursame proses vir die wyfie aangesien sy eiers produseer wat dikwels lei tot gewigsverlies. Derhalwe is die eier-lêpatroon vir broeivolstruise bepaal vir insluiting in die optimeringsmodel (Hoofstuk 7). Resultate van hierdie studie het aangedui dat die ouderdom van die wyfie ‘n rol speel in die hoeveelheid dae tot die eerste eier geproduseer word, sowel as die totale aantal dae waartydens eie produksie plaasvind. Bewyse van die patroon wat beskryf is deur Shanawany (1999) is gevind, maar as gevolg van die hoogs veranderlike eierproduksie en verskeie aantal faktore wat die eierproduksie beinvloed, kon 'n spesifieke eierlê-patroon oor die broeiseisoen nie geïdentifiseer word nie.

Hierdie tesis maak 'n betekenisvolle bydrae tot die kwantifisering van die faktore wat die produksieparameters in broeivolstruise beinvloed. 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.

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Dedications

Being deeply loved by someone gives you strength, while loving someone deeply gives you courage. Lao Tzu

This thesis is thus dedicated to my husband, **Michiel**, and my son, **MC.**

I give my deepest expression of love and appreciation for the encouragement that you gave and the sacrifices you made during this graduate program. Thank you for all the support, patience, motivation and making my life even more joyful!

Notes

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 repetition between chapters was therefore unavoidable. It should be known that each chapter has its own reference list instead of one comprehensive list appearing at the end of this thesis.

Part of this thesis was presented at the following symposiums:

1. 45th South African Society for Animal Science congress (SASAS), 9-12 July 2012, East London, Eastern Cape province, South Africa

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1. Chapter 3

TESSELAAR, G.A., BRAND, T.S., HOFFMAN, L.C., BRAND, Z., & PFISTER, B. (2013). Preliminary results on the effect of different dietary vitamin and mineral levels on certain production parameters as well as egg shell characteristics of breeding ostriches. (*South African Journal of Animal Science* [ISSN 0375-1589 (print) and ISSN 2221-4062 (online)].

2. Chapter 5

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List of Abbreviations

%	percent
µm	micro meter
ADF	acid detergent fibre
cm	centimetre
CSOC	cottonseed oilcake
d	diameter
DE	digestible energy
DIS	dead-in-shell
DM	dry matter
FA	fatty acids
g	gram
GIT	gastro intestinal tract
HCl	hydrochloric acid
IU	international unit
IVOMD	*in vitro* organic matter digestibility
kg	kilogram
L	length
LH	luteinizing hormone
m	meter
ME	metabolisable energy
mg	milligram
MJ	mega joule
mm	millimeter
NDF	neutral detergent fibre
ppm	parts per million
PUFA	polyunsaturated fatty acids
RH	Relative humidity
SAOBC	South African Ostrich Business Chamber SOC
SOC	soybean Oilcake
VCL	vertical crystal layer
VFA	volatile fatty acids
WHC	water holding capacity
Y: A	yolk: albumin

Chapter 1

1.1. GENERAL INTRODUCTION

In the late 1800's a high demand for ostrich feathers driven by the European fashion industry initiated the domestication of ostriches in South Africa. Currently, South Africa is producing more than 70 % of the world's ostrich products, generating revenue from the sale of meat, leather and feathers in the ratio of 20 %, 65 % and 15 % respectively (Stumpf, J. personal communication, 15 December 2014). Due to ostrich meat's growing popularity as a healthier red meat option in Europe, the proportion of the income generated from meat sales has increased steadily since 2000.

In order to keep up with the demand, intensive ostrich production units need to increase the production of ostrich chicks while still keeping production costs as low as possible. Seventy-five percent of the production costs can be attributed to that of the breeder birds' nutrition. Producers are thus caught in a catch twenty-two situation, either producing high quality products but having a low profit margin when providing expensive high quality feed or generating a low income due to the provision of low quality feed and the resultant production of a low quality end product.

Although ostrich breeding in South Africa has come a long way in the past century, relatively little is known about the nutritional factors affecting ostrich reproduction. Great amount of research has gone into growth models for other monogastric animals, such as poultry, turkeys and pigs, incorporating various biological and animal related factors, feed factors, the environment as well as interaction between these factors. These models are currently used all over the world, aiding in the making of important financial and management decisions. Along with a recommendation in economic terms, a least-cost diet is formulated that supplies all the nutritional requirements of that animal at that specific live stage. No such model and feeding system exists for the ostrich industry at present.

In order to develop a mathematical optimization model for breeding ostriches, all possible factors that can influence feed intake and production needs to be investigated. Therefore this study was conducted to identify and quantify the possible factors that affect feed intake and how these factors affect breeding ostrich production.

With the background information in mind, these will be the specific factors focussed on:

- Determine effect of certain nutrients on feed intake and production
    - Vitamins and minerals during the breeding and resting period
    - Calcium and phosphorus in the breeding period
    - Amino acids and fatty acids in the breeding period
- Alternative options to protein sources used
- The effect of different energy levels on feed intake and production
- Determine existence of an egg laying pattern for breeding ostriches

Overall, the development of a mathematical optimization model for breeding ostriches will ensure that local production units can feed their breeders according to their nutritional requirements and at a greater efficiency in future.

Chapter 2

Literature review

2.1. INTRODUCTION

Although ostrich breeding in South Africa has come a long way in the past century, relatively little is known about the nutritional factors affecting ostrich reproduction when compared to other farm animals (Brand *et al*., 2002a; Miao *et al*, 2003; Ipek & Sahan, 2004).

Ostriches were first domesticated in the Klein Karoo, South Africa, in 1860 and by 1865 eighty ostriches were successfully being kept in an extensive production system (Smit, 1963; Jordaan *et al*., 2008). The three main products produced by ostriches - namely the skin, meat and feathers - are all affected by market trends. In the late 1800's a high demand for ostrich feathers was driven by the European fashion industry. This continued until 1914, when the First World War caused the industry to crash (Smit, 1963; Du Preez, 1991; Deeming & Ayres, 1994). At that stage South Africa had around 23 500 domesticated ostriches (Deeming & Ayres, 1994). As the popularity of ostrich feathers declined the focus of production gradually shifted to the skin and meat, with meat production becoming the greatest generator of revenue in 1990 (Jordaan *et al*, 2008; Nel, 2010). The proportion of the income generated from meat sales has increased steadily since 2000. This is a result of ostrich meat's growing popularity as a healthier red-meat option in South Africa and Europe due to its favourable fatty acid profile (Mellet, 1992; Sales & Horbanczuk, 1998; SAOBC, 2002). The generation of revenue from the sale of meat, leather and feathers is now 20 %, 65 % and 15 % respectively, with South Africa producing 70 % of the world's ostrich products despite the decrease in production due to the Avian Influenza outbreak in 2011 (Stumpf, J. personal communication, 15 December 2014).

The production of these ostrich products is influenced by fertility and hatchability rates, as well as the management skills of the producer. In a breeding season, female ostriches can lay up to 80 eggs of which only around 50 % hatch (Mellet, 1993; Ipek & Sahan, 2004; Elsayed, 2009; Abbaspour-fard *et al*., 2010). Males are sexually mature at three and females at two years of age (Van Niekerk, 1996). Although ostriches have a longer economic life, they have lower egg production and hatchability rates when compared to domestic poultry (Ipek & Sahan, 2004).

Lambrechts (2006) noted that nutrition, behaviour and management, as well as the physiological health of the breeding ostriches play an important role in their reproductive abilities.

Nutrition is also highly influential in the management of a successful ostrich farm, as seventy-five percent of the running costs are assigned to obtaining high quality feed for the breeding stock (Brand *et al*., 2002b; Aganga *et al*., 2003, Cooper *et al*., 2004; Kritzinger, 2011). Increases in the prices of raw materials prevent the production of an economical product with a positive profit margin (Cilliers *et al*., 1998). Although commercial producers try to cut feed costs by compromising feed quality and decreasing the levels of protein, energy and/or supplements, this reduces the quality and quantity of ostrich products produced (Brand *et al*, 2002b, Cooper *et al*., 2004).

The growing demand for ostriches and their products, as well as the mounting problems being encountered in the industry indicate the necessity of quantifying the nutrient requirements for ostrich production (Bezuidenhoudt, 1999; Bhiya, 2006; Olivier, 2010; El-Safty, 2012). Determining the nutrients required for reproduction and the feasibility of using cheaper alternative sources of nutrients, without negatively affecting production characteristics, will therefore be explored in this thesis. However, prior to formulating a balanced diet for breeding ostriches, knowledge of their digestive system is required (Gous, 1986).

2.2. THE GASTRO-INTESTINAL TRACT OF AN OSTRICH

Ostriches form part of the Ratite family along with the Emu, Rhea and Kiwi (Cho *et al*., 1984; Cooper, 2005). Domesticated ostriches spend over 50 % of their day feeding; either foraging for food or feeding on a concentrated feed supplied (Deeming, 1996). In the wild, ostriches are highly selective and the dry matter intake per bird will reach about 3kg per day, this consisting of 60 % plant material, 15 % legumes and fruits, four to five percent insects, and the last 20 % of cereal grains, salts and stones (Ullrey & Allen, 1996; Aganga *et al*., 2003). However, formulated domesticated ostrich diets are normally ingested at a rate of 2.1 to 2.5 kg dry matter (DM) per bird per day (Van Niekerk, 1996).

Huchzermeyer (1998) and Fowler (1991) determined that the ostrich tongue is rudimentary and folded over itself when compared to the serrated tongue of the emu. The ostrich’s oesophagus is situated on the right hand side of the neck.

The oesophagus is not fixed to the cervical structure, possibly for protective purposes when fighting, during which ostriches tend to kick towards their opponent's neck (Folwer, 1991). Following the oesophagus is the proventriculus. In ostriches the presence of a sphincter between the oesophagus and proventriculus is lacking; thus enabling the proventriculus to be "washed" if compaction occurs (Huchzermeyer 1998). The ratite family has an enlarged proventriculus which serves as an extendable storage organ in the place of a crop as seen in chickens (Fowler, 1991; Huchzermeyer, 1998; Champion & Weatherley, 2000; Table 2.1).

Bulky feed that is ingested is stored by the ostrich in the proventriculus, where it is mixed with water and the excretions from the deep glands situated in the dorsal part of the proventriculus. The excretions from these simple branched tubular glands include hydrochloric acid (HCl) and pepsin, both of which are mainly involved in protein breakdown (Bezuidenhout & Van Aswegen, 1990; Champion & Weatherley, 2002). The short retention time of feed in the gastro-intestinal tract (GIT) of ostriches limits the level of digestion that can take place (Champion & Weatherley, 2002).

The gizzard, known in ostriches as the ventriculus, is located at a left ventral angle to the proventriculus (Figure 2.1) and is functionally equivalent to the muscular stomach seen in chickens (Bezuidenhout & Van Aswegen, 1990; Huchzermeyer, 1998). Due to the lack of teeth, ostriches ingest stones to aid in the physical degradation of feed that occurs in the ventriculus (Ullrey & Allen, 1996; Champion & Weatherley, 2000). The provision of quartzitic gravel composed of 2-15 mm round stones is therefore beneficial as ostriches tend to swallow 0.83 % of their body weight in stones in the wild (Milton *et al*., 1994).

With the aid of ingested stones, strong contractions of the muscles in the walls of the ventriculus can grind digesta into small enough pieces to pass into the small intestines (Champion & Weatherley, 2000).

The lining of the ventriculus, the koilin layer, is formed by the tubular mucosal secretion of protein-containing cellular debris and sloughed cells (Huchzermeyer, 1998). The koilin layer has a dark green to brown colouration due to bile pigments that are refluxed upwards in the GIT from the duodenum (Fowler, 1991). This layer extends upwards into the proventriculus, but does not completely cover the glandular patch which is necessary for pepsin and HCl excretions (Huchzermeyer, 1998).

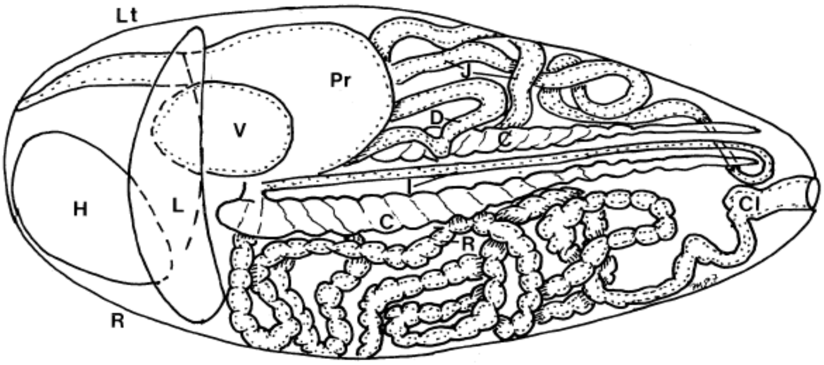

Figure 2.1 *Dorsoventral view of the thoraco-abdominal viscera of an ostrich (Fowler, 1991).*

Lt - left; R – right; H - heart; L - liver; V - ventriculus; Pr - proventriculus; C - cecae; I - ileum; D - duodenum; J - jejunum; R - rectum; Cl - cloaca

Table 2.1 *Measurements of length (cm) of the gastro-intestinal tract of the ostrich (adapted from Fowler, 1991)*

Organ	Dimensions in ostrich (cm)
Stomach	
Proventriculus	14 x 32 (d × L) l
Major gland area	1 x 4 – 7 x 24
Ventriculus	12 x 16 (d × L)
Small intestine	640
Duodenum	80
Jejunum	160
Ileum	400
Large intestine	
Cecum	1 – 8 x 94 (d × L)
Rectum	6 x 800
Cloaca	
Coprodeum	10 x 15 (d × L)
Urodeum	5
Proctodeum	2 to 3
Liver wt. (kg)	2.2
Gallbladder	Absent

d- diameter, L- length

The ventriculus opens through a narrow sphincter, known as the pylorus, into the duodenum. The pylorus ensures the passing of small sized digesta when it is at an acceptable pH (Huchzermeyer, 1998).

The small intestines are approximately six meters long, but will vary according to the diet the ostrich receives (Brand *et al*., 2002a; Cooper & Mahroze, 2004). The next step in digestion takes place in the duodenum, where fluids from the liver and pancreas are mixed with the partially digested food from the ventriculus (McDonald *et al*., 2002).

The duodenum loops around the pancreas while the ileum and jejunum lie in the ventral part of the abdomen between the pelvis and ventriculus (Cooper & Mahroze, 2004). The inner lining of the small intestines consist of long and branched villi (Cooper & Mahroze, 2004). Brunner's glands exist between the villi. They are connected by ducts and help with lubrication and protection of the GIT (McDonald *et al*., 2002). Bile is secreted into the duodenum by the liver (McDonald *et al*., 2002). Pancreatic secretion is stimulated through the release of the hormone secretin into the blood by the entrance of acidic content into the duodenum (McDonald *et al*., 2002). At the terminal end of the duodenum, three pancreatic and two bile ducts open into the GIT and a pH of around seven to nine is sustained (McDonald *et al*., 2002).

As the weight of digesta flows through the small intestines most of the nutrients are absorbed, with most absorption occurring in the jejunum and ileum (McDonald *et al*., 2002). After approximately 1.6 m of jejunum, the beginning of the ileum can be identified by the presence of the vitelline diverticulum (Bezuidenhoudt, 1999). The vitelline diverticulum is a small outgrowth, a remnant of the connection to the yolk sac during the incubation period in the egg (Bezuidenhoudt, 1999).

Ostriches have the ability to utilise low quality forage through the fermentation of undigested particles and nutrients in the large intestines (Cho *et al*., 1984; McDonald *et al*., 2002; Aganga *et al*., 2003; Cooper & Mahroze, 2004; Cooper, 2005). This hindgut fermentation is made possible due to the enlarged and specialized ceca of the ostrich and the vast number of micro-flora occupying it (Aganga *et al*., 2003; Cooper & Mahroze, 2004; Matsui *et al*., 2010a, b). The cecae are connected to the digestive tract at the junction of the small and large intestines (McDonald *et al*., 2002) and are approximately 0.95 to 1.25 m long with their apices in the pelvis (Cooper & Mahroze, 2004).

The cecae have two functions, firstly acting as a fermentation area for plant fibre (Cooper & Mahroze, 2004) and secondly, contributing to the absorption of volatile fatty acids (VFA) produced in the digestive system (McDonald *et al*., 2002; Aganga *et al*., 2003).

The spiral shape of the cecae (Cooper & Mahroze, 2004), as well as the presence of certain bacteria on their mucosal walls (McDonald *et al*., 2002) makes them important organs for hindgut fermentation (Brand *et al.*, 2002a). This ability can be seen in ostriches as young as 10 to 17 weeks of age (Angel, 1993; Brand *et al*., 2002a). Matsui *et al*. (2010a) showed that firobacter species are present in the ceca of ostriches; however ciliate protozoa are absent (Ullrey & Allen, 1996).

With the help of peristaltic movements, digesta is mixed and the fermentation and utilization of fibre can commence (McDonald *et al*., 2002). The VFA's acetate, propionate and butyrate (Ullrey & Allen, 1996) are produced through the fermentation of cellulose and hemicellulose and are subsequently absorbed and metabolized as an energy source. Energy obtained in this manner can supply up to 76 % of the energy required by the ostrich (Brand *et al*., 2002a; Aganga *et al*., 2003). Ostriches can digest up to 60 % of plant cell wall material, the neutral detergent fibre (NDF), in a diet (Ames, 1997).

The absence of villi and the presence of many mucus glands is typical of the colon and reflects the function of the 16 m long organ (Cooper & Mahroze, 2004); this being primarily the absorption of water and electrolytes (McDonald *et al*., 2002). The slow rate of passage of the digesta through the colon helps sustain the microbial population that originated in the ceca (McDonald *et al*., 2002).

While the cloaca is a combination of the rectum and the bladder, urine and faeces are not excreted together as in the chicken or turkey (Duke, 1999; McDonald *et al*., 2002). Water, undigested food residues, digestive secretions, epithelial cells from the digestive tract, inorganic salts, bacteria and products of microbial decomposition are some of the end products defecated in one to five discrete faecal boli just after urination of a low uric acid precipitate (Duke, 1999; McDonald *et al*., 2002).

2.3. CURRENT PROBLEMS ENCOUNTERED IN THE INDUSTRY

Increased raw material prices

As mentioned in the introduction, there is definite evidence that the international and local market has a growing demand for ostrich products. As reported by Black (2001), an ostrich farm needs to reach certain production and reproduction rates in order to survive in the industry. These targets can be seen in Table 2.2.

Local producers need to increase ostrich production while still keeping production costs as low as possible in order to survive. The running of a successful ostrich farm with a positive profit margin can be greatly influenced by the nutrition of the breeding ostriches as seventy-five percent of running costs are spent on feed (Aganga *et al*., 2003). An increase in the price of raw materials, especially protein sources and vitamin-mineral premixes, prevents the economical production of ostrich products.

Table 2.2 *Performance Targets for an Ostrich Farm (Black, 2001).*

Fertility	75 – 80 %
Hatchability (of fertile eggs)	80 – 90 %
Eggs per hen	40 - 70
Chicks (surviving to 3 months of age) per hen	15 - 25
Survival rate from 4 months to slaughter age	90 %
Target weight at 10 months of age	90 – 100 kg
Area of hide per bird at slaughter	1.39 - 1.58 m^2
Boneless meat per bird at slaughter	28 – 35 kg
Ratio of grades 1, 2, 3, and 4 hides for all ostriches slaughtered	50: 30: 10: 10

Producers try to find cheaper feed sources, but the reproduction and production of a breeding flock is greatly influenced by the quality and quantity of the nutrition they receive (Brand *et al*., 2002b; Sussi *et al*., 2003; Cooper *et al*., 2004). Producers are thus caught in a catch twenty-two situation, either producing high quality products but having a low profit margin when providing expensive high quality feed or generating a low income due to the provision of low quality feed and the resultant production of a low quality end product. An example of such a situation is concerning the pelleting of feed, which decreases wastage and minimises dustiness and the separation of feed ingredients, but is also more expensive than the use of meals (Aganga *et al*., 2003).

The optimal solution is therefore either to search for less expensive ingredients that can be utilised without negatively affecting production and reproduction rates and/or increasing production and reproduction rates by improving management and the physiological health of the breeding stock.

Low fertility, hatchability and survival rate of ostrich chicks

Important parameters to consider in the production of slaughter ostriches are the total amount of eggs produced as well as the rate of fertility, the hatchability and the survivability of those eggs (Bronneberg *et al*., 2007; Dzoma, 2010).

When comparing ostriches to domestic poultry, breeding animals have a longer economic life, but very high infertility rates (22.2 % *versus* 5 – 10 %) (Deeming, 1995; Ipek & Sahan, 2004). Approximately 25 – 30 % of the eggs laid annually in the Little Karoo (South Africa) are infertile, with a vast range of factors contributing to this (Mellet, 1993; Van Schalkwyk, 1994; Brand *et al*., 2008).

Ostriches are considered to be seasonal breeders as they are photoperiod dependant (Bronneberg *et al*., 2007; Dzoma, 2010). The breeding season of domesticated ostriches in South Africa, starts in May/June and stretches until the end of January of the following year (Nel, C. J. *et al*., 2010). Weather conditions have a greater influence on the production and reproduction of ostriches than previously believed, as it determines the length of the breeding season and can delay the onset of oviposition in female ostriches (Ipek & Sahan, 2004; Bronneberg *et al*., 2007). In the wild, ostriches show evidence of being opportunistic breeders showing an overall peak in reproduction activity just before the main rains (Sauer & Sauer, 1966; Jarvis *et al*., 1985). As reported by Ipek & Sahan (2004), the initiation of the breeding season causes a cascade of morphological, physiological and endocrinological reproductive changes allowing egg production to commence. The rise in the concentration of the hormone responsible for egg production, luteinizing hormone (LH), already begins a month prior to egg production and influences the growth of the female ostriches' ovaries so that they are able to cope with the reproductive demand (Ipek & Sahan, 2004). As the daylight length increases the number of eggs produced will increase, reaching a peak when day length is at a maximum (Ipek & Sahan, 2004).

Jarvis *et al.* (1985) discovered a series of peaks and troughs in the egg production during the breeding season of domesticated ostriches, showing a possible 6-week cycle pattern of egg laying. This pattern could also be identified in the wild ostriches of Mvuma, Zimbabwe.

Elsayed (2009) found the highest production of ostrich eggs to occur in July (8.94 eggs/female), while the lowest occurred at the beginning and end of the production season (January: 2.63 eggs/female and October: 5.92 eggs/female respectively).

Egg fertility rates follow the same pattern, being low in the beginning (30.2 % and 41.7 %), increasing steadily until peak production in June (83.2 % and 82.4 %) and then decreasing towards the end of the breeding season (62.2 % and 67.6 %).

It is therefore evident that the photoperiod-dependent nature of ostrich reproduction makes the month of the year highly influential on the total number of eggs produced, the fertility and the hatchability (Superchi *et al*., 2002; Bronneberg *et al*., 2007; Elsayed, 2009).

Contamination of the ostrich eggshell due to poor nesting environment hygiene and weather conditions, delay in egg collection and changes in shell structure over the breeding season all contribute to decreasing the hatchability of ostrich eggs (Deeming 1995, 1996).

Table 2.3 *Effect of month of production on ostrich egg number, fertility percentage and hatchability rates (Elsayed, 2009)*

Month	Egg number*	Fertility %	Hatchability %
January	$2.63^{j} \pm 1.19$	30.2	41.7
February	$3.66^{i} \pm 0.99$	44.7	49.9
March	$4.95^{h} \pm 0.69$	72.2	59.6
April	$6.22^{f} \pm 0.65$	79.8	75.6
May	$7.00^{e} \pm 0.66$	85.3	76.2
June	$8.21^{c} \pm 0.62$	87.6	85.3
July	$8.94^{a} \pm 0.63$	83.2	82.4
August	$8.63^{b} \pm 0.52$	79.5	78.1
September	$7.43^{d} \pm 0.62$	66.8	72.1
October	$5.92^{g} \pm 0.73$	62.2	67.6

* Values are means ± SE.

$^{a, b, c}$Means with different superscripts in the same column are significantly different ($P < 0.05$)

The body condition of breeding ostriches also contributes to low fertility and hatchability rates of ostrich eggs (Brand *et al*., 2002b). Obesity is caused by the supply of excess energy above the requirements for maintenance, growth and reproduction and will cause low egg production and fertility rates (Huchzermeyer 1999; Aganga *et al*., 2003). Female ostriches occasionally lose body condition during the breeding season and will normally regain the weight lost during the resting period.

However, if female ostriches fail to regain the weight or start the breeding season with a low body condition score, egg production and fertility rates will be affected (Brand *et al*., 2002b). Infertile eggs can also be caused by problems with the ostrich male.

When males consume high energy breeder diets infertility can result from the interaction between calcium and zinc (Wilson, 1997). A high calcium diet prevents the absorption of zinc, causing poor sperm production.

The age of the hen has a significant influence on the egg and chicks' weight at hatch (Figure 2.2), with the heaviest eggs and chicks being produced by hens of six years of age (Bunter & Cloete, 2004). The weight of the ostrich chick stabilizes after the tenth egg produced in the laying cycle (Bunter & Cloete, 2004). As is found in chickens, average sized ostrich eggs yield healthier chicks with higher survival rates than larger or smaller eggs (Deeming, 1995; Perrins, 1996; Gonzalez *et al*., 1999; King'ori, 2011; El-Safty, 2012).

Figure 2.2 *The effect of hen age on egg and chick weight, expressed as deviations from the average for 2-year-old hens (Bunter & Cloete, 2004)*

The shell thickness and number of pores in the shell is related to the weight and size of the egg, with these therefore influencing the moisture loss during incubation (Gonzalez *et al*., 1999; Hassen *et al*., 2005; Brand *et al*., 2008). As these traits have found to be heritable, genetic selection has and will still be able to make great improvements in the ostrich industry (Gertenbach *et al.*, 2006).

Another component that affects the fertility and hatchability of ostrich eggs is the storage and incubation thereof (Nahm 2001; Hassan *et al*., 2001, 2005). Pre-incubational storage of ostrich eggs for longer than fifteen days affects the loss of egg moisture during incubation and thus the hatchability and survivability of the ostrich chick (Wilson *et al*., 1997; Cloete *et al*., 2001; Hassan *et al*., 2005; Abbaspour-fard *et al*., 2010).

Furthermore, incubation temperatures can also have an effect on the moisture loss and thus hatchability of the ostrich eggs (Hassan *et al*., 2005).

Ostrich chicks are known to be very vulnerable to adverse conditions in the first few days of their life (Olivier, 2010). Stress, a lack of functional development of the digestive tract, and a vast range of other illnesses and/or deformities cause high chick mortality rates in the industry (Verwoerd *et al*., 1999; Cloete *et al*., 2001; Mushi *et al*., 2004). Certain factors affecting fertility, hatchability and the survival of ostrich chicks are unpredictable, while other factors can be managed (Brand *et al*., 2008).

Further research into the nutritional requirements of breeder ostriches will directly increase fertility and thus improve the hatchability and survivability of ostrich eggs.

In spite of the fact that several attempts have been made to determine the requirements of ostriches, reliable information on the specific nutritional requirements for the reproduction of ostriches are still lacking (du Preez, 1991; Cilliers, 1994; Brand & Gous, 2006a,b; Olivier, 2010). With South Africa supplying 75 to 80 % of the world’s ostrich products, further research into this field is required as this might be the reason for low fertility and hatchability rates experienced in the industry (Brand *et al*., 2003; Stumpf, J. personal communication, 12 June 2014).

2.4. NUTRITIONAL REQUIREMENTS AND THEIR EFFECT ON OSTRICH PRODUCTION

As previously mentioned, ostriches have lower egg production and hatchability rates than domestic chickens (Ipek & Sahan, 2004). Breeder ostriches require careful attention as successful and cost-effective production of ostriches begins with the breeders (Cooper *et al.*, 2004). This makes the development of specially formulated diets to improve production and reproduction extremely important. Correct formulation of these feeds, supplying accurate amounts of vitamins and trace elements, will prevent feed wastage and increase profitability (McDonald *et al.*, 2002).

Energy

Ostriches have the digestive system of a monogastric animal combined with the ability to utilise energy from fibre through hindgut fermentation from as early as six months of age (Aganga *et al.*, 2003; Iji, 2008).

It was determined by Matsui *et al.* (2010b), that a highly diverse population of anaerobic micro biota are involved in cell wall digestion and fermentation in the hindgut of the ostrich. It can be seen in Figure 2.3 that ostriches have elongated ceca and colons to accommodate the micro-organisms necessary for hind gut fermentation (Angel, 1996). This fermentation ability enables ostriches to get more out of a diet than for example a domestic chicken. It has been found that when placed on a comparable diet, an ostrich will obtain 40 % more metabolisable energy from the diet than other poultry (Aganga *et al.*, 2003; Kruger, 2007). Brand *et al.* (2000) determined that ostriches can utilise 25 % more energy from fibre than pigs consuming the same diet.

In the past, due to the relative lack of knowledge on breeding ostrich nutrient requirements, diets for ostriches were formulated based on poultry energy values for ingredients (Angel, 1996; Cilliers *et al.*, 1998). Because ostriches have a higher ability to digest feedstuffs compared to chickens, this can lead to the over or under supply of energy, causing profit losses and/or decreasing reproductive performance (Cooper *et al.*, 2004).

Brand *et al.* (2003) postulates that energy is the determining factor for egg production in ostriches. The body mass, body condition, and egg production of breeding females was assessed over two breeding seasons to investigate whether different dietary energy levels had an effect.

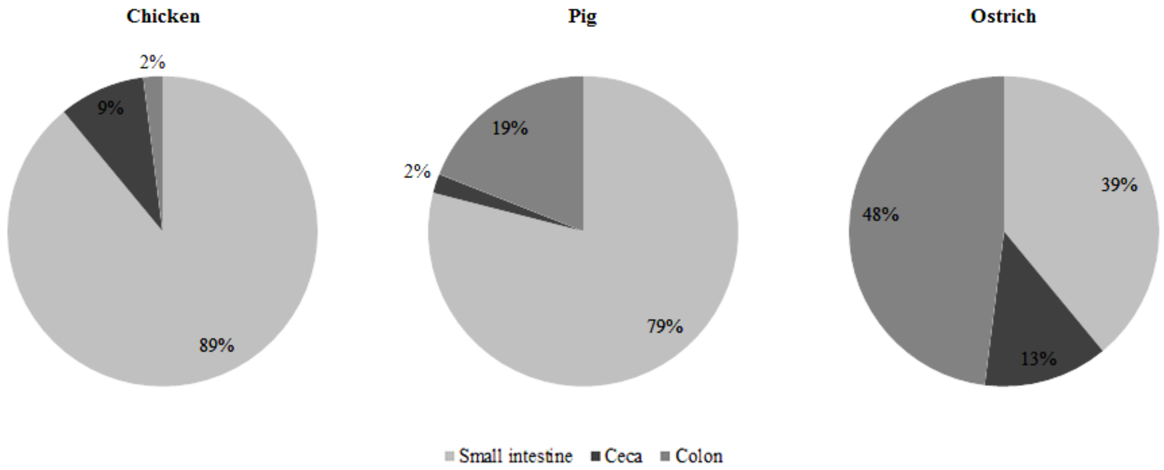

Figure 2.3 *Graphical illustration of the relative length of the small, large intestine as well as the ceca of the pig, chicken and ostrich (Brand et al., 2002a)*

When the ostriches were fed low energy diets they compensated by having longer intervals between eggs, thus laying fewer eggs in the breeding season.

Fewer eggs were laid by the females on the 7.5 MJ/kg ME diet than the other two diets. Other bird species have also been found to decrease the size of the eggs laid to compensate for a deficiency of energy or a nutrient (Perrins, 1996); however this has not as yet been observed in ostriches.

The body weight of the breeding females on the 7.5 and 8.5 MJ/kg ME diets decreased significantly over the breeding season and they had to regain this weight in the resting period before they could breed again (Brand *et al.*, 2003). The dietary protein concentrations had no effect on the egg production, egg mass, or hatchability.

In a study by Olivier (2010), the influence of varying ME levels on the production and egg composition of breeding ostriches was determined. No differences in the number of eggs produced per female (44.9 ± 7.6), the number of chicks hatched (15.7 ± 4.1), the number of fertile eggs (12.0 ± 3.9) or the number of dead-in-shell eggs (12.0 ± 3.1) for the breeding season was found.

There were also no differences found in the change of the live weight of the females over the breeding season (10.6 ± 3.5kg), while the weight of the males increased in a linear fashion as the dietary energy content increased..

In a latter study, Brand *et al*. (2010) divided 90 breeding pairs of ostriches into six groups in order to test the hypothesis that ostriches adjust feed intake according to the dietary energy level – as is found in broilers.

The body weight change (difference in weight between the beginning and end of the season) increased in correlation to the increasing ME of the diets which would seem to indicate that energy was in excess to the birds' requirements.

The age of the females also influenced the quantity of feed ingested as older females ingest more feed due to higher maintenance requirements, this can cause an increase in the production cost of each egg.

This study (Brand *et al*., 2010) indicated the possibility that ostriches also control feed intake to satisfy their energy requirements. No differences in the amount of eggs produced were observed when the six experimental diets were compared.

As reported by Brand *et al*. (2002b, 2003) and Dzoma (2010), the decrease in body condition of breeding ostriches due to the feed containing less than 8.5 MJ ME/kg can cause a 28 % decrease in egg production. Brand *et al*. (2002b) further found that when ostriches were fed energy levels of 7.5 MJ ME/kg DM during a breeding season it had a negative effect on the number of ostrich eggs produced in the following breeding season.

Olivier *et al*. (2009) determined that as long as the energy content of the diet exceeds 25.5 MJ ME per bird per day it will have no effect on reproduction performance of that or the following season.

There is however no consensus regarding a lower limit for the amount of energy required by breeding ostriches in the literature analysed, but Brand *et al*. (2003) did mention that energy could be a limiting factor in egg production. Olivier (2010) determined the ME requirement for egg production (MEe) to be 12.2 MJ ME/egg while the efficiency of ME utilization for energy deposition in the egg (k0) is 0.8.

Protein

Polat *et al*. (2003) studied the effect of different protein levels on ostrich egg production. A significant difference ($P < 0.01$) in the egg fertility ratio, hatch of fertile and hatchability of all eggs was found between the two groups. Polat *et al*. (2003) concluded that the crude protein content should not exceed 20 % as levels greater than this have a negative effect on egg production and associated characteristics.

Both Polat *et al*. (2003) and Brand *et al*. (2002b) found higher blood urea and uric acid concentrations in the breeding ostriches that received the higher protein concentration, indicating an excessive nitrogen intake above maintenance and production requirements.

In a study by Olivier (2010), five diets varying in crude protein content were given to five groups of breeding ostriches. Tthere were no significant differences found in the number of unfertilized eggs (9.1 ± 1.8), dead-in-shell chicks (8.2 ± 1.3) or hatched chicks, (19.5 ± 2.5) or in the change in weight of females (-16.2 ± 1.6 kg); however a difference in the number of eggs laid was observed between the groups (-3.8 ± 2.0 kg).

Brand *et al*. (2003) determined that the protein level of a breeding ostrich diet should never be lower than 10.5 % and gives this as the minimum inclusion level if reproduction is the goal. Polat *et al*. (2003) also noted that a crude-protein content of more than 20 % in the breeder diet should not be exceeded as it can decrease egg production and fertility rates. Milton *et al*. (1994) analysed the diet of wild ostriches and discovered that it always had a crude protein level of 12 %. This may have been an underestimation however as the flowers and seeds that ostriches ingest were not included in the analysis (Milton *et al*., 1994). A study by Olivier (2010) indicated that male breeding ostriches receiving a diet with 12.3 % crude-protein had the smallest change in body weight over the breeding season. This is an indication that the protein level was sufficient in supplying the necessary nutrients.

Vitamin and minerals

Vitamins and minerals are important components of animal nutrition and feed applications (McDonald *et al.,* 2002). They are usually included in the feed in the form of a vitamin-mineral premix and if not included severe problems in the health of the animals as well as production and reproduction can result. Vitamins are defined by McDowell (1989) as a group of complex organic compounds found in minute quantities in natural foodstuffs that are essential to normal metabolism, a lack thereof causing certain deficiency diseases. Minerals are the inorganic elements found in the ash portion of feeds and are just as important as vitamins (Underwood, 1981).

The discovery of vitamins and minerals was a fortunate by-product of the realisation as early as 1753 that certain foodstuffs could cure specific illnesses (McDonald *et al.,* 2002). It was later discovered that it was not the foodstuff as such but the vitamins and minerals contained that relieved the symptoms, and that the illness was caused by a deficiency in these specific key components (McDonald *et al.,* 2002). Hopkins further discovered in 1912 that certain deficiencies caused certain distinct “illnesses” by feeding rats, a monogastric animal, purified diets that were only deficient in a single component (McDonald *et al.,* 2002).

Vitamins can be divided into two groups according to their solubility (McDonald *et al.*, 2002). Vitamin A, D, E and K are fat-soluble and can thus be stored in the adipose tissue of the body (McDonald *et al.*, 2002). The remaining vitamins are classified as water-soluble and can only be absorbed if dissolved in water (McDonald *et al.*, 2002). The water-soluble vitamins cannot be stored in the body and will only be absorbed from the intestines if needed (McDonald *et al.*, 2002).

The physiological make-up and production purpose of an animal will influence its requirements for certain vitamins. There are also species, breeds and individual differences in vitamin requirements.

Historically, in the absence of ostrich nutritional data, chicken data was believed to be a reliable source of information for formulating ostrich feeds (Cilliers *et al*., 1998; Brand & Gous, 2006b). With new research it is now clear that this is not ideal.

Vitamin and mineral requirements as determined for ostriches

Wilson (1997) states that maternal nutrition can have a great effect on the hatchability of the egg as it influences the composition of the content. The content, namely the albumin and yolk, is deposited while still forming inside the hen and then sealed in by a thick layer of shell until a viable chick hatches (Wilson, 1997; King'ori, 2011). The chick will not hatch if the composition of the egg produced by the female has an inadequate, excessive or imbalanced level of nutrients. An example of this is the increased occurrence of malposition in ostrich eggs when there is deficient or excess vitamin A in the breeder bird diet (Angel, 1993). As determined by Angel (1993), the level of vitamin A, D, E, K, B_{12}, thiamine, riboflavin, pantothenic acid, folic acid, biotin, linoleic acid, manganese and iodine in the feed can influence the levels of the same vitamins mentioned in the ostrich egg. However, the water, protein, fat, calcium, phosphorus, amino acid and magnesium levels of the egg are not influenced by the level of these nutrients in the feed (Naber, 1979). Evidently, the nutrient profiles of an ostrich egg can be an indicator of the nutritional status of the hen and the resulting chick.

Calcium is important for hatchability as it plays an important role in the quality of the eggshell, while phosphorus is required for the embryonic development of normal bone as well as successful hatching of the chick (Smith *et al*, 1995; Almeida Paz *et al*., 2008). Calcium and phosphorus need to be ingested in the correct ratio in order to prevent deficiencies in either mineral from occurring (Wilson, 1997).

Both Cooper *et al*. (2004) and Olivier *et al*. (2009) are in agreement that the calcium in the feed should not exceed 0.5 g/kg and should be included in a ratio of 1.8 to 2 to phosphorus. Literature concerning the vitamin and mineral requirements of breeding ostriches is of short supply, but the findings of Angel (1993) and Aganga *et al*. (2003) are depicted in Table 2.4.

Table 2.4 *Joined table of information of deficiencies found in ostriches as well as their symptoms (Angel, 1993; Aganga et al., 2003)*

Nutrients	Specified deficiency symptoms	
	Aganga *et al*., 2003	Angel 1993
Vitamin E and Selenium	Chick dead in shell Weak hatch Sudden death (Downer ostrich), Nervous symptoms. Permanent sterility in males, may result from prolonged deficiencies	Early embryonic mortality High mortality of chicks soon after hatch Reduction in egg production Reduced hatchability Embryonic abnormalities
Vitamin B12 Riboflavin (B2) Biotin	Curled toe seen at hatching, weakness, paralysis, twisted legs and slipped tendon.	Dwarfing of embryos Altered limb and mandible development Oedema
Pantothenic acid	Inflammation of the skin around the beak, eyes and limbs. Feather loss on the head and neck	
Niacin	Poor hatchability of eggs Poor growth of chicks Poor feather development	
Folic acid	Late embryonic death Bending of the tibiotarsus Defects of the mandible	Defects of the mandible Deformed beaks
Calcium, Phosphorus and Vitamin D	Limb deformities (rickets in young ostriches)	
Manganese	Limb deformities and enlarged joints Hyperkeratinisation (thickening of the skin) of the feet and legs	Skull deformities Parrot beak.
Zinc	Reduced hatchability and chick survival	
Iodine		Incomplete closure of naval

Vitamin and mineral requirements as determined for poultry

Various case studies showed that the values derived from poultry nutrition is much lower than what is actually required for ostriches to be efficient producers (Cilliers *et al*., 1998). In a study done by Cilliers *et al*. (1998), values for lysine, methionine, cysteine, isoleucine, threonine and valine compared favourably with the values determined for poultry, but values of leucine, arginine and histidine where higher for ostriches than prescribed with the extrapolation of poultry nutrition.

Vitamins have various effects in poultry. Folic acid is more crucial for the hatchability of the embryo than the production of the egg and thus has a great influence on hatchability. Embryos appear normal, but die just after pipping the air cell (Wilson, 1997). Supplementation of folic acid in the diet will increase the egg as well as chick weight. It is also believed that the prolonged storage of a fertile egg, inside the laying hen, will result in a folic acid deficiency (Wilson *et al.*, 1997).

A deficiency of pantothenic acid in the diet of poultry breeding stock will decrease the hatchability of the eggs as well as increasing the occurrence of swollen hocks and poor feathering. Mortality of the embryo is common during the first four days and on the 13th day of incubation, while chicks that do survive incubation will often die around 18 days after hatching (Wilson, 1997).

Riboflavin plays an essential role in the embryonic development of chicks. Maximum hatchability was achieved in poultry when 2.75 mg riboflavin/kg diet was supplied (Wilson, 1997).

Vitamin B_{12} is essential for the successful hatching of chicken eggs (Wilson, 1997). Deficiency symptoms are breed related, with Road Island Reds being more sensitive than Leghorns (Wilson, 1997). The reduction in egg production resulting from a vitamin B_{12} deficiency will take at least four weeks to recover once the problem has been addressed. Mortality during the first, second and third week of incubation will occur as the period of deficiency increases. Abnormalities include oedema around the eyes, shortened beaks and head-between-thighs malposition (Wilson, 1997). Excessively high levels of vitamin B_{12} or Manganese in the diet will cause lower levels of biotin inside the yolk of the egg, resulting in oedema, increased mortality at day nine and fourteen of incubation, haemorrhages and anaemia in the embryos.

Niacin is required by the chicken embryo for normal development and hatchability. Excess nicotinamide can cause embryonic mortality and decreased hatchability (Wilson, 1997).

Vitamin D is required for the metabolism and transport of calcium and thus plays an important role in the hatchability of eggs (Wilson, 1997). If deficient it causes mortality of the embryo on day eighteen and nineteen of incubation.

Selenium deficiencies decrease hatchability and chicks that do succeed in hatching are weak and prone to gizzard muscle myopathy and leg deformities. Excess selenium can be toxic and cause embryonic mortality and abnormalities (Wilson, 1997).

Incorrect iodine levels, deficiencies or excess, can cause lowered hatchability of eggs (Wilson, 1997). Manganese deficiency has the same effect on the hatchability and hatched chicks show stargazing symptoms (Wilson, 1997).

Knowing the accurate nutritional requirements of breeding ostriches will not prevent ostrich producers from searching for cheaper feed alternatives. As a result, lower quality nutrient sources, with hidden toxins are often used. One such toxin is Gossypol.

2.5. GOSSYPOL AND ITS EFFECT ON REPRODUCTION

The natural toxin, gossypol (Figure 2.4), is produced by members of the genus *gossypium,* one of which is the cotton plant (Gambill & Humphrey, 1993). Gossypol is present in the pigment glands (yellow polyphenolic pigment) of the cotton seed (Siddhuraju *et al*., 2002) and can either be found in a bound non-toxic form or a free toxic form (McDonald *et al*., 2002; Zeng *et al*., 2014).

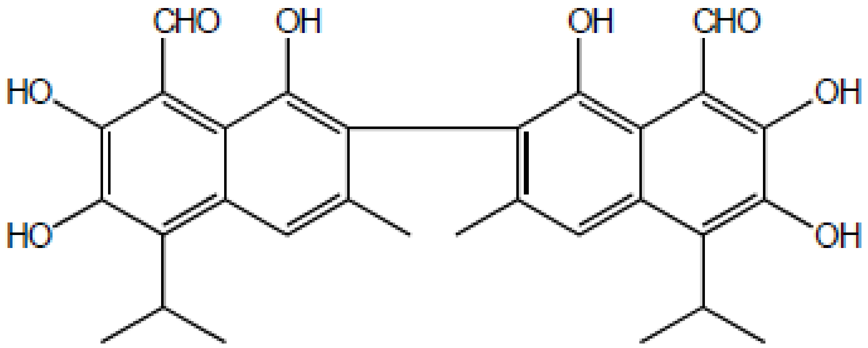

Figure 2.4 *Structure of Gossypol,* $C_3H_{30}O_8$ *(Alexander et al., 2009)*

Gossypol is a polyphenolic composite that protects the plant from herbivores and has negative effects on male reproduction (Gambill and Humphrey, 1993). Gossypol, hemi-gossypol and their derivatives found in cotton are used as a protective mechanism against attacks by pests or contact with micro-organisms (Alexander *et al*., 2009). Monogastric animals seem more susceptible to gossypol poisoning than ruminants, with the testes of the male being the main organ affected.

Cottonseed oilcake is a by-product of the textile industry and is not readily used as a source of protein in the diets of chickens and ostriches because of the presence of gossypol (Adeyemo & Longe, 2007). Adeyemo & Longe (2007) and Zeng *et al.* (2014) reported that many authors are in agreement that feed containing gossypol can safely be used for broilers, providing that the dietary level does not exceed 250 mg/kg of feed. The use of feeds containing gossypol for layer hens or fish has however been banned in the European Union (Alexander *et al*., 2009). Furthermore, Aganga *et al*. (2003) stated that if gossypol poisoning is to be avoided, it should never be fed to ostriches.

Although the mechanism of the toxic action of gossypol is not well known, it has been determined that it inhibits α-amylase (Alexander *et al*., 2009). The gossypol found in cottonseed oilcake is known to cause a decrease in tissue deposition as it forms a complex with proteins in the gut, thereby making it indigestible by monogastric animals (Adeyemo & Longe, 2007). Symptoms of gossypol toxicity include loss of appetite, weight loss, laboured breathing and cardiac irregularity (McDonald *et al*., 2002; Alexander *et al*., 2009). The carrying capacity of the blood is reduced and death is caused by circulatory failure (McDonald *et al*., 2002). Oedema in body cavities post mortem indicates an effect on membrane permeability. Gossypol also causes haemolysis (Gambill and Humphrey, 1993).

Alexander *et al.* (2009) reported that laying hens that consumed cottonseed oilcake containing gossypol showed a decrease in feed consumption, egg production and egg weight as well as discolouration of the egg components. Gossypol influences the permeability of chicken egg membranes, resulting in Iron leaking out from the yolk into the albumin. This causes the yolk to become rubbery and green while the albumin becomes pink. These eggs are not suitable for human consumption (Jacob *et al*., 2011).

Nelson (2003) found that the inclusion of a low-gossypol cottonseed meal at a level of up to 10 % resulted in an improvement in egg production, Haugh units, yolk index and yolk colour of chicken eggs when compared to a standard gossypol-free feed.

Higher inclusion rates caused a decrease in the thickness of the egg shell among other negative effects, as in accordance with the findings of Alexander *et al.* (2009).

In the paper by Adeyemo & Longe (2007), five diets containing different concentrations of gossypol resulted in significant differences in feed intake. This difference in feed intake may be due to the dilution of the cottonseed oilcake. The increased fibre content resulting from the inclusion of cottonseed oilcake also influences the energy level of the feed (Adeyemo & Longe, 2007).

The fibre content of cottonseed oilcake can be beneficial to ostriches due to their capacity to digest fibre in the ceca (Cooper & Mahroze, 2004). According to the literature, a higher percentage of infertile eggs can be caused by feeding gossypol to ostriches; however this has yet to be proven (Gambill & Humphrey, 1993; McDonald *et al.*, 2002; Alexander *et al.*, 2009).

Due to the immense effect gossypol has on reproduction and possible effects on the structure of the ostrich egg, knowledge of the ostrich egg and its components are required.

2.6. THE OSTRICH EGG

The ostrich egg, with the yolk being the largest living cell in the animal kingdom, is approximately 1.2 % of the females' body weight (Burley & Vadehra, 1989; Sales *et al.*, 1996). The average weight of an ostrich egg is 1500 g, consisting of 900 g albumin, 317 g yolk and a shell of 296 g (Cooper *et al.*, 2009).

According to these specifications, the average yolk to albumin ratio (Y: A) is ~2.84. This value is in accordance with the findings of Di Meo *et al.* (2003). The Y: A ratio increases as the age of the hen increases and it has also been confirmed by previous research that there is a small positive relationship between the weight of a chicken egg and its Y: A ratio (Harms & Hussein, 1993; Sahan *et al.*, 2013). Figure 2.5 depicts the longitudinal section through a hens' egg. The ostrich egg is, in comparison, 30 times the weight and three times the length of a chicken egg, but the shell is only six times thicker (Ar *et al.*, 1979).

The shape index is described by Romanhoff & Romanhoff (1949) as the diameter of the egg at its equator, divided by its length from pole to pole, multiplied by 100. Although ostrich eggs are quite large, they still have a high shape index, with values ranging between 76 and 86 (Sales *et al.*, 1996; Cooper *et al.*, 2009).

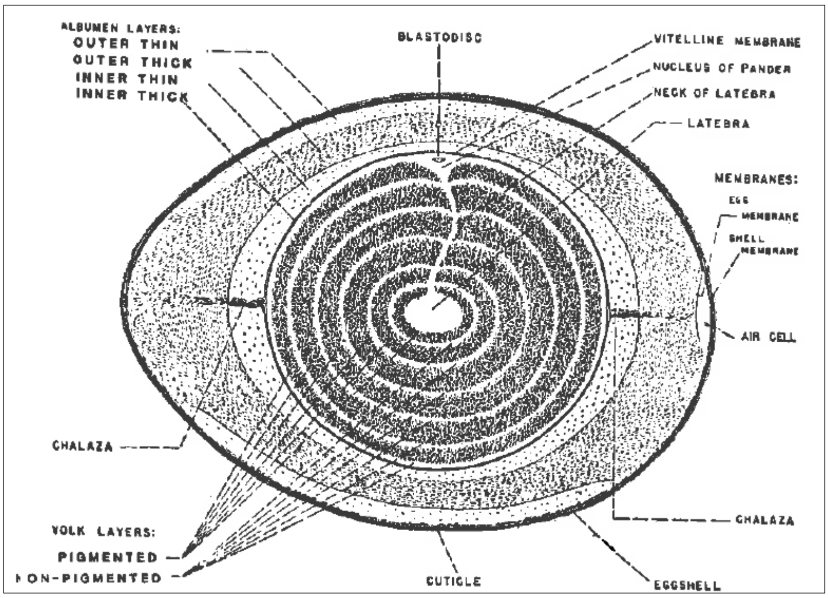

Figure 2.5 *Longitudinal section through a hen's egg (Romanoff & Romanhoff, 1949)*

Superchi *et al*. (2002) evaluated the composition of the ostrich eggs from specific females (crossbred SA Black x Blue neck ostriches) during a breeding season. The results obtained indicated that the weight and shape index of the eggs increased while the thickness of the shell decreased over the breeding season. The eggs used by Superchi *et al* (2002) had an average Y: A value of 2.28. This was lower than the results obtained by Di Meo *et al* (2003) and Cooper *et al*. (2008).

Superchi *et al.* (2002) also found that the shell remained the same, the albumin increased and the yolk percentage decreased over the breeding season. This may be due to the effect of the daylight length on the photo dependant physiological system of the ostrich, as well as the age influence of the female ostrich on egg production and characteristics as is also seen in chickens (Superchi *et al*., 2002; Bunter & Cloete, 2004; Bronneberg *et al*., 2007; Elsayed, 2009; Gous & Nonis, 2010).

Di Meo *et al*. (2003) determined the physical and nutritional characteristics of five hundred and eighty-two freshly laid ostrich eggs, collected over a breeding season of 35 weeks from fifteen breeding pairs of South African Black ostriches. It was determined by Di Meo *et al*. (2003) that the edible components of an ostrich egg are relatively similar to those of a chicken egg, with the exception being the higher unsaturated to saturated fatty acid ratio in ostrich eggs (Table 2.5 and Table 2.6).

There are a few differences in the fatty acid composition of wild and domesticated ostrich eggs, although the average weight of the eggs is the same (Noble *et al.*, 1996; Ullrey & Allen, 1996; Bronneberg *et al.*, 2007). This may be due to the differences in the type of feed ingested as well as the difference in level of production due to the influence of genetic selection on domesticated ostriches (Noble *et al.*, 1996). Definite contrasts can be found between ostrich eggs and the eggs of other avian species (Angel, 1993).

Table 2.5 *External physical characteristics of ostrich eggs during the laying season (Di Meo et al., 2003)*

	Laying period					RSD
	1	2	3	4	5	
Length (cm)	15.16^{b}	15.46	15.5	15.46	15.57^{a}	0.436
Width (cm)	12.69^{c}	12.73^{b}	13.04^{a}	13.07	12.69	0.307
Egg shape index[1]	83.9	82.4	84.3	84.7	81.2	3.66
Shell Thickness (mm)						
Large pole	2.2	2.28^{a}	2.28^{a}	2.13^{b}	2.18	0.152
Equator	2.16	2.25^{a}	2.26^{a}	2.11^{b}	2.23	0.152
Small pole	2.19	2.32^{a}	2.33^{a}	2.20^{b}	2.19^{b}	0.144
Yolk (%)	23.2	23.6	23.9^{a}	23.3	21.6^{b}	1.53
Albumin (%)	57.8	56.7	55.4^{b}	57.8	59.5	2.1
Shell (%)	19	19.7	20.7	18.9	18.9	1.88

Table 2.6 *Chemical composition of egg edible fractions (Di Meo et al., 2003)*

	Laying period					RSD
	1	2	3	4	5	
Dry matter yolk (%)	52.7	50.7	47.5	51.1	50.7	2.2
Dry matter albumin (%)	11.1	11.2b	11.3	11.7	12.0a	0.523
Crude protein (%DM)	48.2	47.9	48	47.7	47.9	1.97
Fat (%DM)	44	44.2	43.8	44.1	44.1	1.16
Ash (%DM)	5.3	5.2	5.5	5.4	5.3	0.72

a,b Values within rows with no common superscript letters are significantly different ($P<0.05$)
RSD = residual standard deviation

The egg consists of albumin, yolk, a shell and membranes, all of which are equally important in producing a healthy viable ostrich chick after incubation (Angel, 1993; Noble *et al*., 1996; Speake *et al*., 1998; Di Meo *et al*, 2003).

The albumin of an egg is a transparent gelatinous weight surrounding the yolk and consists of four parts, namely the outer- and inner-, thick and thin layers (Burley & Vadehra, 1989). Albumin is formed during the egg's descent through the reproductive tract, specifically in the magnum (Solomon, 1991). Albumin in its gelled state consists of 80 % water and 20 % protein, with the latter being made up of more than fourteen major and minor proteins (Solomon, 1991; Burley & Vadehra, 1989). The major and minor proteins found in the albumin play a fundamental role in the development of the embryo.

The albumin of an egg has four main functions: to keep the shape of the egg, to discourage predators with its iron-binding properties, to provide the growing embryo with all its needs (water and proteins) and to protect the egg yolk from microbial invasion (Burley & Vadehra, 1989; Solomon, 1991). The latter function is achieved by the antimicrobial properties of the ovotransferrin and lysozyme proteins present in the albumin (Solomon, 1991). Ovotransferrin has a stoichiometric affinity for certain metal ions while lysozyme belongs to a class of enzyme that breaks the cell walls of gram-positive bacteria (Burley & Valdehra, 1989). In comparison to those of hens and turkeys, ostrich eggs have low levels of these two proteins required to protect the yolk against microbial invasions in the albumin.

It was first determined by Romanhoff & Romanhoff (1949) that the yolk of an avian egg has a defined structure due to the properties of the vitelline membrane. The blastodisc is the most important part of the egg as it contains the DNA and is thus responsible for embryo-formation (Burley & Valdehra, 1989; Solomon, 1991). The yolk varies in the degree of pigmentation as well as the consistency of the fluid, being made up of yellow yolk globules and paler white yolk surrounding the blastodisc (Burley & Valdehra, 1989). The level of pigments found in the yolk is dependent on the level of pigment supplied in the diet as well as the females' absorption capacity (Burley & Valdehra, 1989).

In order to fulfil its function of supplying metabolic energy to the growing embryo the yolk consists of a lipoprotein complex and is high in cholesterol (Sussi *et al*., 2003; Meijerhof, 2009). High levels of vitamin D and A as well as calcium and magnesium are also found in the egg yolk of avian species (Solomon, 1991; Angel, 1993). Lipids make up about 60 % of the yolk and consist of triacylglycerols, phospholipids and cholesterol (Burley & Valdehra, 1989; Meijerhof, 2009).

Once the albumin and yolk have been deposited during the passage of the forming egg through the reproductive tract the entire composite structure is enclosed in a thick, multipurpose layer – the shell. The shell is formed as the egg passes through the isthmus, a section of the avian reproductive tract.

The avian eggshell consists of five or six different layers. These layers, in order from the inside to the outside, are the inner shell membrane, outer shell membrane, mammillary layer, palisade layer, vertical crystal layer (VCL) and the cuticle (Richards *et al*., 2000).

The ostrich eggshell differs from other avian species in the absence of the cuticle layer (Richards *et al*., 2000). The mineral salts, calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$) and tricalcium phosphate ($Ca_3(PO_4)_2$), are deposited in the mammillary, palisade and VC layers of the shell during the egg's movement down the oviduct (Richards *et al*., 2000; Suttle, 2010).

The structural properties of an eggshell include its thickness, porosity and weight density as well as the total surface area of the egg (Ar *et al*., 1979). These properties are intimately related to the weight of the egg and therefore to each other, and need to function together to ensure the successful hatching of a viable chick at the completion of the incubation period (Ar *et al*., 1979). The porosity of the eggshell is important in regulating the gas exchange in and out of the ostrich egg (Abbaspour-fard *et al*., 2010). The five different types of pores, identified by Board & Scott (1980), cover approximately 7.2 % of the total shell surface and have an individual diameter of 785 ųm (Abbaspour-fard *et al*., 2010).

Romanhoff & Romanhoff, (1949) noted that the external characteristics of the avian eggshell are influenced by hereditary, physiological as well as environmental factors. Cooper (2001) and Perrins (1996) are in agreement that the strength of an eggshell is a function of the shape index of the egg which is influenced by nutrition. The hatchability of ostrich eggs is positively correlated with eggshell porosity, but no significant relationship was found between hatchability and the thickness of the shell (SAHAN *et al.* 2003).

Eggshell thickness did however have an effect on the weight lost during the incubation process, with a significantly negative correlation being found (SAHAN *et al.*, 2003).

Undoubtedly, all the factors discussed above will have some sort of influence on the requirements of ostriches above the level of maintenance. Therefore it is crucial to understand how all of these factors work together to be able to develop an optimization model specifically for the breeding of ostriches.

2.7. OPTIMIZATION MODELS

Mathematical modelling is a method of simplifying reality by using single or multiple equations to represent a system's behaviour and is often used in animal nutrition (Gous *et al*., 2006; Thornley & France, 2007). Models, that need large quantities of complicated observations, are used by scientists to simplify and explain the mechanisms that produce the results (Morris, 2006). The evaluation of these models is necessary in order to ensure that all the components required are executed accurately and supply the correct prediction values. These evaluations include testing the predicted outcomes obtained from the model against results from field trials, with this being particularly important for both the upper and lower extremes of performance (France & Dijkstra, 2006; Thornley & France, 2007; France & Kebreab., 2008).

In comparison to other monogastric animals, such as the chicken and the pig, the nutritional requirements of breeding ostriches are not well known (Brand & Gous, 2006a; Olivier, 2010). A large amount of research has gone into developing growth models for slaughter ostriches, incorporating both environmental factors and genetic selection (Ferguson, 2006; Olivier 2010). These models aid in the making of important financial and management decisions. Mathematical models for breeding ostriches are different to those for slaughter ostriches as feed is allocated to the maintenance requirements rather than for maximum growth. Other production parameters such as sperm and egg production also need to be taken into account when modelling the performance of breeding pairs (Olivier 2010).

The nutrient requirements for poultry egg production have been determined by Gous & Nonis (2010) according to the laying pattern of the hen. Luting (1990) and Sakamura *et al*. (2009) determined the proportion of the ME requirement of poultry that is deposited in the egg to be between 0.6 and 0.85.

The equivalent values for ostriches have been determined by Olivier (2010) who determined the efficiency of ME utilization ($k_o = 0.8$), the ME requirement for egg production (MEe = 12.2 MJ/egg), the effective energy requirement for egg production (EEe = 15.9 MJ/bird/day; Equation 2.1), the effective energy requirement for maintenance (EEm = 17.1 MJ/bird/day; Equation 2.2) and the average daily protein requirement (TPt = 175 g/day; Equation 2.3) of breeding ostriches.

Equation 2.1 *Effective energy requirements for egg production equation (Emmans, 1994)*

$$EEe = \frac{TEEe}{2days\ per\ egg}$$

$$= EEa + EEy$$

With $TEEe$ = total effective energy requirement for formation of one egg (MJ)

EEa = effective energy requirement for albumin formation

EEy = effective energy requirement for yolk formation

Equation 2.2 *Effective energy requirements for maintenance (Emmans & Fisher, 1986)*

$$EEm = M_E.Pm^{-0.27}.P$$

With M_E = 1.63 MJ/unit/day

P_M = mature protein weight of ostrich (in kg)

P = body protein weight of ostrich excluding feathers (in kg)

Equation 2.3 *Average daily protein requirement (Emmans, 1989; Olivier, 2010)*

$$TPt = TPm + TPe$$

$$TPm = 0.008\ Pm^{-0.27}$$

$$TPe = \frac{TPEe}{2\ days}$$

With TPm = average daily protein requirement for maintenance

Tpe = average daily protein requirement for egg production

$TPEe$ = total protein requirement for formation of one egg in gram

As noted by Olivier (2010), many challenges exist in the ostrich industry and the use of models incorporating the correct knowledge of breeding ostrich nutritional requirements may provide the solution.

2.8. CONCLUSION

The literature, or lack thereof, indicates that the specific nutritional requirements of breeding ostriches, particularly pertaining to the requirements for optimal reproduction, is not well known (Brand *et al*., 2002a; Miao *et al*, 2003; Ipek & Sahan, 2004). Therefore, this study will be examining the effect of various levels of different nutrients on the production and reproduction parameters of breeding ostriches. The specific nutrients examined include different levels of vitamins, minerals, calcium, phosphorus, crude protein (amino acids) and fatty acids supplied in the feed. To try and decrease production costs, the timing of vitamin and mineral supply as well as different protein sources, will also be examined.

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Chapter 3 [1]

Preliminary results on the effect of different dietary vitamin and mineral levels on certain production parameters as well as egg shell characteristics of breeding ostriches

Abstract

1. Earlier studies on breeding birds indicated no effect of dietary energy content on feed intake. This observation is contradictory to results for other animals and/or poultry where feed intake decrease with an increase in dietary energy level.

2. Literature revealed that a lack of certain nutrients may cause animals to consume more feed than necessary to satisfy their nutrient requirements for these limiting nutrients.

3. In this study eight diets were provided as follows:

- Standard diet without vitamin and mineral premix pack (control diet);
- Standard diet with normal premix pack;
- Standard diet with normal vitamin and 2 × trace elements (M × 2);
- Standard diet with normal trace elements and 2 × vitamins;
- Standard diet with normal premix pack and limestone added as calcium source;
- Standard diet with normal premix pack and monocalciumphosphate added as phosphorus source;
- Standard diet with normal premix pack and soybean oilcake added as crude protein source;
- Standard diet with normal premix pack and linseed added as fatty acid source.

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[1] Successfully published
TESSELAAR, G.A., BRAND, T.S., HOFFMAN, L.C., BRAND, Z., & PFISTER, B. (2013). Preliminary results on the effect of different dietary vitamin and mineral levels on certain production parameters as well as egg shell characteristics of breeding ostriches. (South Africa Journal of Animal Science [ISSN 0375-1589 (print) and ISSN 2221-4062 (online)].

4. Significant differences ($P < 0.05$) were found in the quantity of feed ingested by birds between the diet with surplus minerals (M × 2) (2.3 ± 0.3 kg/bird/day), the diet with no vitamins and minerals added (2.7 ± 0.3 kg/bird/day) and the diet with added fatty acids in the form of linseed (2.9 ± 0.5 kg/bird/day). This indicates the possibility that ostriches may adjust feed intake to satisfy mineral requirements.

5. No statistically significant relationship was found between the thickness and strength of the shell. Significant ($P \leq 0.05$) differences in shell strength (mean value of 154.7, 109.9, 140.4, 142.7, 153.0, 143.4, 138.4 and 151.1 N/cm2 respectively) were found between treatments, but no specific pattern could be identified.

6. Results further revealed no effect of dietary treatment on egg production, dead-in-shell eggs (DIS), infertile eggs or chick production.

7. Further experiments that include certain dietary treatments during the five months resting period are currently being done to quantify the effect of the addition of minerals and vitamins during this period on the production of breeding ostriches.

3.1. INTRODUCTION

Cooper *et al*. (2004) stated that most ostrich performance problems relating to fertility can be traced back to an inadequate breeder diet. Seventy-five percent of the producer’s running costs can be attributed to that of the breeder birds’ nutrition (Brand *et al*., 2002b; Aganga *et al*., 2003; Kritzinger, 2011). Correct formulation of these feeds, to ensure that accurate amounts of vitamins and trace elements are supplied, will prevent feed wastage and increase profitability.

The nutrient requirements of breeding ostriches are not as well-known as of other species and further research into the quantification of the nutrients necessary for optimal production and reproduction is thus required. Earlier studies on breeding ostriches indicated no effect of dietary energy content on feed intake. This observation is contradictory to results for other animals and/or poultry (March *et al*., 1984). Furthermore, literature revealed that a lack of certain nutrients may cause animals to consume more feed to satisfy their nutrient requirements for these limiting nutrients (Brand *et al*., 2010). Supplementation of feed occurs in the form of added premix packages which contain vitamins, minerals and other trace elements.

Vitamins are defined by McDowell (1989) as a group of complex organic compounds, found in minute quantities in natural foodstuffs, which are essential to normal metabolism and, when lacking in the diet, will result in certain deficiency diseases. Minerals are inorganic elements that form part of the ash portion of feeds and are just as important as vitamins (Underwood, 1981). Minerals have four functions in the body, namely structural, physiological, catalytic and regulatory (Suttle, 2010). In the past, extrapolated chicken data was deemed a reliable source of information for determining the nutrient requirements of breeding ostriches; further studies have however shown this not to be the case (Cilliers *et al*., 1998). A lack of certain vitamins and minerals, or an imbalance thereof, can cause reduced hatchability through its influence on the quality of the eggs produced (Wilson, 1997).

The content of the egg is deposited while still forming inside the female and is enclosed prior to the onset of lay in a thick, multipurpose layer of shell. Calcium is vital for the protection of the egg as calcium carbonate ($CaCO_3$) is one of the main components of the shell, being deposited during its passage down the oviduct (Suttle, 2010). The external structure of an egg owes its strength to the dome principle and its functional properties include water vapour qualities, respiratory gas conductance, water loss and metabolic rate (Ar *et al*., 1979).

The structural properties of an eggshell include its thickness, porosity and weight density as well as the surface area of the egg, with all these properties being intimately related to the weight of the egg and therefore to each other (Ar *et al*., 1979). All these structural and functional properties need to function in synchrony with the metabolic growth of the embryo in order to ensure the successful hatching of a viable chick at the end of the incubation period (Ar *et al*., 1979). The increased mortality of embryos in eggs that lose too much or too little weight in the form of moisture during the first week of incubation is indicative of this (Ar *et al*., 1979). Embryos in eggs with low-quality shells also have a higher risk of stunted growth due to infection caused by pathogens invading the egg through the shell (Wilson 1997).

Romanhoff & Romanhoff (1949) stated that the external characteristics of the avian egg are influenced by hereditary, physiological as well as environmental factors. Hamilton (1982) defined shell strength as the ability of the egg to withstand externally applied forces without cracking or breaking. Eggshell quality tests are mainly performed on domestic chicken eggs (*Gallus domesticus*) and correlated with factors such as the diet in general or specific supplement inclusions such as calcium or phosphorus (Ar *et al*., 1979).

The main factor affecting the strength of the hen eggshell is the thickness of the shell (Romanhoff & Romanhoff, 1949; Tyler, 1969; Voisey & Hunt, 1974). This is still to be proven for ostrich eggs. Ar *et al*. (1979) did however prove that a simple positive linear correlation between shell strength and egg weight does exist, with the correlation being higher for larger eggs such as the eggs of an ostrich.

3.2. MATERIALS AND METHODS

The trial was conducted on the Oudtshoorn Research farm in Oudtshoorn (22˚20' E, 33˚58' S and altitude 307m), South Africa during the breeding season of 2009. Ninety-six breeding pairs of ostriches were divided into eight groups of twelve breeding pairs each to determine the effect of the experimental diets on reproductive parameters and feed intake.

Eight different diets were created by adding different levels of certain supplements to a standard commercial breeding diet. These supplements included extra vitamins, trace elements, minerals (Ca and P); crude protein (amino acids) and fatty acids at different inclusion levels.

The eight diets that were provided were as follows:
-Standard diet without premix pack (control diet);
-Standard diet with normal premix pack (Premix 1);
-Standard diet with vitamins and 2 × trace elements (Premix 3);
-Standard diet with trace elements and 2 × vitamins (Premix 2);
-Standard diet with normal premix pack and added limestone as a source of Calcium;
-Standard diet with normal premix pack and added monocalciumphosphate as a source of phosphorus;
-Standard diet with normal premix pack and added soybean oilcake as a source of crude protein and
-Standard diet with normal premix pack and added linseeds as a source of fatty acids.

The age of the birds varied from two to nine years of age. The ostrich breeding pairs were divided into the treatment groups in such a way as to ensure an even distribution of breeding pair age as well as estimated breeding values for egg production. The breeding pairs were kept in breeder camps of ¼ hectare per pair and received the experimental diets *ad libitum* (Van Niekerk, 1996). The dietary protein level was kept constant at 14 % and the metabolisable energy at 9 MJ ME/kg feed.

These levels are in accordance with the levels required for breeding ostriches to maintain body condition and egg production (Brand *et al*., 2002a; b, c & 2003). Listed in Table 3.1 is the raw material content and nutritional composition of the eight different formulated diets which were fed to the breeding pairs in the breeding season from mid-May to mid-December. The nutrient composition of each diet was determined using a Near Infrared Reflectance Analyser (Bran & Luebbe, 1994). Given in Table 3.2 are the different vitamin and mineral levels of the three different premixes.

Table 3.1 *Raw material content and analysed composition of the eight different experimental diets (kg)*

	Diet number							
Ingredients	1[a]	2[b]	3[c]	4[d]	5[e]	6[f]	7[g]	8[h]
Lucerne	670	670	670	670	670	670	670	670
Maize	167	167	167	167	167	167	167	167
Canola Oilcake meal	50	50	50	50	50	50	50	50
Soya Oilcake meal	0	0	0	0	0	0	50	0
Linseed	0	0	0	0	0	0	0	50
Limestone	25	25	25	25	50	25	25	25
Molasses powder	50	50	50	50	50	50	50	50
Dicalciumphosphate (18%P)	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5
Monocalciumphosphate (21%P)	0	0	0	0	0	25	0	0
Common salt (NaCl)	10	10	10	10	10	10	10	10
Vitamin & Mineral Premix 1	0	3.5	0	0	3.5	3.5	3.5	3.5
Vitamin & Mineral Premix 2	0	0	0	4.5	0	0	0	0
Vitamin & Mineral Premix 3	0	0	3.5	0	0	0	0	0
Nutrients								
Crude protein (%)	13.8	14.3	14.2	14.2	14.4	14.1	15.1	14
Fat (%)	2.2	2.1	2.1	2.2	2.2	2.2	2.2	3.3
Fibre (%)	20.0	19.6	19.6	19.7	19.7	20.0	19.1	18.8
Energy (MJ/kg)	16.8	16.8	16.7	16.8	16.3	16.3	16.6	17.3

[a] Treatment 1= no premix pack
[b] Treatment 2= 3.5kg normal vitamin and mineral premix pack
[c] Treatment 3= Minerals X2 and normal vitamin content at 3.5kg
[d] Treatment 4= Vitamins X2 and normal mineral content at 4.5kg
[e] Treatment 5= 3.5kg premix pack with added Limestone (Calcium source)
[f] Treatment 6= 3.5kg premix pack with added monocalcium phosphate (Phosphorus source)
[g] Treatment 7= 3.5kg premix pack with added soya oilcake (Crude protein/ amino acid source)
[h] Treatment 8= 3.5kg premix pack with added linseed (fatty acid source)

Table 3.2 *Content of three different premix levels used in experimental diets*

Nutrient	unit	Premix 1	Premix 2	Premix 3
Vitamin A	mill IU	16	32	16
Vitamin D3	mill IU	2.5	5	2.5
Vitamin B1	gram	2.5	5	2.5
Vitamin B2	gram	6	12	6
Vitamin B6	gram	4.5	9	4.5
Folic Acid	gram	1	2	1
Vitamin B12	mg	10	20	10
Vitamin E	gram	30	60	30
Choline	gram	480	960	480
Niacin	gram	40	80	40
Pathothenic Acid	gram	16	32	16
Vitamin K	gram	2.5	5	2.5
Biotin	mg	100	200	100
Cobalt	mg	100	100	200
Iodine	gram	1	1	2
Selenium	mg	300	300	600
Manganese	gram	125	125	250
Copper	gram	6	6	12
Zinc	gram	100	100	200
Magnesium	gram	45	45	90
Iron	gram	30	30	60
Antioxidants[1]	gram	100	100	100
Limestone carrier[2]	gram	1173	1173	971

[1] contains no vitamins and minerals

[2] contains 36% calcium

The breeding pairs were fed twice a week and all refusals were weighed back once a month to ensure accurate feed intake determination.

Ostrich eggs were collected twice a day, weighed, identified and stored in a cool room at 17˚C with a relative humidity (RH) of 70 % until further analysis. All production and reproduction records were kept including total egg production and chick production.

During the trial period, three eggshell fragments per egg were collected from 1466 ostrich eggs that hatched successfully. The surface area, shell thickness and eggshell strength was determined for all the egg shell fragments collected and the average of the three fragments was taken as being representative of the egg. The eggshell fragments were sampled from around the air sac area after the chick had hatched and were subsequently cleaned with distilled water and dried at room temperature.

The area of the shell fragments was determined by a LICOR leaf area meter comprising of two separate components: an area meter sensor (Model LI-3000A) and a conveyer belt moving at a constant speed (Model LI-3050C).

Due to the machine not being able to accommodate the thickness of the shell fragments, it was necessary to trace the fragments onto brown paper, cut out the traced areas and then send these paper copies through the machine.

Shell strength was determined using an Instron texture machine (Model 4444), while thickness was determined to the nearest 0.01mm with Mitutoyo Callipers (Model CD-8C). Dried shell membranes were included in the measurement of shell thickness.

A one-way ANOVA was performed on the data using Statgraphics.

3.3. RESULTS

Only the reproductive data of the breeding birds that bred for the entire breeding season of 203 days were used. Although the breeding birds received feed *ad libitum*, an average feed intake of 2.6 ± 0.3 kg/bird (mean ± standard error) per day was noted for all the diets. This is low for *ad libitum* intake when compared to the 3.7 kg feed/bird/day determined in a study by Olivier (2010).

The least square means (±SE) and significant differences of the different characteristics of ostrich egg hatchability for the different treatments is summarised in Table 3.3. Listed in Table 3.4 are the least square means (±SE) and significant differences of the ostrich eggshell fragment quality characteristics for the different treatments.

Results showed no significant effect of dietary treatment on total egg production, DIS, infertile eggs or chick production. There were also no significant differences found in the mass difference of males and females due to the effect of the dietary treatments.

Significant differences ($P < 0.05$) were found in the quantity of feed ingested by birds between the diet with surplus minerals (M × 2) (2.3 ± 0.3 kg/bird/day) and the diet with no vitamins and minerals added (2.7 ± 0.3 kg/bird/day). The main difference between these two diets is the presence of the vitamin and mineral premix pack. The decrease in feed intake observed in the group that received the M × 2 feed indicates the possibility that ostriches ingest feed to satisfy both vitamin and mineral requirements. It might also indicate that surplus minerals may create a feed that is less palatable.

Significant differences ($P < 0.05$) were however also found between the diet with added fatty acids in the form of linseeds (2.9 ± 0.5 kg/bird/day) and the diet with surplus minerals (M × 2) (2.3 ± 0.3 kg/bird/day). Although both these diets had a vitamin and mineral premix included, intake of the feed with the extra minerals added (M × 2) was lower.

The possibility thus exists that ostriches ingest feed to satisfy mineral requirements if feed is supplied *ad libitum*.

No statistically significant relationship was found between the thickness and strength of the shell. This is in contradiction to findings with chicken eggs (Romanhoff & Romanhoff, 1949; Tyler, 1969; Voisey & Hunt, 1974).

Significant ($P \leq 0.05$) differences in shell strength (mean values of 154.7, 109.9, 140.4, 142.7, 153.0, 143.4, 138.4 and 151.1 N/cm2 respectively) and shell thickness (1.8, 1.6, 1.8, 1.8, 1.8, 1.7 and 1.8 mm respectively) were found between treatments, but no specific pattern could be identified. If the ostrich eggshell is too strong and/or too thick, correct egg weight loss in the form of moisture will not occur during incubation, causing the embryo to die. However, if the eggshell is too weak or too thin, pathogens may penetrate the egg, causing infections, and excessive moisture loss will occur during incubation, also causing chick mortality (Wilson, 1997).

An unfavourable shell structure will result in an increase in DIS eggs and/or a decrease in egg production due to longer intervals occurring between the laying of individual eggs (Brand *et al*., 2003b). The results of this study revealed no effect of dietary treatment on egg production, DIS eggs, infertile eggs or chick production however.

In the industry it is believed that higher levels of calcium in the feed will result in stronger eggshells and increase the occurrence of DIS eggs (Richards et al., 2000). In this study, no effect of a higher calcium level in the feed was seen on the occurrence of DIS eggs or the shell break strength.

Table 3.3 *Least square means (±SE) and significance for production parameters of breeding ostriches over the breeding season*

Treatment	Total egg production (per female)	Min	Max	% Infertile	%DIS	%Chicks hatched	Male starting weight (kg)	Male end weight (kg)	Male weight change* (kg)	Female starting weight (kg)	Female end weight (kg)	Female weight difference* (kg)	Feed Ingested (g/bird/day)
1	47.5 ± 30.7	0	83	17.4 ± 19.6	19.0 ± 13.6	35.5 ± 27.0	124.2 ± 3.7	127.3 ± 6.3	3.1 ± 5.0	115.5 ± 3.0	114.2 ± 2.6	-1.3 ± 2.1	2737.3^{a} ± 97.8
2	56.5 ± 23.4	0	83	10.6 ± 8.4	23.3 ± 18.0	41.2 ± 22.0	119.1 ± 2.0	123.1 ± 2.9	4.0 ± 2.8	122.0 ± 3.5	115.3 ± 4.3	-6.7 ± 2.4	2531.6^{ab} ± 77.4
3	47.3 ± 18.0	17	73	27.0 ± 32.3	20.6 ± 17.2	33.9 ± 24.4	124.8 ± 2.6	124.3 ± 2.8	-0.5 ± 3.6	115.2 ± 3.4	105.7 ± 4.5	-9.5 ± 3.2	2272.0^{b} ± 97.0
4	59.5 ± 21.5	23	88	24.4 ± 33.4	19.3 ± 13.8	38.6 ± 23.8	126.2 ± 3.8	126.3 ± 4.3	0.2 ± 2.2	108.5 ± 3.7	106.7 ± 3.8	-1.8 ± 2.4	2656.8^{ab} ± 88.4
5	44.0 ± 20.7	0	74	10.0 ± 6.2	29.7 ± 16.1	37.8 ± 19.1	124.9 ± 3.9	129.1 ± 3.5	4.2 ± 0.3	129.3 ± 4.0	126.0 ± 5.1	-3.3 ± 4.2	2571.9^{ab} ± 96.6
6	45.8 ± 20.1	19	83	24.0 ± 26.2	18.3 ± 13.3	37.7 ± 23.9	122.3 ± 2.5	118.8 ± 2.1	-3.5 ± 3.2	118.2 ± 2.5	117.1 ± 4.3	-0.9 ± 3.0	2461.8^{ab} ± 50.1
7	44.8 ± 26.7	8	93	19.3 ± 18.2	22.0 ± 15.4	39.0 ± 24.4	124.3 ± 4.3	132.5 ± 4.9	7.5 ± 3.3	120.7 ± 3.7	113.5 ± 4.5	-7.2 ± 2.9	2546.6^{ab} ± 124.1
8	54.4 ± 20.9	14	79	13.1 ± 10.1	21.4 ± 8.0	49.4±20.2	124.2 ± 3.1	126.7 ± 4.0	2.0 ± 2.9	116.0 ± 3.8	112.7 ± 4.5	-3.3 ± 1.9	2863.9^{a} ± 157.8

$^{a, b, c}$ Least square means within column with different superscripts for treatments differ significantly ($P<0.05$).

*Calculated by the difference in weight at the start and finish of the breeding season

Table 3.4 *Least square means (±SE) and significance for different ostrich egg shell characteristics for the different treatments*

Diet	Thickness (mm)	Area (cm2)	Break strength (N/cm2)
1	$1.8^{a} \pm 0.01$	22.1 ± 0.7	$154.\ 7^{a} \pm 2.3$
2	$1.6^{d} \pm 0.03$	20.0 ± 1.5	$109.9^{d} \pm 4.3$
3	$1.8^{ac} \pm 0.01$	22.0 ± 0.8	$140.8^{c} \pm 2.3$
4	$1.8^{c} \pm 0.01$	22.0 ± 0.6	$142.7^{a} \pm 1.7$
5	$1.8^{a} \pm 0.01$	22.1 ± 0.9	$154.0^{a} \pm 2.6$
6	$1.8^{a} \pm 0.01$	21.4 ± 0.7	$143.4^{c} \pm 2.5$
7	$1.7^{c} \pm 0.01$	21.2 ± 0.8	$138.4^{c} \pm 2.3$
8	$1.8^{a} \pm 0.01$	22.8 ± 0.5	$151.6^{a} \pm 1.4$

^{a,b,c} Least square means within column with different superscripts for treatment differs significantly ($P< 0.05$).

3.4. DISCUSSION

No specific effect of any one of the tested parameters (additional vitamins, minerals, fatty acids and amino acids) was seen on the production parameters considered. Feed intake for the control diet and the diet with the added fatty acids was 20 % higher than for the diet with the additional minerals (M × 2).

The higher feed intake of the birds fed the control diet (no added minerals or vitamins) than those fed the diet with the additional minerals (M × 2) may indicate that the birds in the first treatment group consumed feed to satisfy their need for minerals. If the additional minerals may compensate for the higher feed intake, it may indicate higher profitability levels for the producer. The difference between the linseed diet and the M × 2 diet remains partly unexplained. Literature does however indicate that the provision of unsaturated fatty acids in broiler chicks may depress the uptake of certain trace elements (Atteh & Leeson, 1984).

The provision of additional calcium did not affect the percentage DIS or the shell break strength of the ostrich eggs. The provision of minerals/vitamins during the five months rest period may however also play a role in the results obtained as certain vitamins and minerals can be stored in body organs. An experiment to test the effect of the provision of a vitamin/mineral premix during the rest period and the breeding period is currently being done, since certain vitamins and minerals are stored in the body for relatively long times.

Overall it may be concluded that no major deficiencies of minerals, vitamins, fatty acids and amino acids in standard breeding ostrich diets can be identified using feed intake as an indicator.

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Chapter 4

Effect of vitamin and mineral supplementation during rest as well as the breeding season on production parameters of breeding ostriches

Abstract

1. The production cycle of breeding ostriches comprises of an eight month breeding period (mid-May until mid-January of the following year) and a four month resting period (mid-January until mid-May).
2. Different diets (breeder and maintenance diets) are normally fed in the two production periods in order to ensure optimal production and recovery in the breeding and resting periods respectively.
3. The study used a two by two factorial design, with the breeder and maintenance diets including or excluding a vitamin and mineral premix to determine the effect of the inclusion of vitamin and mineral premixes in the diets used during both of these periods.
4. All data relating to the breeder ostriches' production was monitored, with this including live weight change of the breeder ostriches and total egg as well as chick production.
5. The lack of a vitamin and mineral premix in the resting period had no significant effect on most of the production parameters (male weight change, feed intake, egg production, infertile eggs or chick production), although a tendency for the production of bigger eggs with bigger chicks was noticed. The breeding female ostriches that did not receive a vitamin and mineral premix in the maintenance diet lost less body weight, but had an increasing occurrence of DIS eggs when compared to those receiving the premix.
6. Results showed that the exclusion of the vitamin and mineral premix in the breeding diet had no effect on most of the production parameters measured (male and female weight change, feed intake, egg production, infertile eggs, DIS eggs, chicks or the weight of ostrich eggs and chicks produced).
7. Results from this study are ambiguous in that the presence of a vitamin and mineral in breeding ostrich diets (rest or breeding period) had no effect on the birds' weight loss nor on the specific egg quality parameters, yet there was a significant decrease in DIS egg production. It is suggested that producers supply a vitamin and mineral premix package to the diets of breeding ostriches to decrease the DIS ratio for ostriches.

4.1. INTRODUCTION

The production cycle of breeding ostriches comprises of an eight month breeding period and a four month resting period (Nel, C. J. *et al*., 2010). Breeding ostriches receive different diets in the two different production periods in order to ensure optimal production and recovery in the breeding and resting periods respectively. The breeding ration will be supplied during the breeding season from mid-May until mid-January while a maintenance diet is supplied during the resting period from mid-January until the onset of the following breeding season. These two diets are formulated to differ in the levels of nutrients supplied according to the requirements and production levels of the breeding ostriches in the given period (Van Niekerk, 1996). Both of these diets usually include a quite expensive vitamin-mineral premix pack (Lambrechts, 2002).

Previous studies have revealed that female breeding ostriches have the ability to produce high quantities of eggs during the breeding season from feed and body reserves (Brand *et al*., 2003). These high production levels go hand in hand with a decrease in body condition, which subsequently needs to be regained during the following resting period. An example of this system is the storage of vitamin A in the liver and adipose tissue, which provides the regulatory system with a means of maintaining adequate levels in the bloodstream despite fluctuations in the daily vitamin A intake (Blomhoff *et al*., 1990; Penniston & Tanumihardjo 2006). Calcium, phosphorus and zinc are retained inside the bone, copper is stored in the liver and iron in the kidneys (Larson & Sandström, 1992; Kaya *et al*., 2002). Breeding female ostriches replenish stored reserves of vitamins and minerals during the resting period by ingesting the maintenance diet which includes a vitamin and mineral premix. The ability of ostriches to utilise these body reserves for egg production in the breeding period questions the necessity of including premixes in both the breeding and maintenance rations.

Due to the fact that seventy-five percent of the running costs of an ostrich farm are assigned to the nutrition of the breeding ostriches, increases in raw material prices prevent the production of an economical product with a positive profit margin. The necessity of including these vitamin and mineral premixes in the different production periods will thus be examined.

4.2. MATERIALS AND METHODS

Ostriches used in this trial were selected from the commercial ostrich breeding flock at the Oudtshoorn Research Farm near Oudtshoorn, South Africa (22˚20′ E, 33˚58′ S and altitude 307m) in 2011. This breeding flock is managed according to the Ostrich Manual (Brand, 2010). Ninety-six ostrich breeding pairs in four groups were used in a two by two factorial design to determine the necessity of the vitamin-mineral premix supply for production and reproduction (Figure 4.1).

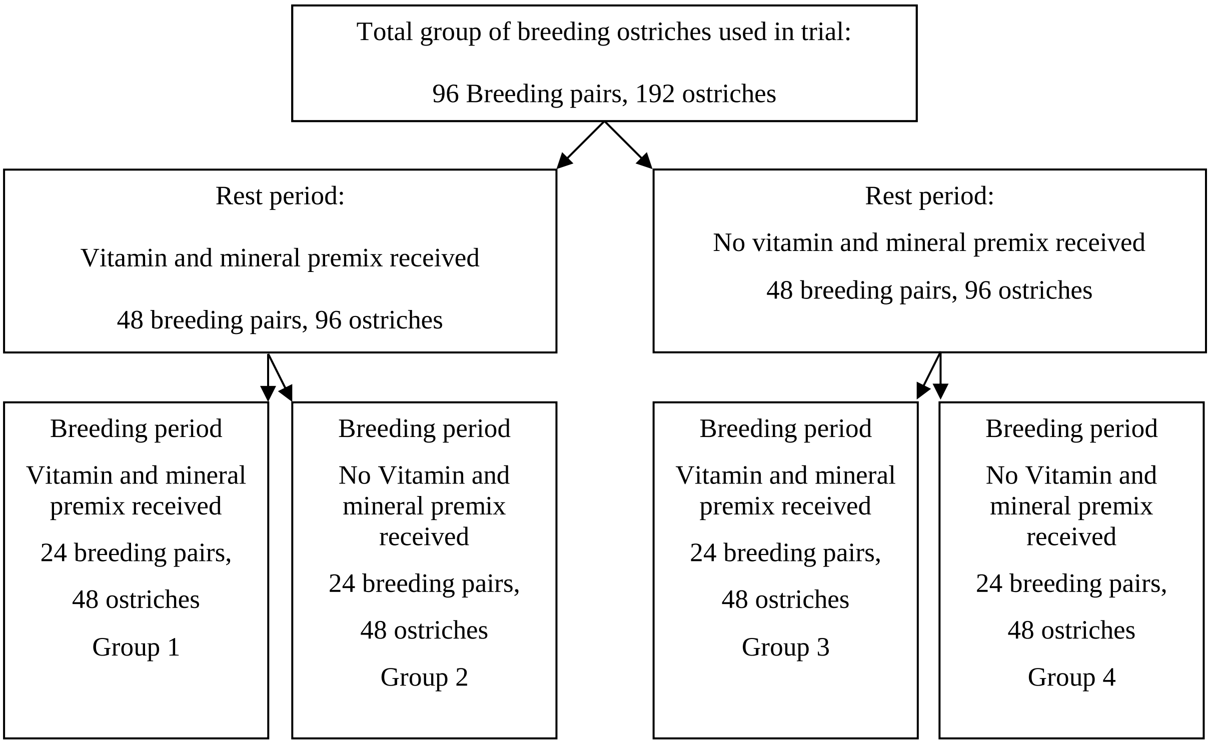

Figure 4.1 *Experimental design used*

By using a two (treatment in the resting period) by two (treatment during the production period) factorial design, the possible interaction between the use of the vitamin-mineral premix during the resting period and the production period was examined. All the groups received a maintenance diet (Table 4.1) during the resting period (mid-December to mid-May) and a breeding diet (Table 4.2) during the breeding period (mid-May to mid-December).

Group one received a vitamin-mineral premix in the resting as well as in the breeding period, while group two received a vitamin-mineral premix only during the resting period. Group three received a vitamin-mineral premix only in the breeding period while group four did not receive any vitamin-mineral premix throughout the production year. The composition of the vitamin and mineral premix used is given in Table 4.3.

Due to the different levels of production experienced, the quantity of the vitamin and mineral supplied differs between the resting and breeding period (2g/kg versus 5g/kg).

The breeding ostriches were divided according to both gender and maintenance diet treatment during the resting period. No data was collected during this time. The separation of males and females is standard procedure and described by Brand. (2010).

At the onset of the breeding season, male and female ostriches were weighed and placed in breeder camps of ¼ hectare per breeding pair. The breeding pairs received the experimental diets *ad libitum* and feed intake was monitored (Van Niekerk, 1996). The ostriches' feed was refilled twice a week and feed refusals were weighed back once a month to determine feed intake. This was done for the entire breeding season of 217 days. All data relating to the breeder ostriches' production was monitored, including the live weight change of the breeder ostriches, total egg production and total chick production. Changes in the live weights of the breeder ostriches were calculated as the difference in live weight before and after the breeding season.

Feed samples were collected every time a new batch was mixed for each experimental diet throughout the trial. The samples were marked, stored in a cool, dry place and transported to Elsenburg Research Department for further analysis once the trial was completed. Feed was analysed according to the Weende system (Van Soest, 1967). The nutritional composition of the two different feeds supplied during the breeding season can be seen in Table 4.4.

Data was analysed by means of One Way Anova using Proc GLM of SAS software version 9.3 (2011). LSMeans were calculated and Bonferonni Post hoc tests were used to determine significance at the 5% level.

Table 4.1 *Maintenance diet fed to the breeding ostriches during the resting period*

Ingredients	**Vitamin and Mineral Premix added**	**No Vitamin and Mineral Premix**
	(g/kg)	
Alfalfa meal (17%)	798.0	798.0
Canola seeds, meal	50.0	50.0
Corn Yel Grain	100.0	100.0
Molasses powder	25.0	25.0
Monocalciumphosphate	14.5	14.5
Common salt (NaCl)	10.0	10.0
Vitamin & Mineral Premix*	2.5	0

*Vitamin and mineral premix composition given in Table 3

Table 4.2 *Breeding diet fed to the breeding ostriches during the breeding period*

Ingredients	Vitamin and Mineral Premix added	No Vitamin and Mineral Premix
	kg.	
Alfalfa meal (17% CP)	610.0	610
Corn Yel Grain	200.0	200
Soybean oilcake meal	105.0	105
Limestone, ground	34.0	34
Molasses powder	25.0	25
Monocalciumphosphate	17.0	17
MHA (methionine) 86%	2.3	2.3
Common salt (NaCl	1.0	1
*Vitamin & Mineral Premix	5.0	0

*Vitamin and mineral premix composition given in Table 3

Table 4.3 *Vitamin and Mineral Premix used during the breeding and resting period*

***Premix Chemical composition**	**unit**	**Premix**
Vitamin A	mill IU	16
Vitamin D3	mill IU	2.5
Vitamin B1	g	2.5
Vitamin B2	g	6
Vitamin B6	g	4.5
Folic acid	g	1
Vitamin B12	mg	10
Vitamin E	g	30
Choline	g	480
Niacin	g	40
Pantothenic acid	g	16
Vitamin K	g	2.5
Biotin	mg	100
Cobalt	mg	100
Iodine	g	1
Selenium	mg	300
Manganese	g	125
Copper	g	6
Zinc	g	100
Magnesium	g	45
Iron	g	30
Antioxidant[1]	g	100
Limestone carrier[2]	g	1173

[1] contains no vitamins and minerals

[2] contains 36 % calcium

Table 4.4 *Nutritional composition of breeding bird diet supplied to the breeding ostriches*

Nutrients	Vitamin and Mineral Premix added	No Vitamin and Mineral Premix
DM (%)	90.4 ± 0.16	90.5 ± 0.18
Energy (MJ ME/kg DM)	17.5 ± 0.05	17.6 ± 0.05
Crude protein (%)	17.7 ± 0.28	17.4 ± 0.22
Fat (%)	3.2 ± 0.15	3.3 ± 0.14
Ash (%)	11.3 ± 0.23	11.1 ± 0.24
Crude fibre (%)	19.3 ± 0.5	19.3 ± 0.45
ADF (g/kg)	24.2 ± 0.59	24.2 ± 0.52
NDF (g/kg)	33.2 ± 0.86	33.3 ± 0.68
Ca (%)	2.3 ± 0.08	2.3 ± 0.08
P (%)	0.6 ± 0.02	0.6 ± 0.02

^{a,b,c} Least square means within row with different superscripts for treatment differs significantly ($P < 0.05$)

4.3. RESULTS

Only the data for the breeding ostriches that were present during the whole breeding season of 217 days were used. The breeding ostriches received feed *ad libitum*, and an average feed intake of 2348.2 ± 89.6 g/bird per day was noted for all the experimental diets. Due to the fact that no interactions were seen between the resting and breeding periods, the results were analysed separately for the two different production periods and are given in Table 4.5 and Table 4.6.

A tendency was noted for a possible interaction between the maintenance and breeding diets in the feed intake results ($P = 0.10$).

Results showed no significant effect of dietary treatment supplied in the resting period on male ostrich weight change (-1.9 ± 1.1 kg), feed intake (2360.9 ± 36.5 g/bird/day), average eggs produced per female (47.7 ± 2.6 eggs/bird/day) or on percentage infertile eggs (34.9 ± 2.8 %) or percentage chicks (26.6 ± 2.5 %). There was a tendency for the egg weight (1244.2 ± 81.3g *versus* 1070.1 ± 92.9 g, $P = 0.09$) and chick weight (757.8 ± 49.4 g *versus* 644.1 ±56.2 g, $P = 0.07$) to be higher in the group that received no vitamin and minerals in the maintenance diet. Significant differences ($P = 0.042$) were found for female weight change between the maintenance diet with vitamins and minerals (-15.7 ± 1.8 kg) and the diet with no vitamins and minerals added (-10.8 ± 1.4 kg).

The breeding ostriches that received a vitamin and mineral premix in the maintenance diet also had significantly ($P = 0.025$) fewer dead-in-shell (DIS) eggs (19.3 ± 2.3 %) when compared to those fed the diet with no vitamins and minerals (27.4 ± 2.7 %).

The inclusion of a vitamin and mineral premix in the breeding period had no effect on the male ostrich weight change (-1.9 ± 1.1 kg), feed intake (2360.9 ± 36.5 g/bird/day), average eggs produced per female (47.7 ± 2.6 eggs/bird/day), percentage infertile eggs (34.9 ± 2.8%), percentage DIS (23.2 ± 1.8%), percentage chicks (26.6 ± 2.5 %) or the weight of ostrich eggs (1154.4 ± 62.4 g) or chicks (699.0 ± 37.9 g) produced.

Table 4.5 *Least square means (±SE) and significance for different characteristics of ostrich egg hatchability for the premix treatments during the resting period*

Parameters	**Vitamin and Mineral Premix added**	**No Vitamin and Mineral Premix**	**P**
Male start weight	127.6 ± 2.7	127.5 ± 2.4	0.90
Male end weight	126.3 ± 2.6	125 ± 2.4	0.75
Male weight difference	-1.3 ± 1.4	-2.5 ± 1.8	0.49
Female start weight	125.6 ± 2.4	127.3 ± 2.2	0.72
Female end weight	109.9^{b} ± 1.9	116.5^{a} ± 2.3	0.04
Female weight difference	-15.7^{b} ± 1.8	-10.8^{a} ± 1.4	0.04
Feed intake (g/bird/day)	2307.8 ± 53.1	2418.4 ± 49.0	0.16
Production			
Average number of eggs (eggs/female)	47.4 ± 3.4	48.0 ± 3.9	0.91
Infertile eggs (%)	38.9 ± 4.1	30.6 ± 3.8	0.14
DIS eggs (%)	19.3^{b} ± 2.3	27.4^{a} ± 2.7	0.03
Chicks hatched (%)	25.9 ± 3.6	27.3 ± 3.4	0.78
*Other (%)	15.8 ± 2.4	14.7 ± 2.0	0.71
Egg weight (g)	1070.1 ± 92.9	1244.2 ± 81.3	0.09
Chick weight (g)	644.1 ± 56.2	757.8 ± 49.4	0.07

^{a,b,c} Least square means within row with different superscripts for treatment differs significantly (P< 0.05)

*Other eggs (%) includes small, dull and broken eggs

Table 4.6 *Least square means (±SE) and significance for different characteristics of ostrich egg hatchability for the premix treatments during the breeding period*

Parameters	**Vitamin and Mineral Premix added**	**No Vitamin and Mineral Premix**	**P**
Male start weight	129.8 ± 2.6	125.1 ± 2.5	0.22
Male end weight	126.7 ± 2.5	124.5 ± 2.4	0.43
Male weight difference	-3.1 ± 1.5	-0.62 ± 1.6	0.46
Female start weight	129.2 ± 2.3	123.3 ± 2.2	0.05
Female end weight	116.0^{a} ± 2.1	109.9^{b} ± 2.1	0.04
Female weight difference	-13.2 ± 1.7	-13.5 ± 1.7	0.80
Feed intake (g/bird/day)	2350.9 ± 48.7	2371.6 ± 55.4	0.90
Production			
Average number of eggs (eggs/female)	50.0 ± 3.5	45.2 ± 3.8	0.20
Infertile eggs (%)	31.8 ± 3.7	38.8 ± 4.3	0.18
DIS eggs (%)	23.6 ± 2.4	22.9 ± 2.7	0.84
Chicks hatched (%)	29.2 ± 3.5	23.8 ± 3.5	0.28
Other (%)	16.0 ± 2.1	14.6 ± 2.4	0.66
Egg weight (g)	1227.6 ± 75.0	1076 ± 100.7	0.14
Chick weight (g)	743.7 ± 45.4	651.0 ± 61.3	0.20

^{a,b,c} Least square means within row with different superscripts for treatment differs significantly ($P < 0.05$)

*Other eggs (%) includes small, dull and broken eggs

4.4. DISCUSSION

Female breeding ostriches have the ability to produce high quantities of eggs using feed and body reserves (Brand et al., 2003). This ability often causes loss in body condition that needs to be replenished during the resting period. It is therefore believed that the supply of vitamins and minerals in the maintenance diet is essential.

Literature revealed that an imbalanced diet, caused by the exclusion of the vitamin and mineral premix in the maintenance and breeder diet can cause an increase in DIS eggs as well decreased survivability of ostrich chicks (Wilson, 1997). Breeding ostriches will ingest more feed to try and overcome the imbalance created and will thus ingest more protein and energy. Increased levels of protein and energy ingested will cause female breeding ostriches to lose less body weight during the resting and breeding period as well as increase the size of the egg by increasing the yolk size (Ahn et al., 1997; Babiker et al., 2010).

Larger chicks that hatch from larger eggs are not as healthy when compared to average sized eggs and chicks (Deeming, 1995; Perrins, 1996; Deeming & Ar, 1999; Gonzalez et al., 1999; King'ori, 2011; El-Safty, 2012).

This can be demonstrated by the tendency found in the production of bigger ostrich eggs (P=0.09) with bigger ostrich chicks (P = 0.07) as well as an 8.1% increase in DIS egg produced (P = 0.03) by breeding female ostriches that did not receive vitamins and minerals in the maintenance diet. The presence of vitamins and minerals in the maintenance diet also caused female ostriches to lose 31.2 % more body weight (P = 0.04) when compared to females not receiving the vitamin-mineral premix. The female ostrich weight at the end of the breeding season did differ significantly (P = 0.04), from the ostriches that received a vitamin and mineral premix breeding diet weighing more. However, the weight change during the breeding season of female ostriches did not differ between treatments in the breeding period (P = 0.80). Breeding ostriches did, in absolute values, ingested more of the feed (maintenance and breeder) with no added vitamins and minerals in them. Due to the fact that there was however no significant differences found in the quantities of feed ingested due to a possible nutrient imbalance (2348.2 ± 89.6 g/bird per day, P = 0.09), and only a tendency to produce bigger eggs (P = 0.09) and chicks (P = 0.07), this phenomenon is biologically difficult to explain.

Results from this study are ambiguous in that the presence of a vitamin and mineral premix in breeding ostrich diets (resting or breeding period) had no effect on the birds' weight loss nor on the specific egg quality parameters measured, yet there was a significant decrease in DIS egg production. Deficiency symptoms may only come apparent following extended periods of vitamin and mineral exclusion. Therefore, until more research results are available, it is suggested that producers supply a vitamin and mineral premix package to the rations of breeding ostriches

According to the findings in this experimental chapter, vitamins and minerals are essential in the production of viable day-old ostrich chicks and should not be excluded from the diet supplied to the breeding ostriches.

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Chapter 5 [2]

Effect of Cottonseed Oilcake as protein source on production of breeding ostriches

Abstract

1. South Africa currently produces 70 % of the world's ostrich products. The profit margin of South African producers from the sale of ostrich meat, leather and feathers currently stands at 20 %, 65 % and 15 %, respectively.

2. Local producers want to increase the production of ostrich products but keep production costs as low as possible. Maintaining optimal nutrition of breeding stock is necessary to increase the production of ostrich chicks thereby decreasing the fixed costs per chick.

3. This research examined the impact on ostrich reproduction of replacing soya oilcake (SOC) as a protein supplement with cheaper cottonseed oilcake (CSOC). Although there is no data available on the impact of CSOC feed on ostrich reproduction, it is well known that gossypol, a naturally occurring toxin in cotton plants, negatively affects male reproduction in other monogastric species and that it may also reduce appetite.

4. Ninety-six breeding ostrich pairs were divided into two groups to compare the effects of diet (CSOC and SOC) during the breeding season on ostrich breeding parameters. The replacement of SOC with CSOC had no significant effect on the number of total eggs produced (47.8 ± 5.3 *versus* 48.3 ± 5.1 per breeding pair, respectively) or infertile eggs (31.5 ± 3.9 *versus* 38.0 ± 5.2, respectively). Also, the number of dead-in-shell chicks (DIS) did not differ significantly ($P > 0.05$) between groups (20.2 ± 3.3 *versus* 26.8 ± 3.8, respectively).

5. Even though none of these breeding parameters differed ($P > 0.05$), the replacement of SOC with CSOC in the diets of breeding birds led to significantly ($P < 0.05$) more chicks hatching per hen from breeding birds fed the SOC (36.1 ± 4.8) than the CSOC diet (17.2 ± 3.8).

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6. Although it would thus seem that feeding breeding ostriches CSOC instead of SOC as a protein supplement will have a detrimental effect on chick production, more data is required to deliver a definitive answer.

5.1. INTRODUCTION

South Africa currently produces 70 % of the world's ostrich products. The profit margin of South African producers from the sale of ostrich meat, leather and feathers currently stands at 20 %, 65 % and 15 %, respectively (Stumpf, J. personal communication, 15 December 2014). In a breeding season, female ostriches can lay up to 80 eggs of which less than 50 % hatch (Mellet, 1993; Ipek and Sahan, 2004; Elsayed, 2009; Abbaspour-fard *et al*., 2010). Fertility, hatchability rates as well as the management skills of the producer influences the production and quality of ostriches and their products (Lambrechts, 2006).

Due to the growing international and local market demand for ostrich products, local producers are continuously seeking means to increase production, whilst maintaining production costs as low as possible in order to increase their profit margin.

Lambrechts (2006) noted that nutrition, behaviour, management, as well as physiological health play an important role in the reproductive ability of the ostrich. Ostrich females experience a long (~8 months) breeding season (Nel *et al*., 2010) and it is therefore of cardinal importance to maintain the optimal nutrition of the breeding stock (Cooper *et al*., 2004). Ostriches are commonly fed a variety of different protein sources however soya oilcake (SOC) is the more common. Lately SOC has become expensive due to its use in the concentrate feeds for other animals such as pigs, poultry and dairy cattle. Ostrich breeders are thus seeking alternative protein sources that may be suitable for use; one such protein source is the cheaper cottonseed oilcake (CSOC). However, it is know that CSOC contains anti-nutritional factors such as gossypol.

Gossypol is a natural toxin produced by cotton and other members of the plant genus gossypium. According to Gambill and Humphrey (1993), it is a polyphenolic composite that protects the plant against herbivores and has negative effects on female and male reproduction. Gossypol is present in the pigment glands (yellow polyphenolic pigment) of cotton seed (Siddhuraju *et al*., 2002) and can either be found in a bound non-toxic form or in a free toxic form (McDonald *et al*., 2002).

In rats, gossypol induces irregular oestrous cycles, reduces the weight of ovaries, while causing a decrease of progesterone and estradiol-17β during the oestrus cycle which initiates early pregnancy. An additional effect is a decreased incidence of pregnancy as well as a decrease in the number of pups born per litter (Gambill and Humphrey, 1993).

More symptoms of gossypol toxicity include loss of appetite, weight loss, laboured breathing and cardiac irregularity (McDonald *et al*., 2002). According to McDonald *et al*. (2002), gossypol reduces the carrying capacity of blood and may ultimately cause death by circulatory failure.

Gossypol has a negative effect on male reproduction due to its degenerative effects on testicular tissue. It inhibits the steroid synthesis of testicular Leydig cells causing an increase in immature spermatozoa, decrease in the number as well as the mobility of spermatozoa in cattle (Chase *et al*., 1990; Martin, 1990).

In roosters, semen volume and concentration decreased due to the decrease in the activity of the essential enzymes of the testes and, laying hens experienced a decrease in egg production, egg weight and egg fertility when the chickens were fed diets containing gossypol (Panigrahi *et al*., 1987; Mohan *et al*., 1989; Lordelo *et al*., 2004; Nagalakshimi *et al*., 2007).

Gossypol also influences the permeability of chicken egg membranes which causes a change in egg colour. Iron leaks out from the yolk to the albumin, causing the yolk to become green and rubbery and the albumin colour to change to pink. These eggs are not fit for human consumption and are infertile (Jacob *et al*., 2011). The ration levels of gossypol determined as safe for feeding to swine, broilers and layers are 100 ppm, 50 ppm and 100 - 150 ppm, respectively (Tanksley and Knabe, 1981; Wardrop. 1981; Adeyemo and Longe, 2007). The use of feeds containing gossypol for layer hens or fish has however been banned in the European Union (Alexander *et al*., 2009).

Very little research has been conducted with the use of CSOC in ostrich diets and no data exists on the susceptibility of ostriches to gossypol. Aganga *et al*. (2003) stated that the only way to prevent gossypol poisoning in breeding ostriches is to never use cottonseed oilcake.

Our objective was therefore to determine to what extent ostrich breeders can use the cheaper cottonseed oilcake (CSOC) to replace soya oilcake (SOC) as a protein supplement without any negative effects (caused by the presence of gossypol in CSOC) on reproduction.

However, in this experiment, even though no data exists for the maximum inclusion levels of gossypol in ostrich diets, low levels of CSOC (10 - 20 ppm gossypol) were used to ensure no permanent damage was caused to the breeding ostriches.

5.2. MATERIALS AND METHODS

The study (ethical clearance number R11/40) was conducted at the Oudtshoorn Research Farm near Oudtshoorn, South Africa (22˚20' E, 33˚58' S and altitude 307 m). The breeding season of ostriches in South Africa starts in May/June and runs until December/early January of the following year (Nel *et al*., 2010).

A completely randomized experimental design was used with 96 ostrich breeding pairs being divided into two groups of 48 pairs. The breeding pairs of ostriches were kept in breeder camps of quarter of a hectare per pair (Van Niekerk, 1996). Two different diets, equal in nutrient contents and pellet size (6 mm), were formulated, each one consisting of a different protein source and fed to the birds *ad libitum*.

Cottonseed oilcake (CSOC) meal, with 41 % protein, was used in the cottonseed oilcake diet as replacement for the standard protein source, soybean oilcake (SOC) meal (control diet), in order to be able to determine the effects of gossypol as well as compare the impact of the two protein sources on ostrich reproduction. Both groups received the same maintenance diet in the resting period, from December of the previous year until the start of the breeding season. The breeder diets, given in the breeding season, were balanced and given to the 96 breeding pairs of ostriches in the breeding season of 217 days from mid-May to mid-December 2011 (Table 5.1). All data relating to the breeder bird production was collected and included live mass change of the breeder birds, egg production as well as chick production. The ostriches' feed were filled-up twice a week and feed refusals were weighed back once a month to determine feed intake. During the average feed intake calculations, the assumption was made that the male and female housed together ingested the same quantity of feed (Brand and Steyn, 2002). Therefore, it is crucial to determine the weight change of the breeding ostriches during the breeding season. Ostriches were weighed at the onset and end of the breeding season to be able to determine the live weight change during this time. Live mass changes were calculated by subtracting the live mass of the ostriches at the end from the live mass of the ostriches at the onset of the breeding season.

Table 5.1 *The ingredient and nutrient composition of two diets formulated with respectively cottonseed oilcake or soybean oilcake meal as protein source*

Ingredients	**Cottonseed Oilcake** **As fed kg/tonne**	**Soybean Oilcake** **As fed kg/tonne**
Alfalfa meal (17%)	539.5	643.7
Maize meal	200.0	200.0
Cottonseed meal, 41% protein	162.3	-
Soybean oilcake meal	-	103.6
Limestone, ground	34.5	33.7
Molasses powder	25.0	25.0
Monocalciumphosphate	20.9	16.8
Common salt (NaCl)	10.0	10.0
Vit & Min Premix*	5.0	5.0
MHA (methionine) 86%	1.8	2.2
L-lysine 95%	1.0	-
Nutrient composition		
Metabolisable energy (MJ ME/kg)	9.0	9.2
Crude protein (%)	18.7	17.8
Lysine (%)	0.8	0.8
TSAA** (%)	0.5	0.5
Arginine (%)	1.2	0.8
Threonine (%)	0.6	0.6
Tryptophan (%)	0.2	0.2
Fat (%)	2.8	2.5
Crude fibre (%)	16.7	17.1
Calcium (%)	2.7	2.7
Phosphorus (%)	0.7	0.7
Gossypol, ppm***	10-20	0

***Premix Chemical composition**

Component	**unit**	**Premix**	**Component**	**unit**	**Premix**
Vitamin A	mill IU	16	Biotin	mg	100.0
Vitamin D3	mill IU	2.5	Cobalt	mg	100.0
Vitamin B1	g	2.5	Iodine	g	1.0
Vitamin B2	g	6.0	Selenium	mg	300.0
Vitamin B6	g	4.5	Manganese	g	125.0
Folic acid	g	1.0	Copper	g	6.0
Vitamin B12	mg	10.0	Zinc	g	100.0
Vitamin E	g	30.0	Magnesium	g	45.0
Choline	g	480.0	Iron	g	30.0
Niacin	g	40.0	Antioxidant[1]	g	100.0
Pantothenic Acid	g	16.0	Limestone carrier[2]	g	1173.0
Vitamin K	g	2.5			

** Total sulfar containing amino acids, [1] contains no vitamins and minerals,
[2] contains 36% calcium, ***ppm: parts per million

Ostrich eggs were collected twice a day weighed, identified, sterilized and stored at a temperature of 17ºC and relative humidity (RH) of 75 % until placed inside the incubator (Van Schalkwyk *et al*., 1998; 1999). During the incubation process, infertile and dead-in-shell eggs were noted and removed from the incubator.

The levels of gossypol in the breeder diets were measured according to the methods described by Hron *et al*., (1990). The percentage gossypol in the cottonseed oilcake meal was determined to be 10 - 20 ppm. Table 5.1 indicates the ingredient and nutritional composition of the diets formulated for the two groups. To ensure that the diets were similar in composition, Lucerne (alfalfa) together with synthetic amino acids was used to balance the N-content. The birds also consumed a minimum of natural vegetation consisting primarily of graminoids, shrubs and succulents that was found in the breeding camps.

Data was analysed by means of One Way Anova using Proc GLM of SAS software version 9.3 (2011). LSMeans were calculated and Bonferroni post hoc test was applied for all mean comparisons. Differences were considered significant if P-values were less than 0.05.

5.3. RESULTS

Only the data of the breeding birds that were present for the entire breeding season of 217 days were used (n = 45 pairs per treatment). Although the breeding birds received feed *ad libitum*, an average feed intake of 2266.7 g/bird/day was noted for the SOC diet and 2457.4 g/bird/day for the CSOC diet. The production parameters of breeding ostrich receiving the CSOC or SOC as a protein supplement is summarized in Table 5.2.

Statistical analysis of the feed intake values indicated that the two protein sources differed significantly with the CSOC diet being consumed more (2457.4 ± 54.0 g *versus* 2266.7 ± 45.5 g). During this period the males receiving the two diets lost ~2 kg body weight whilst the females lost more (12 - 15kg); losses are in line with that experienced by breeding birds *per se*. A breeding pair of birds receiving the SOC diet had the least number of eggs (four) as well as the maximum (91); however, no (P = 0.63) fixed diet effect could be seen on clutch size (~48 eggs per breeding pair). The SOC group had a mean hatchability of 36.1 % ± 4.8, the highest for this trial, while the CSOC group had the lowest hatchability at 17.2 % ± 3.8. A comparison of the characteristics of the ostrich eggs in the CSOC group and the SOC group are shown in Figure 5.1.

The replacement of SOC meal with CSOC meal in breeding ostrich diets had no significant ($P \geq 0.05$) effect on the total number of eggs produced (47.8 ± 5.3 per breeding pair in the SOC group *versus* 48.3 ± 5.1 in the CSOC group) or infertile eggs (31.5 ± 5.9 *versus* 38.0 ± 5.2). However, there was a tendency ($P = 0.06$) for the number of dead-in-shell (DIS) chicks to be higher in the CSOC group (20.2 ± 3.3 *versus* 26.8 ± 3.8).

The replacement of SOC meal by CSOC meal in diets of breeding birds led to an 18.9 % decrease in chick production (8.3 *versus* 17.3 chicks/hen/breeding season, $P < 0.0001$).

Although the number of ostrich chicks that hatched (% chicks) differed significantly ($P \leq 0.01$) between ostriches that consumed the two protein sources (CSOC, SOC), it is still lower than the values found in the industry. Black (2001) determined that the number of viable chicks that hatch per female should be between 26.4 and 46.2 for the producer to survive in the industry.

Table 5.2 *The production parameters of ostrich breeders either receiving cottonseed oilcake meal (CSOC) or soybean oilcake meal (SOC) as protein source*

Parameter	**Protein source**		
	CSOC	**SOC**	**P**
n(breeding pairs)	45	45	-
Male Starting weight (kg)	125.1 ± 2.6	129.9 ± 2.5	0.18
Male End weight (kg)	123.3 ± 2.5	127.9 ± 2.4	0.19
Male Weight change (kg)	-1.3 ± 1.6	-2.1 ± 1.6	0.88
Female Starting weight (kg)	123.1^{b} ± 2.3	129.6^{a} ± 2.2	0.04
Female End weight (kg)	111.3 ± 2.2	114.8 ± 2.1	0.26
Female Weight change (kg)	-11.8 ± 1.8	-14.8 ± 1.6	0.20
Feed intake (g/bird/day)	2457.4^{a} ± 54.0	2266.7^{b} ± 45.5	0.04
Egg production, n	48.3 ± 5.1	47.8 ± 5.3	0.22
Infertile eggs (%)	38.4 ± 5.2	31.5 ± 5.9	0.16
Dead-in-shell (%)	26.4 ± 3.8	20.2 ± 3.3	0.05
*Other eggs (%)	18.0 ± 2.6	12.2 ± 1.7	<0.0001
Chicks hatched (%)	17.2^{a} ± 3.8	36.1^{b} ± 4.8	0.01
Viable chicks, n per hen	8.3 ± 1.8	17.3 ± 2.3	<0.0001

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

*Other eggs (%) includes small, dull and broken eggs

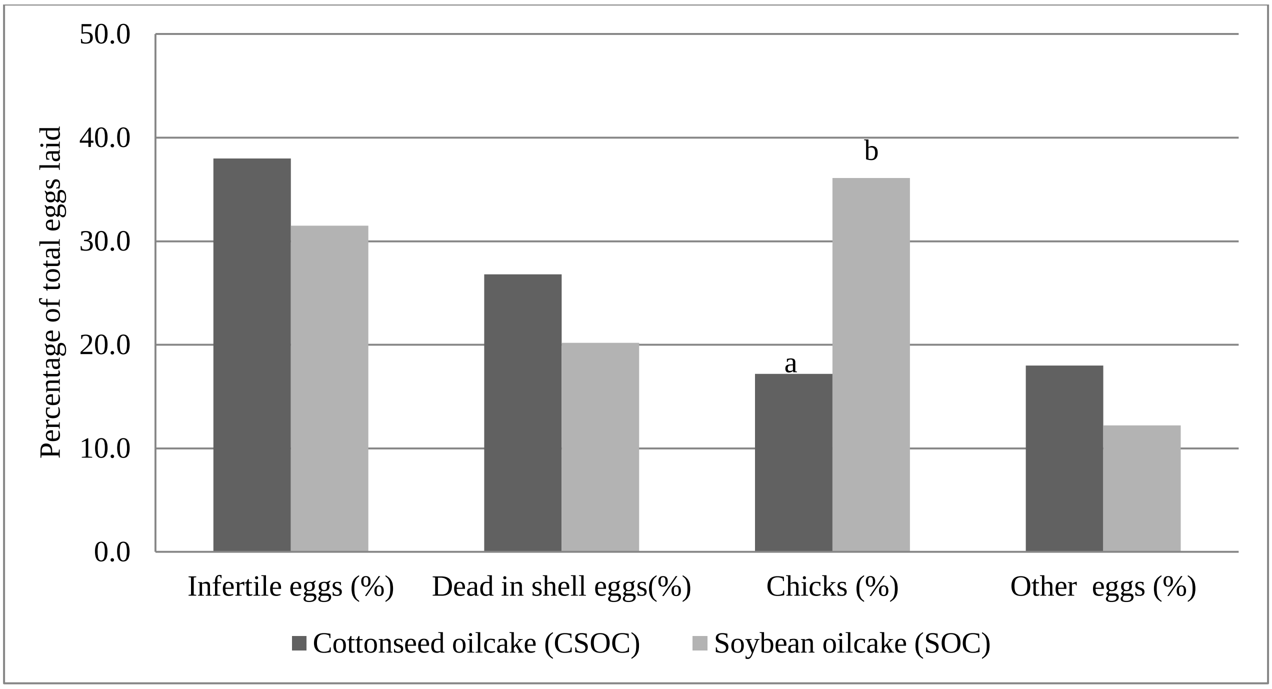

Figure 5.1 *Effect of two different protein sources on the hatchability of ostrich eggs*

5.4. DISCUSSION

According to McDonald *et al*. (2002), negative effects of gossypol include loss of weight and appetite. Although no differences were detected in respect of weight loss between the two groups, feed intake results conflict with the bulk of literature found. In the thesis of Schoon (2012), no differences in feed intake values of growing ostriches (6 to 13 months) were noted with an increase of CSOC meal content of the feed from 0 to 12 %. It is therefore believed that the provision of gossypol in the feed may depress the uptake of an unknown factor. This imbalance causes ostriches to ingest more feed to try and overcome this imbalance. This unknown factor needs to be identified.

Literature also revealed that gossypol can have a negative effect on male semen quality and female egg production (Panigrahi *et al*., 1987; Mohan *et al*., 1989; Lordelo *et al*., 2005; Nagalakshimi *et al*., 2007). The quantity of eggs produced is not the only important measure of ostrich chick production; the number of fertile eggs is just as, if not more important. In this regard the negative effect of gossypol would be seen as a decrease in egg production as well as fertility rates. However, the percentage of infertile eggs (P = 0.16) and egg production (P = 0.22) did not differ radically between the two diets, giving no evidence of fertility problems when using CSOC meal in spite of its gossypol content.

There was no difference ($P > 0.05$) in terms of female or male weight change due to the dietary treatments while egg production, infertile eggs and DIS eggs also did not differ. There was however a decline ($P \leq 0.01$) in the number of chicks that hatched as well as the viable chicks produced between the two diets due to the cumulative effect of the separate characteristics (DIS, Infertility and Other). This may be due to the gossypol content of the feed (10 - 20 ppm).

Results from this study are ambiguous in that diet had no effect on the birds' weight loss nor on the specific egg quality parameters, yet there was a significant decrease in chick production. Therefore, until more research results are available, it is suggested that producers follow the precautionary approach and not use CSOC to feed breeding ostriches.

The use of CSOC as a protein source in breeding ostrich diets is not advised if high quality ostrich chick production is to be achieved.

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Chapter 6

The effect of dietary energy on the production of ostriches as well as the possible carry over effect between years

Abstract

1. The dietary energy content of a feed generally affects the feed intake of animals. A change in the feed intake due to varying the dietary energy content will result in other nutrients such as amino acids being over or undersupplied.

2. A simulation model for ostrich breeding is currently being developed, and knowledge of the effect of dietary energy content on feed intake is crucial for the development of such a model.

3. Research has also shown that a long term effect of feeding low or high energy levels to breeding ostriches exists and that body condition, before and after the breeding season, is a contributing factor to low fertility and hatchability rates of ostrich eggs.

4. The immediate as well as long term effects of feeding breeding ostriches low or high levels of their dietary energy requirements were examined.

5. The trial was done over two consecutive breeding seasons, from Mid-May to Mid-December of 2012 and 2013, with the same breeding ostriches.

6. Five diets were supplied at 120 %, 110 %, 100 %, 90 % and 80 % of the basic energy requirements of breeding ostriches. Feed samples were taken and the production data of all breeding birds was monitored throughout both breeding seasons.

7. In this trial, the level of basal energy supplied did not have a carry-over effect on any of the production parameters measured.

8. Breeding ostriches also showed no indication of regulating feed intake according to energy content of the feed. Literature did however reveal that breeding ostrich feed intake might be influenced by the bulk density of the feed.

9. Female ostrich weight loss decreased linearly ($R^2 = 0.93$, $y = 2.88x - 33.05$, $P = 0.04$) as the dietary energy content of the feed increased.

10. Due to lack of differences in production parameters measured, possible future studies can include the effect of low and high level of basal energy supplied over three or more consecutive breeding seasons.

6.1. INTRODUCTION

In comparison to other monogastric animals, such as the chicken and pig, the nutrient requirements of ostriches are not well defined (Brand & Gous, 2006; Olivier, 2010). A large amount of research has gone into developing growth models for broilers and pigs, incorporating both environmental factors and genetic selection. When fully functional, these models aid in important financial and management decision making.

A simulation model for ostrich breeding is currently being developed, and knowledge of the effect of dietary energy content on feed intake is crucial for the development of such a model. Mathematical models for breeding ostriches are different due to the fact that feed is allocated to maintenance and other production parameters such as feather, sperm and egg production.

The dietary energy concentration of a feed generally affects feed intake in animals. When fed a low energy diet, animals tend to consume greater quantities in order to fulfil their requirements. A change in the feed intake, due to variations in the dietary energy content, will result in other nutrients such as amino acids and minerals being over or undersupplied.

An increase in the price of raw materials forces producers to find cheaper alternatives or to decrease the quality of the feed. However, research has shown that a long term effect of feeding low or high energy levels to breeding ostriches exists and that body condition, before and after the breeding season, is a contributing factor to low fertility and hatchability rates of ostrich eggs (Huchzermeyer 1999; Brand e*t al*., 2002; Aganga *et al*., 2003).

The objectives of this chapter are to evaluate the energy requirements of breeding ostriches in order to quantify the immediate effect of the dietary energy content of the feed on feed intake as well as its long term effect on production.

6.2. MATERIALS AND METHODS

The trial was conducted over two consecutive breeding seasons, from Mid-May to Mid-December of 2012 and 2013, with the same breeding ostriches from the commercial ostrich breeding flock at the Oudtshoorn Research Farm (22˚20' E, 33˚58' S and altitude 307m) near Oudtshoorn, South Africa. The breeding ostriches were managed according to the ostrich manual (Brand 2010).

In the first season, 100 pairs of breeding ostriches were divided evenly according to age and breeding values for egg production. Breeding pairs were kept in separate ¼ hectare camps and received their feed *ad libitum* (Van Niekerk, 1996). During the five month resting period (~5 months), from mid-December until mid-May the following year, males and females were separated and received a standard maintenance diet (Table 6.1 and Table 6.2

All production and reproduction data was noted for both breeding seasons and included ostrich weight change during the breeding season, egg production as well as chick production values of each season.

The treatment design was as 5x5 factorial with factors diet in 2013 (7.5, 8.5, 9.5, 10.5, 11.5 MJ ME/kg) and diet in 2014 (7.5, 8.5, 9.5, 10.5, 11.5 MJ ME/kg).

The composition of the five diets formulated, fed in the first as well as second breeding season, is summarised in Table 6.3.

In the consecutive breeding season the 100 breeding pairs of ostriches were divided up again to ensure that the new groups comprised of at least one of each of the previous diets.

Each group was provided with a different diet, with the five diets being formulated to supply 120 %, 110 %, 100 %, 90 % and 80 % of the basic energy requirements of breeding ostriches respectively. The 100% diet contained 9.5 MJ ME/kg DM, which is what is commercially used in the industry and also what extensive research has shown to be the optimal level (Brand *et al*., 2002, 2003; Olivier *et al*., 2009; 2010; Dzoma, 2010).

Table 6.1 *Maintenance diet received by breeding ostriches during resting period.*

Ingredients	Unit	Quantities
Alfalfa meal (17% CP)	g/kg	798.0
Canola seeds, meal	g/kg	50.0
Corn Yellow grain	g/kg	100.0
Molasses powder	g/kg	25.0
Monocalciumphosphate	g/kg	14.5
Common Salt (NaCl)	g/kg	10.0
Vitamin and Mineral premix*	g/kg	2.5
Nutrients		
Metabolisable energy	(MJ ME/kg feed)	9.4
Crude protein	(%)	17.8
Fat	(%)	2.8
Ash	(%)	8.6
Crude fibre	(%)	21.8
Ca	(%)	1.6
P	(%)	0.6

Table 6.2 *Vitamin and mineral premix chemical composition*

*Premix Chemical composition	unit	Premix
Vitamin A	mill IU	16
Vitamin D3	mill IU	2.5
Vitamin B1	g	2.5
Vitamin B2	g	6
Vitamin B6	g	4.5
Folic acid	g	1
Vitamin B12	mg	10
Vitamin E	g	30
Choline	g	480
Niacin	g	40
Pantothenic Acid	g	16
Vitamin K	g	2.5
Biotin	mg	100
Cobalt	mg	100
Iodine	g	1
Selenium	mg	300
Manganese	g	125
Copper	g	6
Zinc	g	100
Magnesium	g	45
Iron	g	30
Antioxidant1	g	100
Limestone carrier2	g	1173

[1] contains no vitamins and minerals
[2] contains 36%calcium

Feed samples were taken throughout each trial and the production data of all breeding birds of both breeding seasons were monitored. Production data included live weight change during the breeding season, total egg production, chick production, percentage dead-in-shell (DIS) eggs and infertile egg production. The nutrient composition of each diet was determined using a Near Infrared Reflectance Analyser (Bran & Luebbe, 1994). The nutrient content of the five experimental diets is summarised in Table 6.4.

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 was also determined (WHC) (Kyriazakis & Emmans, 1995).

The feed intake of the ostriches was determined by calculating the feed intake per pen and dividing it into two (male and the female) (Brand and Steyn, 2002). Breeding male and female ostriches on the different experimental diets differed (P = 0.05) in their start and end weights.

Table 6.3 *Ingredients of the five experimental diets used in both breeding seasons*

Ingredients		1	2	3	4	5
Percentage of Energy requirement	Unit	120%	110%	100%	90%	80%
Maize	g/kg	400.0	300.0	200.0	100.0	0.0
Wheat hay	g/kg	0.0	100.0	200.0	300.0	400.0
Lucerne hay	g/kg	265.4	225.9	186.4	146.9	107.4
Soybean Oilcake meal	g/kg	208.0	230.7	253.4	276.1	298.9
Molasses Powder	g/kg	50.0	50.0	50.0	50.0	50.0
Limestone	g/kg	46.6	47.4	48.1	48.8	49.6
Monocalciumphosphate 21%	g/kg	14.9	31.0	47.0	63.0	79.1
Common Table salt (NaCl)	g/kg	10.0	10.0	10.0	10.0	10.0
Synthetic methionine	g/kg	0.1	0.1	0.1	0.1	0.1
Vitamin and Mineral premix	g/kg	5.0	5.0	5.0	5.0	5.0

Table 6.4 *Nutrient content of the five different experimental diets fed to the breeding ostriches*

Nutrients		1	2	3	4	5
Percentage of Energy requirement		120%	110%	100%	90%	80%
Metabolic Energy	(MJ ME/kg feed)	11.5	10.5	9.5	8.5	7.5
Crude Protein	(%)	16.7	16.8	16.9	16.9	17.0
Fat	(%)	2.2	2.0	1.9	1.7	1.5
Calcium	(%)	3.6	4.1	4.3	3.2	3.5
Phosphorus	(%)	0.9	1.2	1.4	1.0	1.4
Potassium	(%)	1.4	1.6	1.6	1.4	1.7
Magnesium	(%)	0.3	0.3	0.3	0.3	0.3
Sodium	(g/kg)	7280.6	5278.5	7042.9	7085.0	6933.0
Iron	(g/kg)	544.9	482.2	497.1	465.7	518.1
Copper	(g/kg)	21.5	23.9	21.5	17.6	18.4
Zink	(g/kg)	115.1	116.5	121.0	106.2	118.6
Manganese	(g/kg)	159.4	156.0	163.2	144.7	150.3
Lysine	(%)	0.84	0.86	0.89	0.91	0.93
TSAA	(%)	0.42	0.42	0.42	0.42	0.42
Arginine	(%)	0.95	0.96	0.97	0.98	0.99
Threonine	(%)	0.59	0.59	0.59	0.58	0.58
Tryptophan	(%)	0.21	0.21	0.21	0.21	0.21
Crude Fiber	(%)	8.7	11.1	13.4	15.8	18.1
ADF	(g/kg)	15.6	15.5	19.5	20.1	23.8
NDF	(g/kg)	23.6	22.5	28.7	29.7	35.3
IVOMD	(%)	80.0	79.8	76.4	76.1	73.6
WHC	(g water/ g feed)	7.3	7.5	8.0	8.3	8.7

Abbreviations: TSAA = Total sulpar containing amino acids; ADF = acid digestible fibre; NDF = non-digestible fibre;WHC = water holding capacity of the feed

The changes in live weight during the breeding season were therefore determined by subtracting the weight of the ostriches at the beginning of the season from the weight of the ostriches at the end of the breeding season

Energy ingested per bird per day was calculated by multiplying the energy content of the feed (MJ ME/kg DM) with the quantity of feed ingested per bird (kg DM/bird).

Two eggs were collected per month per dietary treatment (n~150 eggs) for the determination of the yolk: albumin (Y: A) ratio. This was done by separating the three egg components, (yolk, albumin and eggshell) and weighing each separately according to method one described by Hussein *et al*. (1991). The nutrient composition of each diet was determined using a Near Infrared Reflectance Analyser (Bran & Luebbe, 1994).

Factorial analysis of variance with 2013 and 2014 diets as factors was performed on all variables accessed during 2014 using GLM (General Linear Models) Procedure of SAS statistical software version 9.2 (SAS Institute Inc., Cary, NC, USA)). Shapiro-Wilk test was performed to test for normality (Shapiro, 1965). Fisher’s least significant difference (LSD) was calculated at the 5% level to compare treatment means (Ott, 1998). A probability level of 5% was considered significant for all significance tests.

6.3. RESULTS

The consecutive breeding seasons consisted of 217 days each, running from mid-May until mid-December. Only the reproductive data of the breeding ostriches that was present throughout both breeding seasons was used. The least square means (±SE) and significance for the different production parameters of breeding ostriches over both breeding seasons are summarized Table 6.5.

For the breeding season of 2012, a mean and standard error of 2585.2 ± 93.8 g of feed per bird per day was noted over the breeding season for all the diets. This correlates to a mean energy intake of 22.8 ± 0.9 MJ ME/bird/day. The following breeding seasons’ feed intake (2013) had a mean and standard error of 2519.6 ± 54.3 g of feed per bird per day correlating to a mean energy intake of 23.9 ± 0.5 MJ ME/bird/day.

Although previous studies of Brand *et al*. (2002, 2003) indicated that production in current breeding seasons can be affected by nutrition of previous breeding seasons, no such effect was seen in this trial.

The lack of significant results during the breeding season of 2013 was ascribed to the ability of breeding female ostriches to gather the required nutrients for egg formation from the feed as well as stored reserves (Brand *et al*., 2003).

When comparing the two breeding seasons, the breeding season of 2013 had a higher egg production (44.1 ± 1.9 *versus* 34.7 ± 1.9 eggs/female), lower chick production (31.7 ± 4.5 % *versus* 33.6 ± 2.3 %), higher DIS occurrence (39.7 ± 5.5 % *versus* 21.9 ± 1.7 %) and a lower infertility percentage (11.8 ± 1.1 *versus* 29.0 ± 2.5 %) although not significant.

Due to the fact that no interaction of feed energy intake took place between the consecutive breeding seasons, the effect of energy content on the breeding seasons of 2012 and 2013 can be discussed together (Table 6.5 and Table 6.6).

A mean and standard error of 2510.1 ± 30.7 g of feed per bird per day was noted over the consecutive breeding season for all the diets. This correlates to average Metabolisable energy ingestion of 25.0 ± 0.3 MJ ME/kg DM.

The feed intake of the breeding ostriches on the 120 % diet (2669.6 ± 58.6 g) differed significantly ($P = 0.04$) from the feed intake of the breeding ostriches on the 80 % diet (2539.3 ± 37.9 g). Regression analysis of the energy ingested ($R^2 = 0.99$, $y = 2.76x - 1.42$, $P < 0.0001$) by the breeding ostriches also revealed that as the dietary energy content of the feed increased, so did the feed intake, causing an increase in the actual energy ingested by the breeding ostriches (Figure 6.2).

This indicated that for each MJ ME increase in the dietary energy content of the feed, the actual intake of energy per bird increased by 2.76 MJ ME per day. This contradicts the belief that ostriches ingesting feed to satisfy energy requirements. However, literature revealed that the breeding ostrich feed intake might be influenced by the bulk density of the feed.

According to Carstens (2013) ostrich feed intake increases as the feed energy content decreases, which is normally accomplished by increasing the fibre content. The breeding ostriches then try to ingest more feed to satisfy their energy requirements, but this is limited by their maximum gut capacity (Carstens, 2013).

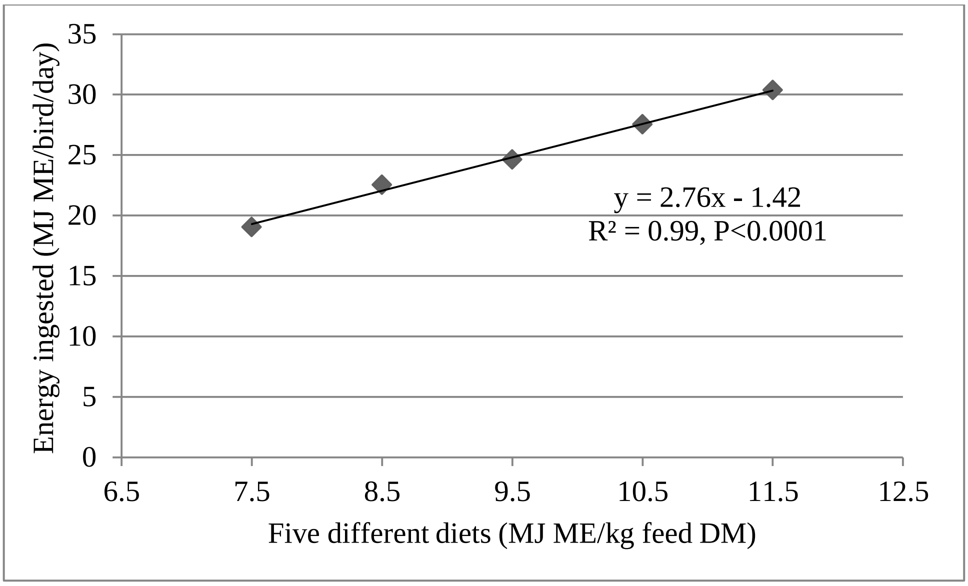

Figure 6.1 *The linear regression of the energy ingested per ostrich per day during the breeding season relative to the dietary energy content on the 5 different energy diets*

Furthermore, feed intake will increase as the fibre content increases until an upper limit is reached due to the gut capacity of the animal, this upper limit is in turn influenced by the indigestible portion (ADF/NDF) of the feed as well as the physical size of the animal. A good indication of a feeds bulk density can be obtained by determining the ADF (acid detergent fibre), NDF (neutral detergent fibre), IVOMD (*in vitro* organic matter digestibility) and WHC of the feed.

The feed with the highest feed intake, the 120% basal energy diet, had lower ADF (15.6 g/kg *versus* 23.8 g/kg), NDF (23.6 g/kg *versus* 35.3 g/kg) and WHC (7.3 g/kg *versus* 8.7 g water/g feed) value relative to the 80 % diet. The percentage IVOMD was also higher (80.0 % *versus* 73.6 %). These results support the finding that the bulk density of the feed is affected feed intake.

During the breeding season, male ostrich nutrient requirements are mainly for maintenance and sperm production. Therefore, weight change during the breeding season is used as an indication of an over or under supply of energy. The gain in live weight by male breeding ostriches indicated that the energy levels supplied in the 120 %, 110 % and 90 % diets were above those required for maintenance and reproduction (Brand *et al*., 2002).

The male ostriches on the 80 % diet were the only group to lose weight during the breeding season and also differed significantly ($P < 0.001$) from the rest of the male ostriches.

Weight change experienced by female breeding ostriches on the 120 % (-0.8 ± 1.9 kg) and 110% (-2.6 ± 1.5 kg) diet differed significantly ($P < 0.001$) from the weight change of the breeding ostriches on the 90 % (-8.6 ± 1.7 kg) and 80 % (-12.4 ± 2.1 kg) diet. The female ostriches that ingested the diets with the lower energy content (90 % and 80 %) lost the most amount of body weight and is what were expected. Regression analysis of the data revealed that female ostrich weight loss decreased linearly ($R^2 = 0.93$, $y = 2.88\,x - 33.05$, $P = 0.04$) as the dietary energy content of the feed increased (Figure 6.2). This indicated that for every MJ increase in the dietary energy content of the feed, the live weight lost by female ostriches decreased by 2.88 kg over the breeding season.

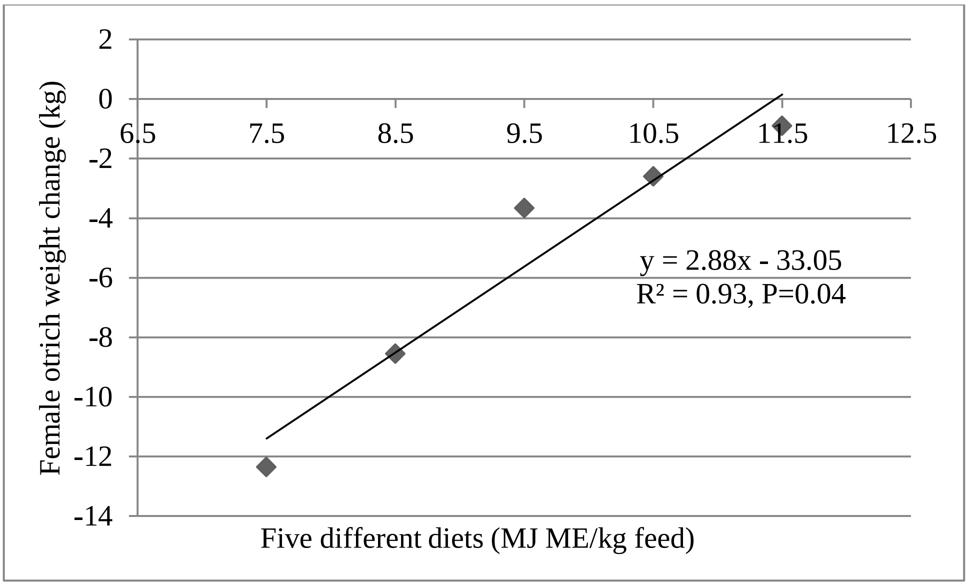

Figure 6.2 *The linear regression of female weight change during the breeding season relative to the dietary energy content*

In a study by Brand *et al*. (2003), breeding ostriches that were fed low energy diets compensated by having longer intervals between eggs, thus laying fewer eggs in the breeding season. Results obtained are in accordance to these findings. The breeding ostriches on the 90 % diet produced the greatest quantity of eggs (44.5 ± 3.2 eggs/female) and differed significantly ($P = 0.04$) from the breeding ostriches on the 80 % diet, producing the least amount of eggs (36.1 ± 2.5 eggs/female).

No significant effect of dietary energy treatment was seen in the percentage DIS eggs (32.6 ± 2.5 %), infertile eggs (18.7 ± 1.3 %) or chicks produced (31.0 ± 1.8 %).

The least square means (±SE) and significance of the ostrich egg characteristics including the Y: A ratio are summarised in Table 6.7. The average ostrich egg weight in this study was 1494.0 ± 36.7 g, with this consisting of 874.1 ± 32.0 g albumin, 310.7 ± 12.8 g yolk and a shell of 298.2 ± 5.7 g. The average Y:A ratio, calculated as 2.9 ± 0.2, is in accordance with the findings of Di Meo *et al*. (2003) and Cooper *et al*. (2008) but higher than the findings of Superchi *et al*. (2002).

Results showed no significant effect of the different diets on the size of the yolk (310.7 ± 12.8 g), albumin (874.1 ± 32.0 g) or the Y: A ratio (2.9 ± 0.2). Significant differences ($P < 0.05$) were however seen in the size of the whole egg as well as the shell mass. The size of the whole ostrich eggs for the 100% diet (1603.8 ± 48.4 g) differed significantly from those for the 110% and 90% diets (1443.3 ± 31.3 g and 1437.5 ± 33.0 g respectively).

Table 6.5 *Least square means (±SE) and significance for production parameters of breeding ostriches during two consecutive breeding seasons*

Production parameters	Dietary energy content (MJ ME/kg feed) first season					Significance level (P)	Dietary energy content (MJ ME/kg feed) second season					Significance level (P)
	7.5	8.5	9.5	10.5	11.5		7.5	8.5	9.5	10.5	11.5	
Energy requirement	80%	90%	100%	110%	120%		80%	90%	100%	110%	120%	
Energy ingested (MJ ME/bird/day)	19.3 ± 0.3	23.6 ± 0.2	26.2 ± 0.4	30.1 ± 0.4	32.8 ± 0.4	0.25	19.1^{e} ± 0.4	22.0^{d} ± 0.4	23.9^{c} ± 0.5	26.1^{b} ± 0.5	28.3^{a} ± 0.69	<0.001
Number of breeding pairs (n)	17	17	17	20	19	-	19	19	22	24	21	-
Male Starting mass (kg)	128.5 ± 3.1	122.4 ± 3.00	136.3 ± 4.7	127.4 ± 3.8	135.1 ± 5.6	0.81	129.7 ± 3.5	124.3 ± 2.7	124.9 ± 3.2	125.6 ± 3.1	128.9 ± 3.0	0.37
Male End mass (kg)	121.5 ± 4.0	126.8 ± 2.9	136.9 ± 3.3	134.2 ± 4.3	141.8 ± 5.3	0.66	130.9 ± 3.4	133.8 ± 2.6	136.5 ± 3.7	134.3 ± 3.2	139.7 ± 2.5	0.22
Male Mass change (kg)	-6.9 ± 2.9	4.4 ± 2.2	0.63 ± 3.0	6.8 ± 2.7	6.6 ± 2.3	0.94	1.2^{b} ± 1.8	9.4^{a} ± 2.2	11.6^{a} ± 1.7	8.7^{a} ± 1.9	10.8^{a} ± 2.0	0.001
Female Starting mass (kg)	118.5 ± 2.5	123.7 ± 3.0	126.7 ± 5.5	119.5 ± 3.1	120.4 ± 4.4	0.51	132.2^{a} ± 3.1	121.1^{b} ± 2.0	127.2^{ab} ± 2.3	123.^{8ab} ± 2.3	125.9^{ab} ± 2.1	0.05
Female End mass (kg)	110.2 ± 3.5	115.8 ± 3.0	122.1 ± 4.2	121.3 ± 2.5	122.4 ± 3.3	0.33	118.3^{abc} ± 1.8	113.4^{c} ± 2.9	123.7^{ab} ± 2.9	118.7^{bc} ± 2.2	124.5^{a} ± 2.9	0.01
Female Mass change (kg)	-8.3 ± 2.9	-7.9 ± 2.7	-4.6 ± 2.9	1.8 ± 2.4	2.1 ± 4.1	0.26	-13.9 ± 2.6	-7.6 ± 2.2	-3.5 ± 2.3	-5.1 ± 1.8	-1.4 ± 1.7	0.08
Feed ingested (g/bird/day)	2567.2 ± 40.1	2776.8 ± 28.1	2762.1 ± 39.0	2862.9 ± 33.5	2855.3 ± 35.5	0.70	2547.0 ± 55.3	2586.5 ± 51.2	2516.6 ± 52.6	2487.2 ± 52.6	2460.5 ± 59.7	0.84
Production												
Egg production (n)	35.8 ± 4.5	32.6 ± 4.8	43.0 ± 4.2	35.6 ± 4.0	29.8 ± 4.9	0.71	32.2 ± 3.3	45.8 ± 4.4	41.8 ± 3.8	45.6 ± 4.2	43.0 ± 3.9	0.46
Infertile eggs (%)	28.7 ± 5.9	28.7 ± 6.0	25.0 ± 5.1	28.3 ± 4.8	37.0 ± 7.1	0.09	32.5 ± 5.3	19.9 ± 4.3	29.4 ± 4.3	36.1 ± 5.1	35.4 ± 6.3	0.62
DIS eggs (%)	19.8 ± 4.1	25.9 ± 4.5	23.1 ± 3.6	22.1 ± 3.2	20.5 ± 4.2	0.71	19.8 ± 2.6	24.6 ± 3.5	21.7 ± 2.5	18.4 ± 2.2	20.8 ± 3.3	0.79
Chick production (%)	41.3 ± 6.3	33.5 ± 5.4	41.0 ± 4.8	32.5 ± 3.5	26.6 ± 6.2	0.62	33.0 ± 4.0	35.8 ± 4.2	32.6 ± 4.8	34.4 ± 3.8	30.2 ± 4.7	0.92
Other (%)	10.2 ± 1.0	11.9 ± 2.2	10.9 ± 1.7	17.1 ± 2.3	15.9 ± 3.4	0.14	8.0 ± 1.2	8.9 ± 2.4	12.9 ± 3.3	11.1 ± 2.2	13.6 ± 2.4	0.49

$^{a, b, c}$ Least square means within row with different superscripts for treatments differ significantly (P<0.05).

*Other eggs (%) includes eggs used for lab analysis and small, dull and broken eggs

Table 6.6 *Least square means (±SE) and significance for production parameters of breeding ostriches across both breeding seasons*

Diet	1	2	3	4	5	Significance level (P)
Energy requirement	120%	110%	100%	90%	80%	
Dietary energy content (MJ ME/kg feed)	11.5	10.5	9.5	8.5	7.5	
Energy ingested (MJ ME/bird/day)	30.7^{a} ± 0.7	27.5^{b} ± 0.4	24.6^{c} ± 0.4	22.5^{d} ± 0.3	19.0^{e} ± 0.3	<0.0001
Male Starting Weight (kg)	130.3 ± 2.8	126.8 ± 2.3	129.0 ± 2.7	123.8 ± 2.1	129.0 ± 2.6	0.40
Male End Weight (kg)	139.3^{a} ± 2.8	134.7^{ab} ± 2.5	136.4^{ab} ± 2.6	131.2^{bc} ± 2.0	127.6^{c} ± 2.8	0.02
Male Weight Change (kg)	8.9^{a} ± 1.3	8.0^{a} ± 1.5	7.4^{a} ± 1.6	7.4^{a} ± 1.6	-1.4^{b} ± 1.7	<0.0001
Female Starting Weight (kg)	125.8 ± 2.4	122.0 ± 1.8	127.2 ± 2.4	121.4 ± 1.7	127.1 ± 2.5	0.17
Female End Weight (kg)	125.1^{a} ± 2.4	119.4^{bc} ± 1.6	123.6^{ab} ± 2.4	112.9^{d} ± 1.9	114.8^{cd} ± 1.8	<0.0001
Female Weight Change (kg)	-0.8^{a} ± 1.9	-2.6^{a} ± 1.5	-3.7^{ab} ± 1.8	-8.6^{bc} ± 1.7	-12.4^{c} ± 2.1	<0.0001
Feed Ingested (g/bird/day)	2669.6^{a} ± 58.6	2621.1^{ab} ± 42.6	2591.4^{ab} ± 37.4	2652.1^{ab} ± 37.4	2539.3^{b} ± 37.9	0.04
Production						
Total egg production (n/female/season)	36.9^{ab} ± 2.9	40.0^{ab} ± 2.9	43.1^{ab} ± 2.8	44.5^{a} ± 3.2	36.1^{b} ± 2.5	0.04
Infertile eggs (%)	21.1 ± 3.2	21.2 ± 3.0	16.1 ± 2.3	17.4 ± 3.1	17.9 ± 2.9	0.77
DIS eggs (%)	28.6 ± 3.6	38.1 ± 7.4	35.6 ± 7.8	26.8 ± 5.8	33.8 ± 7.0	0.73
Chicks hatched (%)	23.2 ± 2.8	36.8± 7.5	34.6 ± 4.9	26.9 ± 3.0	33.5 ± 5.7	0.23
*Other (%)	26.8 ± 3.1	13.9 ± 1.0	13.7 ± 3.2	27.9 ± 4.2	14.8 ± 3.5	0.50

$^{a, b, c}$ Least square means within row with different superscripts for treatments differ significantly ($P<0.05$).

*Other eggs (%) includes eggs used for lab analysis and small, dull and broken eggs

Table 6.7 *Least square means (±SE) and significance of ostrich egg characteristics of breeding ostriches*

Diet	1	2	3	4	5	Significance level (P)
Energy requirement	120%	110%	100%	90%	80%	
Dietary energy content (MJ ME/kg feed)	11.5	10.5	9.5	8.5	7.5	
Energy ingested (MJ ME/bird/day)	30.3^{a} ± 0.7	27.1^{b} ± 0.6	24.1^{c} ± 0.6	21.7^{d} ± 0.5	17.6^{e} ± 0.4	<0.0001
Whole egg (g)	1448.5^{ab} ± 43.6	1443.3^{b} ± 31.3	1603.8^{a} ± 48.4	1437.5^{b} ± 33.0	1537.0^{ab} ± 27.3	<0.01
Yolk (g)	309.6 ± 16.1	291.9 ± 14.5	338.5 ± 11.3	311.8 ± 12.9	301.6 ± 9.1	0.14
Albumin (g)	840.6 ± 33.0	847.8 ± 18.8	936.2 ± 35.8	829.6 ± 38.2	916.4 ± 34.1	0.08
Shell (g)	284.3^{c} ± 4.9	291.1^{bc} ± 8.1	320.7^{a} ± 8.0	284.7^{bc} ± 4.5	310.0^{ab} ± 3.1	<0.001
Y: A ratio	2.8 ± 0.1	3.0 ± 0.2	2.8 ± 0.1	2.8 ± 0.2	3.1 ± 0.2	0.58

[a, b, c] Least square means within rows with different superscripts for treatments differ significantly ($P<0.05$).

6.4. DISCUSSION

Previous studies revealed that female ostrich energy and protein requirement for egg production is 8.5 MJ ME/kg feed DM and 105 g/kg respectively. Female ostriches that received low energy levels (7.5 MJ ME/kg feed DM and lower) during a breeding season tended to lose more body weight, increase intervals between eggs being laid and therefore laying fewer eggs. In the following breeding season, a carry-over effect will result in a decreased egg production in the consecutive breeding season (Brand *et al*., 2002a, 2002b, 2003). In this trial, however, the level of basal energy supplied did not have a carry-over effect on any of the production parameters. The lack of results might be due to the opportunity of recovery in the five month resting period.

Dzoma (2010) and Brand *et al.* (2002b, 2003) found that the decrease in the body condition of breeding ostriches fed diets containing less than 8.5 MJ ME/kg feed can cause a 28 % decrease in egg production. Olivier *et al*. (2009) on the other hand, determined that a dietary energy content exceeding 25.5 MJ ME per bird per day will have no effect on reproduction performance.

Results from this trial confirm that ostriches receiving lower energy diets produce fewer eggs. The breeding ostriches on the 90 % diet (44.5 ± 3.2 eggs/female) produced more and differed significantly ($P = 0.04$) from the breeding ostriches on the 80 % diet (36.1 ± 2.5 eggs/female).

Although all five diets formulated differed in the amount of energy supplied in the feed (MJ ME/kg feed DM) as well as the energy ingested (MJ ME/bird/day), breeding ostriches showed no indication of regulating feed intake according to the energy content of the feed. An increase in the energy content of the feed also caused a linear increase in the quantity of energy ingested per bird per day ($R^2 = 0.85$, $y = 3.08 x - 3.22$, $P < 0.0001$).

The feed intake of the breeding ostriches on the 120 % diet differed significantly from the feed intake of the breeding ostriches on the 80 % diet. Literature revealed that breeding ostrich feed intake may therefore be influenced by the bulk density of the feed.

With an increase in the fibre content, the feed intake of breeding ostrich increases until an upper limit is reached. This upper limit is determined by the gut capacity of the bird as well as the indigestible portion of the feed.

During the breeding season, male ostrich nutrient requirements are mainly for maintenance and sperm production. Weight change during the breeding season is therefore used as an indication of an over or under supply of energy and protein. Female ostrich nutrient requirements during the breeding season are greater than those of the male due to the costly production of fertile eggs. The ability to produce eggs from feed as well as body reserves, results in female breeding ostriches losing weight during the breeding season.

Weight lost should be regained during the resting period to ensure optimal reproduction in the following breeding season. Female ostriches on the 100% energy diet, a diet fed in the industry, lost an average of 3.7 kg during the breeding season while producing the most chicks (14.9 ± 0.2 chicks/female). Female ostrich weight loss decreased linearly ($R^2 = 0.93$, $y = 2.88 x - 33.05$, $P = 0.04$) as the dietary energy content of the feed increased. This indicated that for every MJ increase in the dietary energy content of the feed, the live weight lost by female ostriches decreased by 2.88 kg. Based on this information, the ideal energy intake for breeding female ostriches is recommended to be 25.5 MJ ME/bird/day.

This is higher than the findings of Brand (2003) and the maximum inclusion level determined by Olivier (2010).

Due to lack of differences in production parameters measured, possible future studies can include the effect of low and high level of basal energy supplied over three or more consecutive breeding seasons.

In conclusion, the breeding ostrich diet commercially used in the industry, containing 9.5 MJ ME/kg DM, what extensive research has shown to be the optimal level, is still the best representation of what is required for optimal production and reproduction.

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Chapter 7

Ostrich egg laying patterns and ostrich egg content over the breeding season

Abstract

1. Mathematical modelling is a method of simplifying reality by using a single or multiple equations to represent a system's behaviour. These models are often used in animal nutrition, but not yet for the ostrich industry at present (Gous *et al*., 2006; Thornley & France, 2007).

2. An egg production model for broiler breeder hens has been successfully developed by Gous & Nonis (2010). The model incorporates the age of the hen, environmental factors, genetic selection and supplies the nutritional requirements of the hen according to her egg laying pattern.

3. In order to develop a mathematical optimization model for breeding ostriches, the egg laying pattern of breeding ostriches needs to be determined.

4. Shanawany (1999) described breeding ostriches having a strict every second day egg laying pattern. Female breeding ostriches will produce 20 to 24 eggs and rest for seven to ten days before starting again.

5. Data collected for this study included the day to day egg laying and egg weight data of female breeding ostriches flock from the Oudtshoorn Research Farm during four breeding seasons between 2004 and 2009.

6. Data from breeding ostriches used for this study showed the normal egg production pattern during the breeding seasons. Results indicated that the days until first egg, total days in lay and average number of eggs produced were strongly influenced by the age of the female ostrich.

7. Although the six-week egg laying pattern described by Jarvis *et al.* (1985) could not be seen, evidence of the pattern described by Shanawany (1999) was found.

8. Unfortunately, due to the phenomenon that egg production of female breeding ostriches is highly variable, and that a vast number of factors influences the production of ostrich eggs, a specific egg laying pattern over the breeding season could not be identified (Bunter et al.,2001; Olivier, 2010).

7.1. INTRODUCTION

Mathematical modelling is a method of simplifying reality by using single or multiple equations to represent a system's behaviour. These models are often used in animal nutrition, specifically monogastric animals such as poultry, turkeys and pigs (Gous *et al*., 2006; Thornley & France, 2007). When fully functional, these models aid in important financial and management decision making giving recommendations in economic terms as well as supplying a formulated least-cost diet that supplies all the nutritional requirements of that animal at that specific growth stage. No such model and feeding system exists for the ostrich industry at present.

An egg production model for broiler breeder hens has been successfully developed by Gous & Nonis (2010). The model incorporates the age of the hen, environmental factors, genetic selection and supplies the nutritional requirements of the hen according to her egg laying pattern. In order to develop a mathematical optimization model for breeding ostriches, the nutrient requirements for egg production, as well as the egg laying pattern of breeding ostriches need to be determined.

A high demand for ostrich feathers, driven by the European fashion industry, initiated the domestication of ostriches in South Africa around 1860 (Smit, 1963; Gertenbach *et al*, 2008; Jordaan *et al*., 2008). Wild and domesticated ostrich are considered to be seasonal polygamous breeders with their physiological systems photoperiod dependant (Bronneberg *et al*., 2007; Dzoma, 2010).

In the wild, ostriches display evidence of being opportunistic breeders showing an overall peak in reproduction activity just before the main rains (Sauer & Sauer, 1966; Jarvis *et al*., 1985). A wild ostrich clutch will consist of twelve to eighteen eggs, with the female producing two to three clutches in a breeding season.

Domesticated ostriches in South Africa, on the other hand, can lay up to 80 eggs in a breeding season, from mid-May until mid-January, depending on management, genetics and nutrition (Ullrey & Allen, 1996; Ipek & Sahan, 2004; Elsayed, 2009; Abbaspour-fard *et al*., 2010, Nel *et al*., 2010).

Shanawany (1999) described the egg laying pattern of domesticated breeding ostriches to be strictly every second day until 20 to 24 eggs are laid. Most ostrich farms artificially incubate the eggs, ostrich eggs are therefore removed out of the nest every day to ensure optimal chick hatchability and record keeping (Brand 2010).

Female breeding ostriches will thus take a short break of between seven and ten days before starting the every-second-day egg laying pattern again (Shanawany, 1999). Jarvis *et al.* (1985) discovered a series of peaks and troughs in the egg production during the breeding season of domesticated ostriches, showing a possible 6-week cycle pattern of egg production. This pattern could also be identified in the wild ostriches of Mvuma, Zimbabwe (Jarvis *et al.*, 1985).

The eggs produced by a female breeding ostrich are approximately 1.2 % of her body weight and consists out of albumin, yolk, a shell and membranes (Burley & Vadehra, 1989; Angel, 1993; Noble *et al.*, 1996; Sales *et al.*, 1996; Speake *et al.*, 1998; Di Meo *et al*, 2003). These four components need to function properly and therefore need to contain the right quantities of the nutrients required to produce a viable ostrich chick (Brand, 2010). The ability to produce fertile eggs from feed as well as body reserves is a costly one, resulting in female breeding ostriches losing weight during the breeding season. The weight lost should be regained during the resting period to ensure optimal reproduction in the following breeding season.

Knowledge on the pattern of egg production and what factors affect it is required for inclusion into the mathematical optimization model to ensure optimal nutrition for breeding ostriches during egg production.

7.2. MATERIALS AND METHODS

Data used for this study was obtained from the ostrich breeding flock from the Oudtshoorn Research Farm (22˚20ʹ E, 33˚58ʹ S and altitude 307m) near Oudtshoorn in South Africa. The breeding ostriches were managed according to the ostrich manual (Brand 2010).

Collected data includes the day to day egg laying and egg weight data during four breeding seasons (between 2004 and 2009). Methods for collection, sanitation and storage of the ostrich eggs at the experimental site are well documented (Van Schalkwyk *et al.*, 1998; 1999). Briefly, eggs were collected daily, weighed and identified by date and female of origin. A total of 435 female ostriches, from the three genotypes, South African Blacks (*Struthio camelus* var. *domesticus*), Zimbabwean Blue (*Struthio camelus australis*) and Kenyan Red Necks (*Struthio camelus massaicus*) and their crosses, produced 4500 eggs during the four breeding seasons of approximately 251 days each.

The weight of the eggs and its separate components were also determined for 319 ostrich eggs collected during the time period of 2010 to 2013.

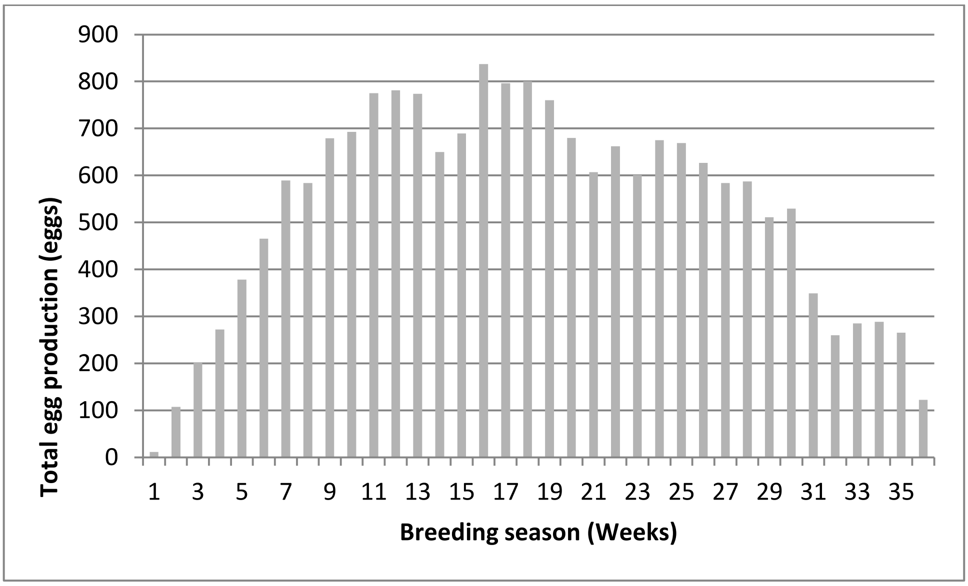
This was done by separating the three egg components, (yolk, albumin and eggshell) and weighing each separately according to method one described by Hussein *et al*. (1991).

Statistical analysis of the data included the GLM procedure of SAS software (SAS, 2008).

7.3. RESULTS

The 4500 eggs laid produced ~3200 day old ostrich chicks (approximately 71.1% hatchability). Breeding ostriches used for this study showed the normal egg production pattern during the breeding season (Figure 7.1). As the daylight length increased the number of eggs produced increased, reaching a peak in end-August/begin-September when day length is at a maximum (Ipek & Sahan, 2004, Lambrechts, 2004). A natural resting period, usually in October (Figure 7.1, week 21, 22 and 23), followed the peak in egg production. Egg production increased again until December/January (Brand, 2010).

Figure 7.1 *Combined egg production of breeding ostriches from mid- May to mid- January during 2004 until 2009.*



The least square means (±SE) and significance for the different egg production parameters and characteristics due to the age of the female breeding ostrich are given in Table 7.1 and Table 7.2. The days until first egg describes the time (in days) it takes the female ostrich to produce her first egg after being put into the breeder camps with males. Days in lay describes the time (in days) from the first egg of the season until the last egg for the season is produced.

Table 7.1 *Ostrich egg production characteristics according to the age of the female ostrich*

Female age

Parameters	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**P**
N	**48**	**119**	**32**	**24**	**12**	**8**	**27**	**27**	**2**	**-**
Days until first egg	101.9^{a} ± 7.9	58.9^{b} ± 3.7	51.3^{b} ± 4.7	44.3^{b} ± 4.9	65.2^{ab} ± 10.5	44.9^{b} ± 6.2	37.1^{b} ± 2.9	37.8^{b} ± 3.4	40.0^{b} ± 0.0	<0.0001
Days in lay	102.8^{b} ± 6.7	150.5^{a} ± 4.4	164.5^{a} ± 6.4	159.8^{a} ± 8.3	131.9^{ab} ± 15.0	175.6^{a} ± 6.3	166.4^{a} ± 8.2	176.1^{a} ± 7.2	138.0^{ab} ± 0.0	<0.0001
Days until last egg	195.8 ± 7.9	209.4 ± 4.1	215.8 ± 6.7	204.0 ± 9.3	197.1 ± 13.2	220.5 ± 10.2	37.1^{b} ± 2.9	213.9 ± 7.4	178.0 ± 0.0	0.47
Eggs produced per female	20.1^{c}± 2.3	28.7^{bc} ± 3.0	41.6^{ab} ± 5.0	40.7^{abc}± 3.9	41.3^{abc} ± 9.2	26.6^{bc} ± 4.3	56.3^{a}± 5.9	46.9^{ab} ± 7.3	45.0^{ab} ± 0.0	<0.0001
Egg laying frequency (eggs/day)	0.54 ± 0.1	0.46 ± 0.1	0.41 ± 0.04	0.45 ± 0.04	0.69 ± 0.1	0.59 ± 0.04	0.60 ± 0.04	0.49 ± 0.04	0.52 ± 0.004	0.68
Average egg weight (g)	1365.2 ± 15.2	1401.6 ± 11.2	1367.5 ± 12.8	1395.9 ± 20.1	1408.1 ± 46.8	1378.7 ± 24.4	1404.2 ± 16.0	1357.6 ± 24.8	1497.8 ± 0.0	0.25
DIS (%)	37.4^{ab} ± 7.0	39.6^{a}± 4.9	34.3^{abc} ± 8.1	27.3^{abc} ± 9.2	5.5^{bc} ± 1.8	$19.^{abc}1$ ± 12.0	6.9^{bc} ± 3.6	2.1^{c}± 0.5	0.0^{c} ± 0.0	<0.001
Infertile (%)	23.8^{d} ± 4.4	30.3^{cd} ± 2.4	32.2 ± 4.0	36.8^{cd} ± 4.7	47.6^{c} ± 0.8	40.8^{c} ± 6.1	46.7^{c} ± 1.8	49.0^{b} ± 0.2	51.1^{a} ± 0.0	<0.0001
Hatchability (%)	69.3^{a} ± 4.1	64.1^{a} ± 2.0	62.4^{ab} ± 3.8	58.8^{ab} ± 3.8	46.8b ± 1.0	49.4^{b} ± 4.0	49.6^{b} ± 1.4	48.8b ± 0.3	48.9^{b} ± 0.0	<0.0001
Chicks hatched per female (n)	9.9^{b} ± 1.9	12.0^{b} ± 1.6	16.8^{ab} ± 2.9	16.3^{ab} ± 2.7	21.0^{ab} ± 4.5	12.3^{ab} ± 2.4	26.1^{a} ± 3.0	28.1^{a} ± 3.5	22.0^{ab} ± 0.0	<0.0001
Chick weight (g)	688.8 ± 48.5	732.6 ± 28.9	818.2 ± 10.3	845.1 ± 13.9	891.9 ± 41.6	809.9 ± 12.6	826.5 ± 12.9	808.0 ± 12.3	888.5 ± 0.0	0.05

^{a,b} Columns means with different superscripts differ significantly (P ≤ 0.05).

Table 7.2 *Ostrich egg characteristics according to the age of the female ostrich*

	Female age								
Parameters	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**P**
N	**22**	**84**	**87**	**17**	**33**	**31**	**15**	**3**	**-**
Egg weight (g)	1383.0 ± 35.3	1439.7 ± 19.4	1431.6 ± 13.7	1458.2 ± 42.6	1440.3 ± 24.0	1397.3 ± 28.0	1396.9 ± 37.3	1573.1 ± 36.5	0.37
Yolk weight (g)	283.4^{b} ± 9.2	317.7^{a} ± 4.4	316.1^{a} ± 4.6	324.2^{a} ± 13.8	341.0^{a} ± 6.2	317.1^{a} ± 9.8	338.1^{a} ± 12.0	381.1^{a} ± 43.6	<0.001
Albumin weight (g)	809.2± 28.4	819.3 ± 14.9	814.2 ± 11.8	826.7 ± 33.2	801.6 ± 19.5	789.0 ± 17.8	768.0 ± 36.0	881.2 ± 74.8	0.58
Shell weight (g)	279.5 ± 5.7	291.7 ± 3.6	292.2 ± 3.3	299.2 ± 6.4	290.4 ± 4.9	282.4 ± 4.8	282.3 ± 5.7	308.1 ± 19.8	0.26
Yolk: albumin ratio	2.9^{a} ± 0.1	2.6^{ab} ± 0.1	2.6^{ab} ± 0.1	2.6^{ab} ± 0.2	2.4^{b} ± 0.1	2.5^{ab} ± 0.1	2.3^{b} ± 0.2	2.3^{b} ± 0.1	<0.01

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

Days until last egg describes the time (days) that passed from the first day of the breeding season until the last egg was laid. The total quantity of eggs laid was divided through the total days in lay to get an egg laying frequency per breeding pair.

According to previous studies, female ostriches can be divided into one of three age groups because of its effect on egg and chick production (Badley, 1997; Brand *et al*., 2008, 2011, 2012; Bunter & Cloete, 2004; Bunter, 2002; Cloete *et al*., 2006; Ipek & Sahan, 2002; Lambrechts, 2004). The three groups were as follows: the two year old females, the three to seven year old females and the females older than eight years of age (Table 7.3 and

Table **7.4**). The two year old females, which were introduced into the production system for the first time, had lower fertility and hatchability rates (Brand et al., 2007; Cloete *et al*., 2006). Breeding female ostriches older than 8 years of age are usually culled due to an increase in embryonic deaths causing a decline in hatchability rates (Badley, 1997; Brand *et* al., 2007; Bunter, 2002; Bunter & Cloete 2004; Cloete *et al*., 2006).

Young female breeding ostriches (2 years) took the longest time before producing their first egg (102.6 ± 7.6 days), were in lay for the shortest time period (98.7 ± 7.2 days) therefore producing the least number of eggs in a breeding season (40.0 ± 3.6 eggs/female). This is in accordance with the findings of Bunter (2002) and Cloete *et al* (2006).

Table 7.3 *Ostrich egg production characteristics according to the age of the female ostrich*

	Female age			P
Parameters	2	3 to 7	8+	-
Days until first egg	102.6^{a} ± 7.6	55.6^{b} ± 2.6	37.4^{c} ± 2.2	<0.0001
Days in lay	98.7^{c} ± 7.2	154.6^{b} ± 3.2	171.2^{a} ± 5.4	<0.0001
Days until last egg	201.2 ± 7.1	210.2 ± 3.0	208.7 ± 5.6	0.45
Eggs produced per female	40.0^{c}± 3.6	63.4^{b} ± 2.0	88.2^{a} ± 3.1	<0.0001
Egg laying frequency (eggs/day)	0.41^{b} ± 0.04	0.46^{b} ± 0.02	0.55^{a} ± 0.03	<0.01
Average egg weight (g)	1406.3 ± 22.3	1400.6 ± 8.4	1390.8 ± 13.6	0.81
DIS (%)	5.9^{b} ± 1.0	12.4^{a}± 1.0	17.9^{a} ± 3.1	<0.002
Infertile (%)	16.3^{b} ± 4.3	11.8^{b} ± 1.6	23.4^{a} ± 5.7	<0.03
Hatchability (%)	77.7^{a} ± 4.2	75.8^{a} ± 1.8	58.7^{b} ± 4.6	<0.001
Chicks hatched per female (n)	31.2^{c} ± 2.8	48.1^{b} ± 1.5	51.8^{a} ± 1.8	<0.003
Chick weight (g)	810.3 ± 7.9	842.0 ± 3.5	819.0 ± 3.6	0.056

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

Table 7.4 *Ostrich egg characteristics according to the age of the female ostrich*

	Female age			P
Parameters	2	3 to 7	8+	
Egg weight (g)	1405.1 ± 27.4	1429.0 ± 11.3	1421.1 ± 45.1	0.84
Yolk weight (g)	286.5^b ± 10.8	323.9^a ± 3.3	347.6^a ± 13.3	0.001
Albumin weight (g)	824.1± 23.9	805.9 ± 8.9	776.9 ± 38.2	0.56
Shell weight (g)	284.5 ± 6.9	290.6 ± 2.1	288.6 ± 6.2	0.72
Yolk: albumin ratio	2.9^a ± 0.1	2.5^b ± 0.04	2.3^b ± 0.2	0.002

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

In this trial the ostriches above eight years of age took the shortest time to produce their first egg (37.4 ± 2.2 days), had the most days in lay (171.2 ± 5.4 days) and produced the greatest number of eggs (88.2 ± 3.1 eggs/female). Although this age group of females had the highest occurrence of DIS eggs (17.9 ± 3.1 %) and infertility rate (23.4 ± 5.7 %), they still produced the greatest number of ostrich chicks (51.8 ± 1.8 chicks per female respectively) during the breeding season. The egg laying frequency was also affected by the age of the female breeding ostriches (P = 0.01). An average egg laying frequency of 0.46 ± 0.02 eggs per day was noted for all the females with no significant effect (P = 0.5) of female age on the specific parameter seen. This ratio is affected by the quantity of eggs laid as well as the total days in lay of breeding ostriches. Female breeding ostriches, eight years and older, had the highest frequency (0.55 ± 0.03), while the young female breeding ostriches (2years) had the lowest frequency (0.41 ± 0.04).

Comparing the egg characteristics produced by female breeding ostriches from different ages, results indicated that the age of the female had no significant effect on the average egg weight produced per female (1426.8 ± 10.4 g), albumin weight (805.1 ± 8.3 g) or shell weight of the egg (290.1 ± 2.0 g). Significant differences were however detected in the quantity of egg yolk produced (P = 0.001) between the two year old females and the older ostriches (three years and older). This also affecting the yolk: albumin ratio (P = 0.002). The young females (two years old) produced the smallest yolk weight (286.5 ± 10.8 g) and resulted in the largest Y: A ratio (2.9 ± 0.1) when compared to the yolk weight and Y: A ratio of the ostrich females between the ages of three and eight (323.9 ± 3.3 g; 2.5 ± 0.04) as well as the older female breeders (347.6 ± 13.3 g; 2.3 ± 0.2) respectively.

7.4. DISCUSSION

The breeding ostriches used in this trial showed normal egg production patterns during the breeding seasons between 2004 and 2009 (Bunter & Cloete, 2004*)*.

Results from this study indicated that the age of the female breeding ostrich had a significant effect (P > 0.05) on most of the production parameters tested (days until first egg, days in lay, eggs produced per female, egg laying frequency, %DIS, %infertile, and hatchability). Results indicated that the two and three year old female breeding ostriches took the longest to produce their first egg (Figure 7.2).

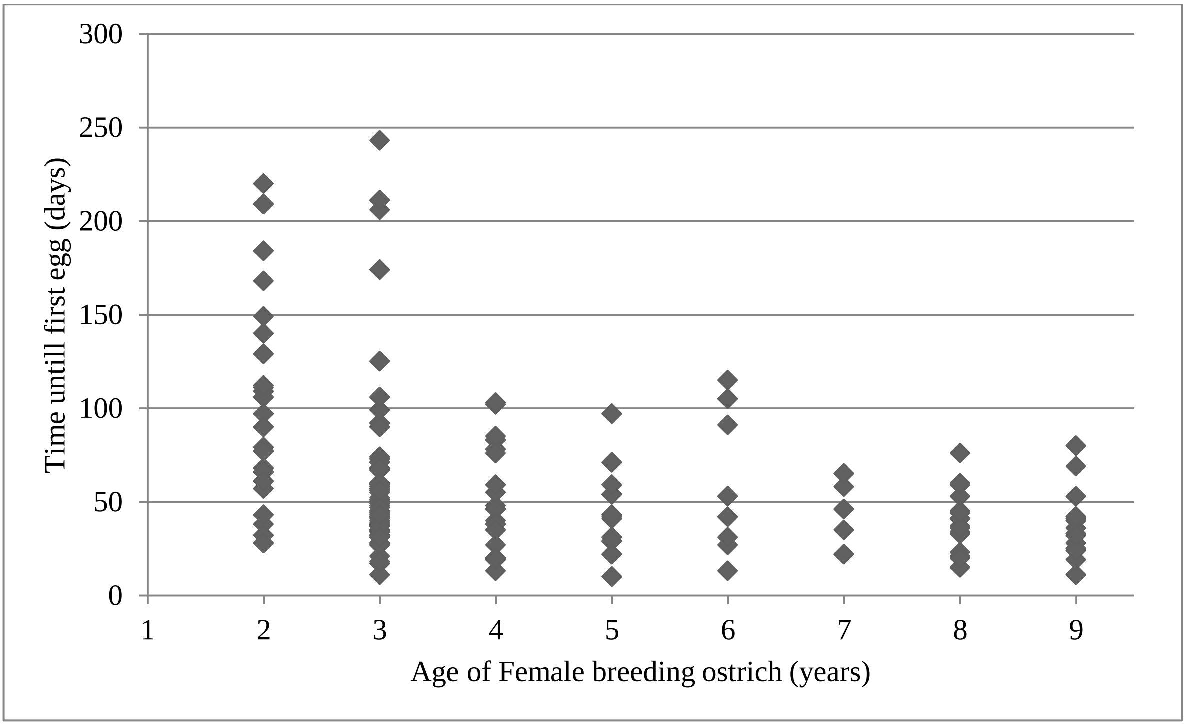


Figure 7.2 *Effect of female breeding ostrich age on the total days until the first egg is produced*

An increase in the hormone LH, which is responsible for egg production and the growth of the ovaries, already occurs a month prior to egg production of breeding female ostriches. Literature revealed that the ovaries of young female ostriches (two and three years of age) might require a longer growth period to be able to cope with the reproductive demand (Ipek & Sahan, 2004).

The six-week pattern described by Jarvis *et al*. (1985) could not be seen in the breeding ostriches used in this trial. The pattern described by Shanawany (1999), having a strict every second day egg laying pattern and taking a break of seven to ten days after producing 20 to 24 eggs, corresponds to an egg laying frequency of between 0.41 and 0.44 eggs/day/female. Statistical analysis of the egg laying frequency of the breeding ostriches indicated that 52.8% of the flock produced more than 0.41 eggs/day.

This study supports information of Shanawany (1999) that breeding ostriches show an strict every second day egg laying pattern.

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Chapter 8

8.1. SUMMARY AND GENERAL CONCLUSIONS

To development a mathematical optimization model for breeding ostriches, all factors that affect feed intake need to be determined and investigated. Literature indicated that the specific nutritional requirements of breeding ostriches, particularly pertaining to the requirements for optimal reproduction, are not well known (Brand *et al*., 2002a; Miao *et al*, 2003; Ipek & Sahan, 2004). Therefore, these five experimental chapters examined and determined the effect of various levels of different nutrients on the production and reproduction parameters of breeding ostriches.

In the first study (Chapter 3), the effect of certain nutrients on feed intake and production of breeding ostriches was evaluated. No major deficiencies of minerals, vitamins, fatty acids and amino acids in standard breeding ostrich diets could be identified using feed intake as an indicator. Evidence was found that breeding ostriches might ingest feed to satisfy mineral requirements while the provision of unsaturated fatty acids could depres the uptake of certain trace elements. The provision of additional calcium in the feed of breeding ostriches did not affect the percentage DIS or the shell break strength of the ostrich eggs. It was then believed that the supply of additional vitamins and minerals during the resting period might have had an effect on the results.

Therefore, the next study (Chapter 4) was done to determine the effect of the addition of minerals and vitamins during the resting and breeding period on the production of breeding ostriches. The inclusion of a vitamin and mineral premix in the resting period had no effect on the average eggs per female, percentage infertile eggs or live weight change for either the males or female breeding ostriches. The supply of vitamins and minerals during the resting period did however decrease percentage DIS eggs but increased feed intake during the breeding season. During the breeding season, the presence of a vitamin and mineral premix in the feed had no significant effect on eggs produced per female, percentage infertile eggs, percentage DIS eggs or feed intake. The absence of a vitamin and mineral premix in the breeding period caused a decrease in chick production of 5.7%, but also decreased the culling percentage of day-old ostrich chicks, due to weight, with 4.5%. It can be concluded that the presence of a vitamin and mineral premix is essential in resting as well as the breeding period.

Producers try to cut production costs by searching for alternative feed sources or giving lower quality feed to breeding ostriches. Therefore, the use of cottonseed oilcake (CSOC), to replace soya oilcake (SOC), as protein source was investigated for its possible use in Chapter 5. The replacement of SOC meal with CSOC meal as the protein source in breeding ostrich diets had no effect on the average number of eggs produced per female, infertile eggs or DIS eggs produced. The use of CSOC meal in diets of breeding birds led to an 18.9% decrease in chick production. Results from this study are ambiguous in that diet had no effect on the birds' weight loss nor on the specific egg quality parameters, yet there was a significant decrease in chick quality and quantity. Therefore, until more research results are available, it is suggested that producers follow the precautionary approach and not use CSOC to feed breeding ostriches.

The supply of sub- optimal feeds to breeding ostriches is another way producers try to cut production costs. Research has shown, however, that the feeding low or high energy feeds to breeding ostriches can be detrimental to their reproduction. The objectives of Chapter 6 were thus to determine the possible immediate as well as long term effects of feeding breeding ostriches low or high levels of their dietary energy requirements. The trial took place over two consecutive breeding seasons with the same breeding ostriches. Unfortunately no carry-over effect was seen due to the five diets supplied (120%, 110%, 100%, 90% and 80% of the basic energy requirements of breeding ostriches). Yet again breeding ostriches showed no indication of regulating their feed intake. Literature did reveal that the bulk density of the feed might be responsible for the lack of results. Possible future studies can include the effect of low and high level of basal energy supplied over three or more consecutive breeding seasons.

The development of an egg production model for broiler breeder hens by Gous & Nonis (2010) has open the door for the development of such a model for breeding ostriches. Egg production is a costly process resulting in female breeding ostriches to lose body condition. Objectives of Chapter 7 were to determine the factors that affect egg production. The data used for this study consisted of the day to day egg laying pattern of breeding ostriches during the breeding seasons from 2004 until 2009 from the Oudtshoorn Research Farm breeding flock. Results showed a strong relationship between the ages of the female ostrich, the days until first egg and the total days in lay. Literature revealed that the young female ostrich's ovaries might require more time to grow before egg production can commence (Ipek & Sahan, 2004).

Evidence was found that breeding ostriches do show a strict every second day egg laying pattern with a possible resting period between seven and ten days after twenty to twenty-four eggs are produced. Unfortunately, a specific egg laying pattern or cycle over the breeding season could not be identified due to the egg production of female breeding ostriches being highly variable, and a vast number of factors influencing the production of ostrich eggs. This was also noted as the reason by Bunter *et al*. (2001) and Olivier (2010) respectively.

Recommendations for future research include testing the mathematical optimization model with the new information incorporated. Due to a lack of results for the "carry-over" effect in Chapter 6, research needs to determine the long term effect of sub-optimal feeds, supplied over three or more consecutive breeding seasons on production of breeding ostriches. Furthermore, the use of other protein sources should still be researched to identify replacements for SOC without negatively affecting production and reproduction parameters.

It has also been noted that the average feed intake of the breeding ostriches, in the separate experimental trials, has been much lower than the level of 3.7kg feed/bird/day as reported by Olivier (2010). This might be due to the breeding ostriches also consuming a minimum of natural vegetation found in the breeding camps.

This thesis makes a significant contribution towards quantifying the factors affecting production and quality parameters in breeding ostriches. Most of the results obtained in these studies will be incorporated in to the mathematical optimization model by Gous and Brand (2008) for more accurate predictions concerning feed intake and other production parameters.

When complete, the mathematical optimization model for breeding ostriches will ensure that the production and reproduction of breeding ostriches will increase, delivering a high quality product (day-old chick) with a positive profitable margin. If the model is correctly implemented, it may lead to more efficient reproduction and growth numbers, something the ostrich industry needs to thrive.

8.2. REFERENCE

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