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Reducing Mortality Rates in Ostrich Chicks

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Foreword

Successful ostrich farming is largely dependent on the ability of farmers to rear sufficient numbers of viable and healthy chicks. However, high mortality of ostrich chicks particularly during the first few months of life is a problem.

This project involved a review that examined factors both prior to hatch and after hatch that could lead to high mortality in chicks. Appropriate breeder management, fertile egg handling and storage and incubation can improve hatchability and survival rates of chicks. Ostrich chick mortality can also be reduced by correct housing, feeding and health management of chicks at hatch and during the brooding period.

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Peter O'Brien
Managing Director
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What the report is about
This project involved a review that examined factors both prior to hatch and after hatch that could lead to high mortality in chicks. Appropriate breeder management, fertile egg handling and storage and incubation can improve hatchability and survival rates of chicks. Likewise ostrich chick mortality can be reduced by correct housing, feeding and health management of chicks at hatch and during the brooding period. Low mortality (10-15%) can be achieved by good hygiene, proper feeding and housing and good management.

Who is the report targeted at?
This report is targeted at Australian and overseas ostrich farmers.

Background
High chick mortality in commercial ostrich farming is a problem around the world. In South Africa, chick mortality up to 3 months of age is reported to be 50% (Smith et al., 1995). In Queensland, More (1996) reported that average mortality for chicks at 4 months was 37%. In Israel, mortality rates range from 15-50%. Increasing chick survivability will increase profitability for ostrich farmers and will make the ostrich industry more competitive. Chicks are especially vulnerable during the first few weeks after hatching and frequently succumb to disease, various disorders and stress (Huchzermeyer, 1994; Samson, 1997). Stressors are not only a direct cause of mortality but can also make chicks susceptible to disease and infection (Jensen et al., 1992). Other factors affecting survivability include: 1) starvation; 2) leg problems; 3) navel infection and; and 4) yolk sac infections.

Aims/objectives
This review was undertaken to examine the effect of management issues on chick mortality. Issues examined included: Floor materials (eg. concrete floors with rub mats, native grass or lucerne pasture and earth floor), litter materials (eg. chopped straw, lucerne hay, dry hay and sheep manure covered with wire grids), housing/sheds (eg. traditional, mobile shed and eco-sheds), heating (eg. temperature and methods and sources of heating), stocking rate, probiotics and enzymes, preventative health measures (eg. clostridial, avian influenza and avian pox vaccination), feeding fibre (eg. sources of fibre and chopped length of fibre), egg collection time (eg. collection methods), egg cleaning (eg. cleaning methods), egg pre-storage (eg. storage period, temperature and relative humidity), incubation and hatching conditions (eg. temperature, carbon dioxide levels, relative humidity levels, oxygen level and ventilation).

Methods used
Extensive literature searching of materials on the internet and through literary data bases was used to track past and current research on the effect of management on chick mortality. Consultation was made with various ostrich farmers in Australia.

Results/key findings
Through this literature review, the following issues should be addressed by industry to reduce ostrich chick mortality. These include: 1) collecting eggs soon after lay and keeping them under proper storage conditions; 2) proper set up of incubator and hatch parameters and keeping both areas clean; 3) elimination of cold stress and hence susceptibility to infection and disease; 4) keeping the brooding area clean with proper bedding, not over stocked, optimum heating and exercise; 5) recommended nutrition and feeding systems; 6) condition chicks to human presence and handling; 7) gentle restraint, handling and transport of ostrich chicks; 8) good biosecurity and hygiene and recommended vaccination to minimise bird infection.

Implications for relevant stakeholders for:
Ostrich farmers should be beware of the factors associated the chick mortality on their own farm and improve the management and rearing conditions accordingly, which will improve the chick health and welfare and hence improve the profitability. Total chick costs in Australia have been reported to be $239/chick. Average mortality at 4 months was 37.1% for 394 chicks on 11 farms in Queensland (More, 1996). Using appropriate management strategies could reduce the mortality and make savings of $50/chick. This equates to a saving of $1.125m/year for the ostrich industry based on 22,500 ostriches predicted to be slaughtered in Australia in 2008.

Recommendations
The ostrich industry should adopt the following protocols to minimise ostrich chick mortality:

- Collect and store fertile eggs appropriately,
- Ensure incubator and hatching are operating as per instructions,
- Establish best practice methods for brooding, rearing, management and feeding,
- Maintain biosecurity, and
- Condition chicks to handling.

Introduction

Proper farm management and adequate feeding of younger ostrich chicks are key factors determining the profit of ostrich farming and the competitiveness of the industry in the international market. Successful ostrich farming is largely dependent on the ability of farmers to rear sufficient numbers of viable and healthy chicks. High mortality of ostrich chicks particularly during the first few months of life is well documented around the world (Adams and Revell, 1998; Lopes et al., 2005; Iji per.comm.; More, 1996; Peters et al., 2005). In South Africa, chick mortality is reported to be 50% up to 3 months of age (Smith et al., 1995). In Australia, More (1996) reported that average mortality for chicks at 4 months was 37%. In Israel, mortality rates range from 15-50%. In Europe, mortality up to 4 weeks of age is still over 50% (Adams and Revell, 1998). The reason for this may be because of inadequate knowledge of the feeding and management of younger ostrich chicks. Ayo and Minka (1994 cited by Peters et al., 2005) reported factors which caused the death of chicks in a Nigerian ostrich farm were lower limb deformities which affected 36.7% of the chicks hatched.

Inappropriate feeding due to lack of knowledge of chick nutrition and digestive physiology resulted in death of chicks due to solid masses such as lucerne hay and maize found in the proventriculus and gizzard (Sato et al., 1994). Bodyweight of ostriches increases 11-fold from 3 days to 72 days of age. Compared with bodyweight, the relative weight of the proventriculus/gizzard, caeca and colon increases significantly with age. The relative weight of the small intestine is highest at 41 days of age (Iji et al., 2003). Shorter villi at the duodenum was found in ostrich digestive tract from day 3 to 72 days of age. This may indicate that the total activity of membrane-bound enzymes is low at these ages. Iji et al. (2001) reported that the total activity of those enzymes in broiler chickens increases with age as the villi grow longer. However, trypsin was not detected in the newly hatched ostrich but the enzyme was active from 27 days of age. The activity of amylase was also low and relatively unchanged from hatch to 72 days of age (Iji et al., 2003). In ostriches, enzyme and acid secretion is restricted to an area of only 25% of the total inner surface area of the proventriculus. This is in contrast to other birds in which the entire surface of the proventriculus secretes digestive enzymes (Cooper and Mahroze, 2004). This may indicate that the enzyme activities are low for ostriches, particularly at young ages and may be a factor contributing to chick mortality.

Ostriches are born without gut bacteria, but after 10 days some of the microbes appear (Mead, 2000). Clearly fermentation ability at very early ages in ostriches is poor but gradually develops after gut bacteria are present. Gas production from the hind gut is rapid at 55 days and increases with age (P. A. Iji and T. S. Boomker, per. comm. University of New England, Australia), indicating that fermentation is very active at this age. There were also higher activities of microbial protease, β-D-glucosidase and β-D-galactosidase in the caeca and colon than in the ileum. Lopes et al. (2005) reported that bacteria from a healthy ostrich gut could prevent pathogenic bacteria infection, reduce chick mortality, improve absorption of yolk sac and increase the profit. Feeding live insects and adult dung could improve the protein and fibre utilization. Milton et al. (1993) fed termites (*Microhodotermes viator*) to ostrich chicks aged 3-9 weeks as protein source. The benefits of coprophagy have been described as adding useful gut microflora to help chick digestion (Cooper, 2000).

This report reviews issues that occur during the breeding and incubation stage that may result in high mortality of chicks at hatch. In addition, hatching, rearing and feeding, handling, transport and health of ostrich chicks that impact on chick mortality are reviewed. In general, good hygiene, proper housing and feeding are factors that reduce chick mortality.

Literature Review: Management strategies to reduce ostrich chick mortality

Introduction

Since the mid-1980s, there has been worldwide interest in the farming of ostriches for feathers, meat, skin and oil. Concerns about the high levels of ostrich chick mortality have largely been a result of the move toward intensive and semi intensive conditions which are not typical of their native habitat (Uhart *et al*. 2006). Two main factors affect the production of ratites; one is poor hatchability and the other is low chick survival rate (Navarro *et al.* 1998; Navarro and Martella 2002). The major causes of ostrich chick mortality up to 3 months of age are the paresis syndrome and limb deformities (Ashash *et al*. 1996). In assessing ostrich chick mortality it is important to examine the key factors that may impinge on mortality particularly those that relate to impact of breeder background, hatchery management, brooding, rearing and transport. Appropriate management of breeders, good egg hygiene, incubation, hatching, and best practice brooding, handling and transport of chicks will result in reduced mortality. For example, in Israel, one farm achieved 10-15% mortality of ostriches up to 3 months of age under a semi-extensive rearing system. Chicks were reared on lucerne and concentrate during the day and kept in heated shelters at night (Verwoerd *et al.* 1999).

Breeders

It is important females select their own partner which apparently contributes to superior egg production, fertility and hatchability leading to healthier chicks. This can be done by careful observation of birds in a large communal pen to detect whether the hen shows a preference for a male and then pair them in a breeding pen (Adams and Revell 1998; Essa and Cloete 2004). Adams and Revell (1998) recommended that young breeders are best kept in pairs for good productivity, while in trios for 5-6 years of age.

It is vital that owners keep a wide range of records, which should be kept, including percentage of fertile eggs, percentage hatchability, percentage of chicks surviving to 12 months and individual bird pedigrees for selecting good breeders (Glatz 2000*a*; 2000*b*). An aggressive bird should be culled according to temperament because they spend time fighting other males at the expense of mating frequency. Aggression can be inherited and progeny will generally be more flighty and due to interactions between birds have poorer skin grades and higher mortality during the chick stage.

Hens without supplementary calcium are likely to be in negative calcium balance during periods of egg production, leading to poor egg quality and greater chance for death of chicks at hatch. Free access to a calcium supplement such as coarse shell grit in a separate feed container is suggested for all laying hens. Shell grit also aids in this process and provides calcium to the birds (Glatz 2000*a*). A high energy and protein diet for ostrich breeders could cause a high percentage of infertile eggs (Brand *et al.* 2000). Smith *et al.* (1995) reported that breeding birds fed *ad libitum* laid 24.5% infertile eggs, while 11.5% infertile eggs was found when feeding birds with 2 kg (dry matter basis) of a breeder diet. Deficiency of vitamins (vitamin A and E) and minerals (Se) had been linked to infertility (Hastings 1991; Hicks 1993). Vitamin A and D is important for egg production, hatchability and fertility and vitamin E and K for hatchability (http://www.blue-mountain.net/articles/p47.htm). Junqueira *et al.* (2007) reported that additional lipids (such as sunflower seeds) provided to breeders one month before beginning of laying period tended to increase the numbers of eggs, improve fertility and hatchability.

Hatching

Low hatchability of ostriches is well known and many chicks that do hatch subsequently die. The factors that affect hatchability including egg hygiene, egg storage conditions and period, incubation temperature, humidity, egg orientation, egg turning, ventilation and sanitation. Incubation temperature for ratites ranges from 35.9-36.5ºC (Wilson 2003). Estimated relative humidity requirements are 15-20% during incubation and 40% during hatching. Optimal turning frequency has not been determined for ostrich fertile eggs. However, better results can be achieved by turning the eggs once per hour automatically. Eggs set with large end (air cell) up and turned around the small axis gives good results (Wilson 2003). Levels of oxygen and carbon dioxide that need to be maintained in the incubator for ostrich eggs are 21% and 0.05-0.10% respectively. Egg weight loss during incubation is important if high hatchability is to be achieved. An egg weight loss of 12-17% during the 38 days of incubation is recommended for ostrich eggs. The major factors contributed to egg weight loss are shell porosity and relative humidity. Other factors include egg size and incubation temperature (Wilson 2003). Hygiene of egg, incubator and hatchery plays an important role in achieving high hatchability. When the chicks are not hatched in optimum conditions or exposed to stress conditions during incubation, high chick mortality can result.

It is well documented that the hatchability of ostrich eggs is low and varied, ranging from 3.3% to 80% (Deeming and Ar 1999). Low hatchability could be caused by poor control of incubation parameters (temperature, humidity, air circulation, egg position and turning), improper egg handling (egg collection, egg washing methods, improper egg storage) and egg quality (egg size, nutrients in eggs, shell thickness and porosity) (Philbery *et al.* 1991; Wilson *et al.* 1997; Cooper 2001). There are also reports that the nutritional status of female ostriches (Angel 1993), and microbial contamination of the eggs (Deeming 1996*a*) affect the hatchability and subsequent survival rate of chicks. However, oedemas and malposition are key factors causing embryo mortality (Deeming 1997), particularly when the head of the embryo is positioned at the end of the egg away from the air space (Deeming and Ar 1999). More evidence was reported by Ley *et al.* (1986), who found death in embryos was caused by severe oedema (45%) alone and in combination with malpositioning (55%). A similar result was reported by Brown *et al.* (1996). Malpositioning resulted in 55% of embryo death during the last 10-14d of incubation. Other factors which impact on hatchability and liveabilty of hatched chicks include nutrition of breeders and breeding season (Ipek and Sahan 2004; Cooper 2001).

Egg quality: Ostrich egg weight ranges from 350g to over 2,200g. Jost (1993) (Cited by Cooper 2001) recommended that eggs weighing 1,300 to 1,700g give the best hatchability. Ideally, incubating eggs of similar weight in the same batch will yield good results as the incubation conditions are easier to maintain (Deeming and Ar 1999). Extremely large and small eggs have lower hatchability due insufficient weight loss during incubation (Deeming 1995; Gonzales *et al.* 1999; Sahan *et al.* 2003). The oversized eggs have a smaller proportion surface area for gas exchange and water vapour while undersized eggs may lose excessive water during incubation. Egg weight loss during the incubation was 8.8-19.7% (Jarvis *et al.* 1985), 13.2% (Swart *et al.* 1987) and 15.6% in nature (Burger and Bertram 1981). Weight loss of 13-15% during artificial incubation is recommended by Ar *et al.* (1996). Eggshell thickness also affects hatchability (Sahan *et al.* 2003). More chicks hatch from eggs with thinner shell (Satteneni and Satterlee 1994; Brown *et al.* 1996; Gonzales *et al.* 1999). Egg pore density of ostrich eggs is positively related to egg weight loss and hatchability (Satteneni and Satterlee 1994; Gonzales *et al.* 1999; Sahan *et al.* 2003). Eggshell thickness is not related to egg size, but medium sized eggs had significantly higher eggshell porosity (number of large pores per cm^2 of shell), higher egg weight loss and higher hatchability compared to small or large eggs (Gonzalez *et al.* 1999).

Eggs laid toward the end of the season or from hens fed diets deficient in Ca or P, or from hens with a defective oviduct function will have a lower hatchability. These eggs are more susceptible to infection (Shane and Minteer 1996). A high energy grain-based diet may result in mid-embryonic mortality such as oedematous chicks with subcutaneous haemorrhages (Stewart 1996). However, Brand *et al.* (2003*a*) showed that different energy levels (7.5, 8.5 and 9.5MJ/kg) combined with different protein levels (105, 120 and 135g/kg) and relevant amino acids had little or no influence on ostrich egg composition.

Breeding season also plays a role in hatchability. Ipek and Sahan (2004) compared egg hatchability between seasons and found that hatchability was 64.3% in the first season, increased in the subsequent years and reached 73.1% in the fifth year, but seasons did not influence weight loss of eggs and length of incubation (Table 1).

Table 1. Incubation variables in ostrich related to different ages (mean ±SEM) (Ipek and Sahan 2004)

Breeding season	1998	1999	2000	2001	2002	P
Weight loss of eggs	12.97±0.7	12.89±0.6	12.24±0.6	12.64±0.6	12.41±0.5	NS
Mean length of incubation	1025±23.6	1027±24.1	1028±22.0	1026±21.3	1028±22.8	NS
Chick weight at hatching	950.4^{c}±22.4	988.7^{b}±26.7	1031.2^{a}±28.8	1039.7^{a}±27.3	1035.5^{a}±26.4	**
Hatchability of fertile eggs	64.3^{c}±2.8	69.6^{b} ±1.6	70.2^{ab}±2.0	71.8^{a}±2.3	73.1^{a}±2.8	**
Hatchability of total eggs	37.5^{c}±1.1	43.2^{b} ±1.3	48.1^{a}±1.2	50.9^{a}±1.3	51.7^{a}±1.3	**
Fertility	58.3^{c}±2.0	62.2^{b} ±1.9	68.5^{a}±2.0	71.0^{a}±2.9	70.7^{a}±2.7	**
Malpositioned embryos	14.3^{a}±1.8	8.7^{b} ±1.3	8.1^{b} ±1.1	7.7^{b} ±0.9	7.3^{b} ±0.7	**
Deformed chicks	11.1^{a}±1.5	6.2^{b} ±0.9	4.0^{c} ±0.6	3.6^{c} ±0.4	3.3^{c} ±0.8	**
Assisted chicks during hatching	22.2^{a}±2.3	18.7^{b} ±1.8	12.0^{c} ±1.7	10.7^{c} ±1.8	10.0^{c} ±1.9	**

Time of egg collection: Eggs should be collected several times a day with the last collection at sundown. Copper (2001) recommended that eggs should collected 10-15 minutes after laying. Eggs left in the nest are frequently rolled, damaged or even eaten by adults and increases susceptibility to bacterial infection, particular when left overnight (Stewart 1996). Eggs collected in the evening resulted in lower mortality of chicks than collected next morning (van Schalkwyk 1998). Immersion sanitization of the egg shell does not improve hatchability of internally contaminated eggs. Large numbers of eggs should be placed in padded crates to minimize shaking during transport (Stewart 1996). Eggs should be handled with disposable gloves or a plastic bag (Shane and Minteer 1996) or sterile towel (Cooper 2001) to prevent possible contamination.

***Egg cleaning*:** Keeping eggs clean is an effective way to prevent contamination. Nests should be located away from feeding areas to reduce faecal contamination (Cooper 2001). Sand should place in the nests and regularly replaced to keep the nests clean and dry. A common practice is to remove adherent dirt on the egg with a dry cloth or sand paper when collected (Glatz 2000*a*). A dry egg should be lightly buffed with a soft-bristle brush only on specific areas to remove adherent dirt without destroying the cuticle. Eggs may be carefully rinsed, sprayed, or immersed in warm solutions, including sodium hypochlorite, chlorhexidine, quaternary ammonium compounds or phenolics. However, these methods may damage the cuticle and lower resistance to subsequent bacterial contamination (Stewart 1996). If the egg is wet or contaminated, the surface is dried with a blow drier and then buffed. The eggs can be air dried and placed in storage (Stewart 1996). In the domestic poultry industry, the egg surface is coated with a fine layer of commercial disinfectant solution containing either a quaternary ammonium or phenolic compound formulated to prevent contamination. Disinfectants are applied either by a hand spray, aerosol, or by fogging. Disinfectants should not produce any residue on the shell surface which may interfere with air exchange through pores during incubation (Glatz 2000*a*). Severely contaminated eggs can be washed by immersed in a 37.8°C phenolic or quaternary ammonium solution for 30-45 seconds, but the procedure may reduce hatchability by encouraging movement of micro-organisms from the surface into the interior of the egg. Eggs are rinsed in clean water and dried using a sterile towel (Shane and Minteer 1996). Cooper (2001) recommended that eggs can be safely cleaned by a dry cloth first and then lightly mist-sprayed with 5g/L of a Virkon solution. Van Schalkwyk *et al.* (1997) studied different disinfection methods on hatchability and found that the hatchability percentage was higher and late embryonic death was lower for the eggs disinfected by UV compared to eggs washed using a peroxigen powder compound and quaternary ammonium.

***Storage*:** There is no standard method to store ostrich eggs in terms of temperature, humidity and turning. Embryos start to develop at 29.4°C. Ostrich eggs held at or above this temperature results in an increase in early embryonic mortality after the second day of incubation. Cooper (2001) recommended that eggs can be stored for 7 days under UV lighting but no storage temperature and relative humidity (RH) were mentioned. Eggs maintained between 12.8°C and 18.3°C may be safely stored for 7d (Berry http://www.osuextra.com), but hatchability will be significantly reduced after 10d (Shane and Minteer 1996). Eggs stored up to 6d in different positions such as with air space at the top or bottom, or held with long axis horizontal did not affect egg embryonic mortality (van Schalkwyk 1998). However, Gonzalez *et al.* (1999) recommended that ostrich eggs can be stored for a minimum of 10d without reduction of hatchability under storage conditions used in the poultry industry (Table 2). A similar result was reported by Bertram (1979), who found that eggs can be safely stored up to 10d at 18ºC and 69% RH.

Table 2. Mean (±SE) egg weight loss and hatchability of ostrich eggs subjected to short *vs.* long periods of pre-incubation storage (Gonzalez *et al.* 1999)

Length of pre-incubation egg storage	Egg weight loss (%)	Hatchability (%)
Short (≤5 d)	13.0 ± 0.6	63.2 ± 7.9
Long (>5 d and ≤ 10d)	13.3 ± 0.7	74.3 ± 7.5

However, Nahm (2001) reported that eggs can be safely stored up to 19d at 15.5-15.6ºC without controlling the humidity level. Hassan *et al.* (2005) suggested that the most effective storage period was ≤15d (20°C and 65% RH) to maintain hatchability for ostrich eggs when eggs were incubated at 36.5-37.0°C and 25% RH for 38d. RH near 75% is recommended to prevent water loss from eggs during storage (Shane and Minteer 1996). In contrast, Foggin and Honywill (1992) recommended storage RH should be around 35% to prevent the development of over hydrated chicks. Eggs should be turned daily (Berry http://www.osuextra.com) or rotated 180º once daily (Deeming 1996*b*) during storage. Heating ostrich eggs at 36°C for 4h prior to setting them in the incubator significantly reduced embryonic deaths compared with eggs that were not preheated (Brand *et al.* 1997).

Incubation

The incubator and incubation room should be properly managed. The incubator should be cleaned and properly disinfected and tested at least 12 hours prior to use to allow adjustments to be made (Glatz 2000*a*). Proper maintenance of the incubation conditions including temperature, humidity, air circulation and correct positioning of eggs and adequate turning could improve the hatchability and subsequent health and welfare of the hatched chicks and reduce mortality. Cooper (2001) recommended that optimal incubation temperature is 36-36.5°C with a RH of 20-30%.

Incubation temperature**:** Eggs can be successfully incubated over the range 35.0-37.0°C (Deeming 1993). Ar *et al.* (1996) recommended the optimum incubation temperature is 36.4°C. Increasing incubation temperature from 36.0-37.2° will reduce hatchability from 73 to 44% (Stewart 1996). Similar results were found by Hassan *et al.* (2004), who reported that mortality was increased at 37.5°C compared to at 36.5°C. van Schalkwyk *et al.* (1999) also found lower hatchability (33.8%) at 37.3°C compared to 36°C (63.3%) and 36.5°C (60%). However, low incubation temperature also increases embryonic mortality and results in soft, weak chicks (Shane and Minteer 1996). The incubation period reduces by about 2d when the incubation temperature increased from 36.5 to 37.5°C (Hassan *et al.* 2004). However, Stewart (1996) noticed that increasing incubation temperature from 35.0 to 36.7°C decreases the incubation period by 3d. It is suggested that for every degree increase in incubation temperature there will be a reduction in the incubation period by 2.5 days (Jarvis *et al.* 1985; Deeming *et al.* 1993).

Incubation humidity**:** Ideally, the actual humidity level used to incubate ostrich eggs should be based on the average weight loss for all eggs produced from the flock (Shane and Minteer 1996). A weight loss of 13.4% to 39d of incubation was suggested by Deeming *et al.* (1993), similar to egg weight losses (13.2%) under natural hatching conditions (Swart *et al.* 1987). To achieve this egg weight loss, RH should be less than 30-35% during incubation (Cooper 2001). Philbey *et al.* (1991) reported that a 20-40% of RH during incubation improves the hatchability. Insufficient egg weight loss (Gonzalez *et al.* 1999) or the lowest weight losses (<7%) and highest weight losses (>17%) (Deeming and Ar 1999) will result in low hatchability. RH level used depends on selected temperature, egg quality and air circulation in the setter. For example, higher incubation temperatures require lower humidity. This is because higher temperatures increase the metabolic rate of the embryo and hence produces more metabolic water (Glatz 2000*a*). Ideally, eggs should be separated by size and shell quality and incubated under different conditions to compensate for variability. General, small or large eggs or with thick shells lose less weight than medium or thin-shelled eggs (Gonzalez *et al.* 1999) and hatchability was high for high eggshell porosity. However, Deeming and Ar (1999) reported that low or high eggshell conductance will result in insufficient or excessive egg weight loss respectively during incubation. Adjusting the humidity of the incubator according to the shell properties may be a useful technique to achieve sufficient egg weight loss for successful hatching (Rahn *et al.* 1981). Decreasing RH during incubation for eggs with low conductance shells could improve hatchability by 5% and increasing RH for eggs with high shell conductance could increase hatchability about 9% (Ar *et al.* 1996). Christensen *et al.* (1996) recommended that humidity of the incubator should be less than 25% to allow a 15% initial egg mass loss during the 45d incubation period. Clearly humidity levels in the incubator play a key role in hatchability and subsequent mortality of chicks.

Air circulation and ventilation**:** Circulation is the movement of air within the incubator. Cooper (2001) recommended air flow rate in the incubator of about 45L/h/egg. Ventilation is required to supply oxygen and reduce carbon dioxide level in the incubator. However, there is lack of information on ostrich incubation ventilation. Recommendations for commercial poultry incubation are above 20.5% of oxygen and below 0.5% of carbon dioxide. Hatchability was reduced by about 5% for each 1% decrease in oxygen (Shane and Minteer 1996). Above 0.5% CO_2 in the incubation air can increase embryonic deathsvf (Smith *et al.* 1995).

Position and turning of eggs**:** During incubation eggs should be positioned with the large end up, and if possible, at a 45º angle. Positioning the eggs on the side is also acceptable (Glatz 2000*a*). Shane and Minteer (1996) recommended to incubate ostrich eggs for 10days in a horizontal position then reposition the egg with the air cell upward for the rest of the incubation period. Eggs positioned with their long axis horizontal for 2-3 weeks in an incubator and then re-positioned with their long axis vertical for the rest of incubation has improved hatchability compared to the eggs either vertically or horizontally positioned throughout incubation period (Smith *et al.* 1995; van Schalkwyk 1998). However, vertical setting of ostrich eggs is common in commercial hatching to save incubator space. van Schalkwyk *et al.* (2000) recommended that vertical setting eggs and rotated through 90º around the short axis will produce acceptable hatchability.

Turning eggs during incubation improves hatchability by stimulating the growth of the embryo (Deeming 1993) and preventing the embryo attaching to the inner shell membrane and providing a uniform temperature (Hallam 1992). The eggs should be turned at least twice daily (8 to 10 times per day is better) until 39d when the eggs are transferred to the hatcher. Setting eggs in the horizontal position without turning will have lower hatchability (27%) (van Schalkwyk *et al.* 2000). Frequency of turning can be reduced if the turning angle is large. Manually turning of eggs through 180º twice a day is sufficient, but hatchability is lower compared to eggs turned hourly (van Schalkwyk *et al.* 2000). Hatchability was about 60% by manually turning eggs through 180º around the short axis and through 60º around the long axis twice a day and about 80% by automatically turning eggs through 60º around the long axis. Cooper (2001) reported that 85.7% of hatchability could be achieved by positioning eggs in a vertical position and turning eggs 8 times/day.

Hatching: Turning eggs will reduce hatchability during the last few days of development as the embryos rotate by themselves into position for hatching. Ar *et al.* (1996) reported that only 19% of fertile eggs needed assistance if egg weight loss was 13%, but 75% of hatching chicks needed assistance when the weight loss was 6%. Deeming and Ayres (1994) found that mortality of assisted chicks was 75% and the birds that survive birds had extremely poor growth. It is not recommended that the chick is assisted out of the shell unless the incubation period is over 42 days. If the chick is rushed, the navel may not have properly closed. An infected navel results in a dead chick (Berry http://www.osuextra.com). Sahan *et al.* (2003) suggested that the ostrich farmers should determine the characteristics of their eggs and match incubator conditions to these eggs to improve the hatchability.

Ostrich chick rearing

Ostrich chicks are susceptible to disease and infection, various disorders and stress during the first few weeks of their life (Jensen *et al.* 1992; Huchzermeyer 1994*a*; Deeming and Angel 1996; Samson 1997; Barri *et al.* 2005). These problems often result in high mortality, which is one of the major welfare problems in the ostrich industry. They require special attention during this period to ensure chick welfare is not compromised. Once the chicks reach three months of age, they are relatively hardy and only need protection from bad weather (Glatz 2000*a*). It is important to keeping young ostriches warm, raise them in stress free environments and give them sufficient space for exercise. Allowing them to go outside as soon as possible for exercise and sunshine are important for their growth and development.

Brooding systems

Ostrich chicks normally remain in the hatchery for a few hours or for 2 days until their navels close and are dry. The newly hatched chick navel may be swabbed with an iodine/Betadine solution to prevent bacterial infection. The brooding area should be clean, sanitary and provide a comfortable and secure environment.

Brooders can be a cardboard box with proper bedding (such as hay) and heating (such as a heat lamp) in one corner of a room. Small brooder boxes are recommended by Verwoerd *et al.* (1999) because chicks can be kept warm is a small isolated area. In South Africa and Australia, a common practice is to keep 20-30 newly hatched ostrich chicks enclosed in small area inside a building, which can be fenced by a circle of plastic crates or hardboard or a raised welded metal mesh (Verwoerd *et al.* 1999). The floor of the brooder area should be covered with slip proof material to avoid leg damage. Overhead heat is recommended in the brooder area due to floor heating causing more leg problems. In the USA, heat pads or similar materials are used in brooder area to keep chicks warm (Verwoerd *et al.* 1999). However, there should be enough space to allow ostrich chicks to move away from heat source in case chicks overheat. Temperature recommended for ostrich chicks in a brooder box varies because the rearing environmental conditions are differ. Deeming *et al.* (1996) recommended 32ºC, but 26.5-32ºC was recommended by Jensen *et al.* (1992) and 24ºC by Kocan and Crawford (1994).

Chicks should be encouraged to exercise in outside pen runs as soon as possible (if weather permits) to strengthen their muscles. Ostrich chick activities should be monitored to prevent impactions since they will eat almost anything when they are grazing outside. The chicks should initially only be allowed outside for short periods and then gradually increase the time. Early exercise is required to prevent ostrich chicks suffering from leg problems.

Rearing systems

Ostrich chick rearing systems include all-in all-out systems or mixed age groups kept in the same large enclosure. All-in all-out system keeps similar age chicks in the one facility up to 12 weeks of age (Deeming *et al.* 1996; Verwoerd *et al.* 1999). This system could control the rearing environment better, improve biosecurity and prevent disease (Verwoerd *et al.* 1999). There is considerable debate in both Australia and overseas on which rearing system produces the lowest mortality.

Intensive rearing: In Australia, chicks are kept indoors during the first 3-7d with a rearing temperature of 26-32ºC (Jensen *et al.* 1992). The chicks are moved out onto pastures during the day. Under this system, chicks can be kept in the rearing house until 3-4 weeks of age (Glatz 2000*a*). In Israel, 30-50 chicks are kept in a 3 x 3m enclosure and 3 x 10m exercise area for 4 weeks. Then birds are moved to large areas (25 x 25m) with heated (22ºC) shelters (Verwoerd *et al.* 1999). Outdoor enclosures can be made of timber or steel posts sheets with 75% shade cloth about 1.0-1.2m high is sufficient to keep ostrich chicks up to 12 weeks of age (Tuckwell 1997).

Semi-intensive: In this system, 25-50 day old ostrich chicks are raised on pasture (usually lucerne) with 45cm high fences until about 6 weeks. A concentrate diet is provided. Chicks are kept in a shelter with heating during the night. Movable shelters are common which enable birds to have access to fresh pasture. Birds (about 6 weeks of age) will be moved to large enclosure which can hold 150 birds and fed on chopped lucerne and concentrate (Verwoerd *et al.* 1999).

Foster parent rearing: Foster parent rearing is a common practice in South Africa (de Kock 1996). Ostrich chicks can be reared extensively with foster parents up to 25 chicks younger than 14 days of age per adult female (Verwoerd *et al.* 1999; Earle 1994). Chicks also can be reared semi extensively with foster parents (about 100 chicks per adult pair) with housing at night only. Using foster parents encourages chicks to exercise (Glatz 2000*a*). Regions with sudden changes in weather are not suitable for this rearing system as adult birds can only shelter 10-15 chicks (Verwoerd *et al.* 1999). A pair of adults can be fostered around 30-35 chicks in colder months while 60 chicks can be fostered in warmer months (de Kock 1996). Foster rearing may be impossible if there is lack of breeding stock (Verwoerd *et al.* 1999). It is important for foster parents to have good fostering behaviour skills and accept the new chicks, otherwise the young birds could be killed or injured by being trampled, kicked or from being thrown (de Kock 1996).

Housing

Brooders and shelters protect ostrich chicks from predators (dogs, foxes, etc.) and bad weather. The facilities should have good ventilation and be easy to clean. In South Africa and Australia, shelters are constructed from a variety of materials, including modified shipping containers, wooden shacks, modified corrugated iron agricultural sheds and modified pig and poultry houses as well as custom-built buildings (Verwoerd *et al.* 1999).

Traditional sheds: Traditional sheds have a solid floor with an exercise run. The runs should be bedded with sand or light soil sown with lucerne or short hard wearing grasses (Tuckwell 1997). The shed can be divided into a few "runs". The disadvantages of this method include high labour, risk of pathogen build-up and high capital cost (Glatz 2000*a*).

Igloos: 30 chicks at 3-5 days of age can be kept in small portable igloos on a lucerne pasture paddock until 4-5 weeks of age. Chicks can forage on lucerne or grass inside the enclosure, which could be moved 2-3 times a day. Igloos are heated by gas lamps and covered by plastic blinds to control the temperature (Tuckwell 1997). Chicks are kept within a 30cm high cardboard ring under the heat lamp at night. Each night, clean straw bedding should be provided in the ring. A hessian cover can be used to cover the top of the cardboard ring to reduce heat loss in cold conditions. The cardboard ring is removed in the morning and the igloo is moved to a different location (Tuckwell 1997). High ammonia levels are a problem in the igloos and can contribute to chick death. In addition, provision of heating to outdoor igloos using gas needs to be carefully managed to avoid overheating, loss of gas supply and ammonia build up.

Transportable shed: The sheds can be built from various materials such as insulated "fridge panel" or plastic. The shed can be moved by wheels or by a skid system attached to the shed or by using a fork lift. Common pasture used is lucerne. Normally, the chicks are restricted inside the sheds overnight or during bad weather and then the sheds are moved to different locations each morning until 8 weeks of age (Glatz 2000*a*). A sterile carpet mat is placed on the sand floor of the shed. A gas heater can be used as heating source. Around 50-60 ostrich chicks (2-3 days of age) can be introduced into the shed (Tuckwell 1997). Similar problems of maintain in inadequate heating to birds has resulted in high mortality of ostrich chicks.

Flooring/Bedding

Proper flooring and bedding is important to reduce ostrich chick mortality. A cold or slippery floor could cause bird infections and leg injuries. The common types of floor in Australia are concrete, dirt, sand or deep litter floors (Glatz 2000*a*). In South Africa, floors are earth, sheep manure, rough concrete or concrete covered with rubber mats, or galvanized welded mesh raised 2-100cm above the floor. In Israel, the floor is concrete with dry hay bedding covered by mesh to stop hay ingestion and to separate the chicks from urine (Verwoerd *et al.* 1999). In UK, a rough concrete floor with an area electrically heated to 20°C is used (Deeming *et al.* 1996). In USA, heated floors were common, but it resulted in leg problems due to birds sitting down to keep warm. In Australia, a sterile carpet mat floor is used in removable sheds and hard surfaces are used in traditional sheds (Tuckwell 1997). Glatz (2000*a*) recommended that a rubber coated floor will prevent chicks eating foreign material (e.g. straw bedding) which can cause impaction.

Concrete floors: Concrete floors should have a non-slip surface, and are easy to clean and disinfected particularly in brooding units. However, chicks do not do well on concrete floors in Australia, although Mushi *et al.* (1998) reported that concrete floors have been used in Botswana for growing ostrich chicks up to 14 weeks of age.

Dirt floors: Dirt floors need to be replaced regularly by replacing the surface layer of soil with fresh earth. Dirt floors can be difficult to keep clean and can generate significant dust or mud (Glatz 2000*a*).

Sand floors: Relatively fine sand floors can be successful. However, the sand cannot be too fine due to the high dust levels generated as ostriches prefer to sit on sand when resting. Producers have noticed birds having sand baths especially at night. Sand should be replaced regularly (Glatz 2000*a*).

Deep litter: Litter materials that can be used are sawdust, chopped straw, pine shavings, washed builder's sand, hay or rice hulls. The litter should be covered by wire mesh for the first 7-10d to prevent ostrich chicks eating the litter and develop impaction. Litter should be changed frequently to remove urine and faecal output from ostriches (Glatz 2000*a*). Newspaper, cardboard, plastic, or other slippery flooring should not be used.

Litter management is essential to minimize chick mortality. If litter gets wet, ammonia concentrations increase and can contribute to hock burn and breast blisters. If the litter becomes dusty, it can reduce chick growth by depressing the immune system. Respiratory infections resulting from lung lesions increase when the air is contaminated. Litter moisture levels of 25-30% are recommended as it benefits the litter condition, manure handling, air quality and health and safety for farmers or workers. Sawdust can generate high dust levels and health problems. Spraying oil to reduce dust may be a solution. Less than 2.4mg/m^3 dust level is recommended. Similarly rice hulls have poor absorbency and straw is slow to break down and thus both are best mixed with wood shavings. It is important to ensure there are no risks of chemical contamination, including insecticides, rodenticides, agricultural chemical residues and mycotoxins as a result of fungal contamination and no risks of contamination by wild birds and rodents. The recommended depth for litter is a minimum of 50mm (Glatz 2000*a*).

Heating

Cold rearing conditions could result in poor yolk sac absorption or secondary infections of ostrich chicks since they are very sensitive to cold (Verwoerd *et al.* 1999). Chicks under 3 months of age will not perform well in a cold environment. The chicks normally require heat in the sheds overnight for the first 2-3 weeks (Glatz 2000*a*). Some authors recommend keeping chicks indoors for 3-4 weeks after hatching with suitable heat source (du Preez 1991; Jensen *et al.* 1992). Others suggest chicks be allowed outdoors when the weather is sunny and temperatures are not too cold (>15 to 20ºC) and kept indoors with heating at night or when there is bad weather during the day (Hicks-Allredge 1993). Ostrich chick behaviour can indicate whether they are too hot (wings extended and panting) or too cold (huddling near the heat source and not feeding) (Deeming *et al.* 1996).

When ostrich chicks are heat stressed for long periods normal development of the immune system is affected (as observed in other avian species) (Hicks-Allredge 1993) and results in poor appetite (Deeming *et al.* 1996), increased risk of dehydration (Verwoerd *et al.* 1999) and bacterial infections (Glatz 2000*a*).

Temperature: In a commercial farming environment, ostrich chicks are normally kept in the hatcher or brooder at a temperature about 32ºC for 1-2 days after hatching (Deeming *et al.* 1996). However, temperatures used for young ostrich chicks vary from 21-26.5ºC to 32-35ºC in the industry. Verwoerd *et al.* (1997) recommended that the youngest chicks should be raised under temperature starting around 30ºC with a drop of 0.5ºC each day until reach 26ºC (±1ºC). However, the maximum weight gain of ostrich chicks will be achieved in 10-22°C temperature range in the 4-5 week rearing period. In South Africa, the whole brooder room is heated by domestic oil heaters and temperature maintained above 30°C for 2-7 days (Verwoerd *et al.* 1999).

Heating sources: Heating sources can be infrared light, ceramic oil, gas lamp or electrical heaters in South Africa (Verwoerd *et al.* 1999). Gas lamps in igloo shelters are used on both South African and Australian farms (Tuckwell 1997). Heated floors were reported to cause chick leg problems. Success with focal gas heating in the sheds is also possible but automatic thermostat control of temperatures is crucial to prevent overheating (Glatz 2000*a*).

Heating methods: The South Africans prefer room heating rather than spot heating. Whole room heating has been tried in Australia with limited success probably because of density problems and lack of environmental control. Preference in Australia is given to placing chicks in a masonite circle and covering with hessian bags depending on the heating required. Sometimes chick areas have been preheated by using a heated blanket or to preheat the sand or the floor with no additional heating provided (Glatz 2000*a*). Chicks can be held in groups of 10-15 in solid rings and partially cover the rings with hessian bags. This utilises the heat generated by each chick to warm the others (Glatz 2000*a*). Best results are obtained when rearing houses are provided with overhead heating combined, with adequate air movement to eliminate drafts and ensure constant temperatures throughout the housing unit (Glatz 2000*a*).

Ventilation

Poor ventilation in enclosures results in high ammonia levels, which influences the health of chicks. Levels of 10-15ppm of ammonia in the air of the shed can be smelt while 25-36ppm of ammonia will cause eye and nasal irritation in humans (Glatz 2000*a*). The ventilation rates applying to poultry may be applicable for ostriches. Ventilation rates for poultry range from 1.0 to 9.7 m^3/hr/kg at normal temperatures or about 12.1 m^3/hr/kg in hot weather (>30°C) for adults. Equivalent rates for younger birds are 0.1 to 1.0m^3/hr/kg or 1.3m^3/hr/kg and for older birds 1.0 to 10.4 m^3/hr/kg or 13.0 m^3/hr/kg, respectively. Ventilation rates can be checked with hand held meters (Glatz 2000*a*). Vertical fans can be used to stop ammonia accumulation at chick level and extractor fans can be used to exchange air from this level (Verwoerd *et al.* 1999).

Feeding chicks

Absorption of the yolk sac provides nutrients for ostrich chicks for the first few days, but differences of opinion still remain on when feed should be provided to them. Generally, ostrich chicks lose weight in the first few days. For example, weight loss of ostrich chicks occur in the first 7 days due to utilization of egg yolk and then weight increases by about 1.3 kg/week up to 12 weeks (Mushi *et al.* 1998). Kocan and Crawford (1994) recommended that chicks can be kept without food and water for 6-8 d after hatching. However, Verwoerd *et al.* (1999) recommended that chicks should have access to feed and water from day one to help the development of the digestive tract. This is supported by Noy *et al.* (1996), who reported that feed consumption soon after hatch increases the rate of yolk utilization. Ostrich chicks will eat any soft food such as finely cut lucerne, lettuce, cabbage or other vegetables. Supplying a certain amount of green feed at short intervals will encourage ostrich chicks to forage. For example, chopped fresh lucerne fed with starter diets will stimulate intake of food (Glatz 2000*a*). Christensen and Nielsen (2004) also reported that leaving cabbage inside the pen, encouraged chicks to peck at the cabbage and reduces pecking at fixtures in the pen, reducing boredom and improving the welfare of chicks. After one week chicks can be allowed to graze on lucerne pasture during the day, ensuring the area is free of wire or sticks which can be ingested and penetrate the proventriculus, resulting in death.

There are a number of methods which can be used to stimulate chicks to commence eating: 1) place young chicks with older chicks; 2) foster parenting; 2) provide boiled infertile eggs; 3) stir the feed by hand at least eight times a day on day 2, 3 and 4; 4); use attractive colours (e.g. hammer milled corn); and 5) provide insects such as live crickets and mealworms. In general feed intake can be increased by making the feed more attractive, improving the palatability and stimulating feeding by frequent stirring of the feed or frequent operation of automatic feeders (Glatz 2000*a*).

Ostrich chicks should be fed *ad libitum* with a good quality and balanced feed ration for at least the first 4 months of age. Feed and water containers can be hung from the roof to prevent ostrich chicks falling over containers on the floor (Verwoerd *et al.* 1999). A plastic trough is better than a metal trough because the sharp edges of metal trough can cause injury (Musa *et al.* 2005) or death. At night chicks should be kept indoors with an infrared heat lamp during the colder weather. Some farmers provide water only during night in the shelters (Glatz 2000*a*). Rearing chicks in groups of similar weight can improve chick growth (Mushi *et al.* 1998). Rapid growth over 2-4 months of age results in leg deformation which eventually leads to the death of some ostrich chicks with mortality rates as high as 41.20% (Musa *et al.* 2005). High fibre diets and more exercise may be help to reduce the mortality.

Feeding fibre to ostrich chicks: Inappropriate feeding due to lack of knowledge of chick nutrition and digestive physiology resulted in death of chicks due to solid masses such as lucerne hay and maize found in the proventriculus and gizzard (Sato et al., 1994). Shorter villi at the duodenum was found in ostrich digestive tract from day 3 to 72 days of age. This may indicate that the total activity of membrane-bound enzymes is low at these ages. The activity of amylase was also low and relatively unchanged from hatch to 72 days of age (Iji et al., 2003). Low enzyme activities, particularly for younger ostriches, may be a factor contributing to their mortality. Lopes et al. (2005) reported that bacteria from a healthy ostrich gut could prevent pathogenic bacteria infection, reduce chick mortality, improve absorption of yolk sac and increase the profit. Feeding live insects and adult dung could improve the protein and fibre utilization. Milton et al. (1993) fed termites (*Microhodotermes viator*) to ostrich chicks aged 3-9 weeks as protein source. The benefits of coprophagy have been described as adding useful gut microflora to help chick digestion (Cooper, 2000).

There are conflicting reports in the literature on the utilization of fibre by young ostrich chicks. Angel (1996) reported that ostrich chicks can move and forage for feed within the first 48 h after hatching. However, ostriches are born without gut bacteria, but some of the microbes appear after 10 days born (Mead, 2000). Ostriches (body weight between 5-50 kg) can digest 66% and 38% of dietary hemicellulose and cellulose respectively (Swart et al., 1993a). This may be because the microflora of the caecum and large intestine are similar to that of the rumen when an ostrich is 3-6 weeks old (Janssens et al., 1996). In addition, fermentation occurs at the age of 55 days since gas production from the hind gut is rapid at this age (P. Iji, per. comm.). However, at age of 3 weeks, the digestibility of fibre is only 6.5% i (Angel, 1993). High fibre feed can result in intestinal obstruction in young chicks. *Ad libitum* exposure to lucerne from 7 days of age results in decreased growth and lower body weight at 28 days of age compared to birds on pelleted diets (Schiavone et al., 1999). The performance of ostrich chicks on low energy/high fibre diets was studied by Salih et al. (1998). They found that there was no significant difference in DM intake (817, 818 and 773 g/d respectively) of ostriches fed three experimental diets (high energy (14.5MJ/kg); medium energy (12.0MJ/kg) and low energy (9.5MJ/kg)). However, chicks on medium-energy diet had a higher average daily gain (392g/d) compared to the high-energy (368g/d) and low-energy diets (321g/day). There was no significant difference in feed conversion rate of birds consuming the high energy/low fibre diet (2.09kg DM/kg gain) and the medium energy/medium fibre diet (2.02kg DM/kg gain). Both were lower than the low energy/high fibre diet (2.42kg DM/kg gain). Farrell et al. (2000) compared cockerels (2kg) to ostriches (10-20kg) in fibre utilization. They found higher DM digestibility (84%) and AME (16.26MJ/kg DM) in ostriches for diets which included 20% of milled wheat straw than in cockerels (61%, 12.63MJ/kg DM) and concluded that ostrich have a much better capacity to digest fibre than adult cockerels for feedstuffs high in fibre. There is lack of information on effect of enzyme added in diets to improve health of younger ostriches. More research is needed for fibre feeding such as quantity of fibre and source of fibres, which can be included in the diets for young ostriches.

Preventing infection

Ostrich chicks normally lose 10% of their hatch weight by 5-7 days of age then they gain weight continually. If chicks continue to lose weight the fading chick syndrome can develop due to infections. Chicks born with poor health or are severely stressed will have abnormal cloacal bursas and thymuses. It is essential to give these birds individual attention and to remove any potential stressors from their environment. Once they develop clinical symptoms, they can seldom be saved (Glatz 2000*a*).

Naval infection can result in death of chicks. The navel should be checked to ensure it is closed before a chick leaves the hatcher at 7 days. A 7% iodine solution can be applied to novel to prevent infection. A second treatment may be necessary in 2 or 3 days. If a dried umbilical attachment is still present (looking like a large coarse hair) it should be pulled from the navel and the area treated with iodine. This procedure can reduce the risk of yolk sac infections (Berry http://www.osuextra.com).

Yolk sac infection is one of major factors causing early death of ostrich chicks. Most chicks die within 14-21 days after hatch (Deeming *et al.* 1996). Yolk sac infection is commonly attributed to poor hygiene during egg handling and incubation (Deeming 1997; Speer 1996) or navel infections after hatch (Huchzermeyer 1999). Other factors such as incorrect brooding temperature (too cold or too hot), cold concrete brooder floors, insufficient water intake and a delayed start to feeding can cause yolk-sac infection (Huchzermeyer 1999). A uniform environment and less stress rearing conditions can help yolk absorption (Verwoerd *et al.* 1999). Surgical removal of the infected yolk sac has been practiced (Kenny and Cambre 1992) or use can be made of a large needle and syringe to suck the contents of yolk sac followed by injection of a small amount of antibiotic solution into the yolk sac (Huchzermeyer 1999).

Toe trimming

Over 50% of ratite skin processed are being downgraded due to damage on farm, during transport, in the lairage and during processing (Glatz 2005*a*). Toe trimming is one way to minimize this damage (Glatz 2005*c*). The claws should be trimmed at day old by removing the distal phalangeal joint with a red hot blade using a Lyon beak trimming machine (Glatz 2005*b*). The big argument against toe trimming is the concern that birds will die soon after the process due to stress or will suffer chronic pain in the toe stump (Lunam and Glatz 2000). In addition when the bird is walking or running on wet ground or hilly ground it is difficult for the toe trimmed birds to maintain footing. If toe trimming is not done according to best practice chick mortality may occur. When toe-trimming is done correctly ostrich chick behaviour is modified and reduces the potential for skin damage in the first two weeks after hatching (Glatz 2003; Glatz 2007).

Stocking rate

Stocking densities used for young ostriches varies from 16 to 40m^2/bird (Verwoerd *et al*. 1999). Over stocking can cause death in chicks from suffocation. Optimum stocking levels have not been clearly defined as outlined below. The chick body weight is often used to calculate stocking density. Deeming *et al*. (1996) recommended a minimum floor space of 0.125 m^2/kg while Wade (1995) suggested 0.3-1.4m^2 in the brooding area with 18.5-37m^2/bird in the outdoor run. In Zimbabwe the space requirement suggested for day old chicks is 0.16m^2/chick increasing by 10% per week (Hallam 1992). In South Africa, young chicks are normally kept inside the shelter (2-3 chicks/m^2) in groups of 30-50 at night and allowed to run outside during the day according to the weather conditions. The outside run can be 2-3m by 10-15m in dimension for chicks from hatch up to 4-6 months of age (Verwoerd *et al*. 1999). In Israel, 50-60 chicks (<4 weeks old) are kept in a 3x3m enclosure. However best results are achieved at a lower density (30-50 birds) with an exercise area of 3 x 10m for every 50 birds. In USA, groups of 10 chicks or more are reared from hatch to 3 months of age in 8 x 40m pens (Verwoerd *et al*. 1999). Under good management and housing conditions it is recommended that chicks are housed in groups with a shed density of up to 3 chicks/m^2 and 5m^2/chick of outside run in the first 4-6 weeks. Birds in Australia tend to be kept in groups of about 50 birds/pen. Cornetto *et al*. (2003) determined the effect of stocking density (33.5, 16.8 and 11.2m^2/bird) on performance of birds (21-98 days of age). Density had a significant ($P<0.05$) effect on body weight, weight gain and feed consumption. Body weight (41.5 kg) was higher ($P<0.05$) for the low density group compared to the moderate (38.5 kg) and high density (34.7 kg) groups at 98 d of age. However density did not significantly affect the feed to gain ratio. It is crucial to ensure that there are sufficient feeders and drinkers and birds are not overstocked (Glatz 2000*a*).

Transport/handling

Young chicks can be restrained as a group in an enclosed area or shed to be caught individually. Young birds can be physically restrained by holding their legs together and up against the body (Hastings 1991). A young chick can be handled by sliding the hand between the legs from the back and lifting it under the abdomen, leaving the legs to dangle free (Sales and Smith 1995). Chicks should not be lifted by their head, neck or wings or held upside down. Staff working with the chicks should wear the same coloured clothes and boots. Chicks of the same size should be kept together to prevent bigger birds trampling or suffocating them (Glatz 2000*a*). Rough handling can cause death in chicks.

Up to 2 months of age, the chick can be picked up, while supporting the chest with one hand and placing the other hand on the back (Sales and Smith 1995). One person can guide juvenile birds (4-8 months of age) by grasping the tail with one hand and a wing with the other. It is important not to lift birds by their wings (Wotton and Hewitt 1999). One person can move the bird by pressing on the rump from behind, while the other person holds the neck and/or beak and directs the bird from the front (Sales and Smith 1995). Birds should be moved quietly and gently because once the birds become agitated, the whole procedure becomes stressful for both the birds and the stockperson (Wotton and Hewitt 1999). Hooding of the bird will calm them down (Earle 1994). In properly built yards, post-handling stress is dramatically reduced. When driving them from one area to another do not shout or run after birds. Move the birds slowly and used fenced off lanes for birds to walk along (Glatz 2000*a*).

Transport age: Ostriches should be transported in groups according to their age. There is evidence that translocating juvenile ostriches from concrete-paved to sand floored pens and mixing with other batches of ostriches causes stress and potential mortality to ostriches indicating by an increase in the heterophil:lymphocyte ratio (Kamau *et al.* 2002). Wotton and Hewitt (1999) recommended the following age groups be transported separately: day-old chicks and three month-old birds, three to six month old birds.

Distance: It is difficult to maintain airflow, shade and minimise the vibration when ostrich chicks are transported especially over long distances (500 km). A journey of 10-15h results in 'capture myopathy' (exertional rhabdomyolysis) due to long period of physical exertion (Crowther *et al.* 2003). Sufficient space to allow birds to sit is recommended for long journeys (Glatz 2000*a*). Air sprung trucks are recommended for use for long-distance transport of ostriches. Air sprung suspension smooths out the bumps and prevents sway, especially when going over rough roads (Glatz 2000*a*).

Space: Space allowances should be calculated according to the age. $0.1m^2$ /bird for month-olds to is recommended (Mitchell 1999). Transporting birds in a small group and providing sufficient space for birds to sit down could prevent injury and death. This may be because that setting are more calm with lower heart rates during transport (Crowther *et al.* 2003), find it easier to maintain their balance (Wotton and Hewitt 1999) and prevent birds trampling over each other (Glatz 2000*a*). The force acting in standing birds results in changes to the integrity of the muscle cell membrane, which increases the plasma activity of intracellular enzymes (Mitchell *et al.* 1996; Wotton and Hewitt 1999).

Crate/Vehicles: Proper transport facilities are important for ostrich welfare. Young chicks can be transported in sturdy cardboard boxes (2-3 birds/box depends on size of chicks) (Earle 1994).

Stress

Two types of stressors (irritant and intermittent) during transportation were categorised by Crowther *et al.* (2001). Irritant includes continuous noise, vibration, heat exposure, crowding and intermittent includes sudden flashes of light and noise from passing vehicles. Vibration and movement during transport can make birds loss their balance which can result in injury. Behavioural changes during transportation may be an indicator of stress. The physical stress signs include head bobbing, neck arching (Mitchell *et al.* 1996), blinking very slowly, neck-twisting and jumping (Payne 1993) fluffing out their wings, hyperventilating and keeping their beaks permanently open (Glatz 2000*a*). An increase in plasma glucose concentration is also noticed due to stress-induced mobilisation of glycogen reserves, associated with fatigue during the transportation (Wotton and Hewitt 1999). Stress caused by the changing environment can also cause abnormal eating behaviour such as over eating of any available material (sticks, plastic bags, wire and bedding) and lead to impaction (Foggin 1992).

Heat stress: Ostriches are very susceptible to heat stress which could cause dehydration (Adams and Revell 1998; Crowther *et al.* 2003). The source of heat is the radiation from the animals themselves and heat from outside such as hot days. Dehydration is indicated by the excretion of thick, white, concentrated urine after transportation (Yagil *et al.* 1996, Crowther *et al.* 2003). However, Wotton and Hewitt (1999) suggested that it may not be a correct indicator because similar white urine was found in hens which were not dehydrated (Levy *et al.* 1996). The behaviour of 'gular pumping' was noticed in heat stressed ostriches. This is a physical mechanism of lowering the tongue to increase the intermandibular air volume and therefore increasing body water evaporation (Payne 1993).

Ventilation

When possible, the transport of ostriches during extremes of temperatures should be avoided. When temperatures are above 30ºC extra care with the provision for ventilation. If there is a smell of ammonia in the truck then ventilation is inadequate. High ammonia levels can agitate the birds and cause behavioural problems and potential death.

Ostrich health

Ostriches may be infected by viruses carried by wild birds and other animals which interact with them. Farmers should be aware of signs of illness, including staying alone, standing hunched up, laying down on, lethargy, not eating, loss of vigour, changes in faeces or urine, vomiting, coughing, panting, lameness, dull, brittle feathers and swelling on the body or legs. Maintaining good hygiene, proper housing and brooding and adequate stocking rate can improve ostrich welfare and production. Sick and injured ostriches should be treated without delay and isolated if necessary. Records of sick animals, deaths, treatment given and response to treatment should be maintained to assist disease investigations. Ostriches with an incurable sickness, irreparable injury or painful deformity that create unacceptable levels of suffering should be humanely euthanased. Newly acquired stock should be quarantined from existing stock for 4-6 weeks to minimise risk of the introduction of a disease (Glatz 2000*a*).

Leg problems

Leg deformities including twisted or bowed leg bones and swollen or deformed hock joints or rolled toes (Stewart 1994; Speer 1996) commonly occur in young or growing ostriches. This is normally caused by poor management during hatching and early development of young ostriches (Speer 1996; Samson 1996; 1997). Feeding a high protein starter diet and a lack of exercise results in rapid growth (body weight over 4.5kg at age of 28 days for ostriches) and hence leg problems (Jensen *et al.* 1992; Samson 1997). Housing chicks in cement floors with high stocking density also contributes to leg problems (Samson 1996; 1997). Samson (1996) concluded that management should be checked if over 5% of chicks on a farm suffer from leg problems.

Nutrient deficiency will cause leg deformities. Bezuidenhout *et al.* (1994) found that bone mineralization was poor in deformed bones. Rolled or twisted toes could be caused by deficiency of B-complex vitamins (such as riboflavin deficiency) or unsuitable surface (Huchzermeyer 1994*b*; Dunn 1995; Deeming *et al*. 1996). Slipped tendons could be caused by deficiency of manganese (Black 1995; Dick and Deeming 1996). Bow legs could be caused by an imbalance in the Ca and P ratio or protein level. Low serum Ca (Chang *et al.* 1988), Se deficiency and genetic abnormalities (Stewart 1994) are other factors causing leg problems. Deformation of the chest wall with a skewing to one side was found coincident with leg rotations in ostriches (Foggin 1992; Samson 1997).

Mildly affected birds should have their feed intake restricted. Stewart (1994) reported that surgery has poor results on treatment of the leg deformities. Attempts can be made to hobble or splint affected legs but severely affected birds rarely recover and are best euthanased (Glatz 2000*a*). Rolled toes could be improved by supplying corrective shoes (Wade 1992) or toel trimming (Samson 1997).

Impaction

In ostriches impaction is caused by excessive ingestion of material which accumulates in the proventriculus and ventriculus. Samson (1997) classified the impaction into acute (weak birds in a few days) or chronic (weak birds in weeks to months), hard (caused by hard materials such as rocks, sand) or soft (caused by fibrous materials such as grass), and partial or complete. Impaction often occurs in young ostriches (less than 6 months old) (Stewart 1994). Common impaction materials include grass, stones, wet sand, hay (such as long stemmed alfalfa) or woody stems, straw and leaves, and even plastic and metallic objects (Komnenou *et al.* 2003). Impaction can occur when the birds are under stress from high stocking densities; loud irregular noises, and excessive human handling (Hicks 1992). Samson (1997) reported that pantothenic acid deficiency can cause chronic impaction in chicks through excessive ingestion of grass and dirt. If one bird suffers from impaction, others in the same pen should be checked. Unthrifty and malnourished birds will have a high risk of impactions compared to birds housed under good management (Speer 1996). Good management could reduce impactions by reducing stress factors such as transport of birds around the farm, removing foreign material from the bird enclosure and feeding birds *ad libitum* with balanced nutrients.

If birds are suspected of eating foreign materials, they should be fed liquid paraffin or psyllium (60-120 ml, BID, *per os*) (Honnas *et al.* 1991; Frasca and Khan 1997). The clinical signs include weakness, severe dehydration, increased faecal output and an enlarged proventriculus (Komnenou *et al.* 2003). In contrast, reduced faecal output and different coloured faeces was reported by Foggin (1992). Treatments include flushing the proventriculus with water, mineral oil, or diluted propylene glycol (1:10) for mild impaction. A proventriculotomy or an esophagostomy can be used to remove the materials for severe impactions (Gamble and Honnas 1993). Undetected ingestion of hard objects could result in gastric stasis. Some objects can be detected by metal detectors and radiographs. Surgery is the only way to remove the object (Samson 1997).

Heavy metal poisoning

The areas with high levels of heavy metals could cause heavy metal poisoning in ostriches. Clinic signs include anorexia, depression, and lack of coordination, even death. Ingestion of metal objects such as metallic debris in addition to sand, glass and aluminium can cause sickness or death of birds. Common materials include nails, screws, nuts, staples, and pieces of welding rod, battery fragments, coins and lead sinkers. Farmers must site their facilities carefully and attempt to minimise access of birds to metal objects (Glatz 2000*a*).

Infections and diseases

Ostriches are susceptible to diseases found in avian species. Contact with wild birds or commercial poultry, environmental stresses including high stocking density and poor hygiene could cause infections (Shane and Tully 1996). Most diseases are related to farm management including feed and water supply, climate, stress, hygiene and incubator/brooder management. Proper management of these areas can reduce the risk of disease infection. For example, chicks not drinking enough water could have cloacal prolapse (Samson 1997). Details of bacterial (*Anthrax*, *Salmonellosis*, *Escherichia coli* infections, *Colibacillosis*, *Pausterellosis*, *Tuberculosis*), fungal (*Aspergillosis*, *Zygomycosis*), and parasitic (*Protozoa*, *Nematoda*, *Cestoda*, *Trematoda*, *Arthropoda*), mites and lice, ticks, miscellaneous arthropod infections in the ostrich were reviewed by Cooper (2005). The ostrich water trapping mechanism located in nasal sinuses can provide an ideal environment for the incubation of *Aspergillus* spores as this fungus favours a moist and warm environment (Cooper 2000) and can cause respiratory diseases in birds (Tully 1998). In young birds, infection usually occurs as an acute outbreak with high morbidity and high mortality (Glatz 2000*a*).

Other infections include clostridial enteritis, a common condition for all ages of ratites (Stewart 1994) and enterocolotis (Frazier *et al.* 1993). Changes in diet and interactions among viruses, digestive system infections and parasites often are contributors to clostridial enteritis (Shane and Tully 1996). *Clostridium perfringens* and *Clostridium difficile* are common factors causing neonatal ostrich chick enteritis (Shivaprasad 2003). Poor management of hygiene, overcrowding, low or high temperatures and excessive handling is the main factor causing bacterial enteritis (Foggin 1992). *Clostridium difficile* may result in enterocolitis and high mortality in young ostriches (Frazier *et al.* 1993). Establishment and maintenance of normal intestinal flora is crucial. Dosing the chicks as early as possible after hatch with a commercial pro-biotic containing live bacteria is practiced. Plain yoghurt can also be used (Deeming *et al.* 1996).

Parasites are a problem for ostriches on some farms. Sotiraki *et al.* (2001) took faecal samples from farms in Greece to examine the gastrointestinal parasites in ostriches and found 90% of the ostrich farms were infected by parasites; the most common being protozoa (Table 3).

Table 3. Parasitic species found in the faeces from 336 ostriches (Sotiraki *et al.* 2001)

Parasitic species	Number (%) of birds infected
Protozoa	
Balantidium species	249 (74.1)
Amoebae	265 (78.8)
Blastocystis species	1 (0.3)
Coccidia	14 (4.2)
Cryptosporidium species	2 (0.6)
Nematodes	
Strongylid eggs	146 (43.4)

Ostriches can be affected by quill mites, which damage feathers quite severely and therefore preventative treatment should be applied frequently. Lice are less common. Ticks can cause damage to the skin, resulting in poor quality leather. Paralysis due to tick bites is limited to the areas where the offending tick occurs. The birds often recover if the ticks are removed. Craig and Diamond (1996) recommended treatment for ticks consists of direct application of 5% carbaryl dust or 2% malathion spray. Histomoniosis (caused by the protozoon *Histomonas meleagridis*) is also a parasitic disease, which damages the caeca and liver (McDougald 1997). The clinical signs of histomonas in rheas include depression, anorexia, yellowish diarrhoea (McMillan and Zellen 1991), but no clinical signs of this disease have been found in ostriches. Wireworm causes a compensatory production of thick mucous which affect digestion (Craig and Diamond 1996). Mukaratirwa *et al.* (2004) recommended regular de-worming of birds can reduce infections.

Respiratory infections also occur in ostriches. It could be caused by viral and bacterial infections or confinement of birds for long periods with inappropriate ventilation (Stewart 1994).

Cloacal prolapse is commonly found in male juveniles ostriches aged up to six months (Bezuidenhout *et al.* 1993). Clinical signs include severe diarrhoea, intestine impaction, malnutrition (Speer 1996) and tenesmus (Lumeij 1994; Hoefer 1997). Cloacal prolapse may be associated with *H. meleagridis*, which may occur due to contact with backyard poultry (Iordanidis *et al.* 2003). Samson (1997) recommended a therapy for ostriches which included application of an anti-inflammatory antibiotic ointment, replacement of the swollen tissue into the cloaca under anaesthesia, and placement of a purse-string suture.

'Avian influenza is a disease of birds caused by a number of strains (or isolates) of serotypes (or subtypes) of the influenza A virus which are endemic in birds. Influenza A virus is the only species in the genus influenza virus A of the orthomyxoviridae family of viruses' (http://en.wikipedia.org/wiki/Avian_influenza). The influenza viruses occur naturally among birds. Wild birds normally carry the viruses in their intestines, but usually do not cause sickness. However, if domesticated birds direct contact with other infected poultry, or through contact with surfaces (such as dirt or cages) or materials (such as water or feed) contaminated with the virus may become infected with avian influenza virus. The extremes of virulence infection with avian influenza viruses which affects multiple internal organs have a mortality rate up to 90-100% often within 48 hours (http://www.cdc.gov/flu/avian/gen-info/facts.htm). For example, currently, the outbreak of an avian influenza A (H5N1) in Asia, Europe, the Near East, and Africa killed millions of poultry (http://www.cdc.gov/flu/avian/outbreaks/current.htm).

A deadly strain of avian influenza A (H5N2) had killed more than 1,500 ostriches on two farms in South Africa and health officials have culled 30,000 ostriches to stop transmission (Altman LK http://query.nytimes.com/gst/fullpage.html?res=9402E0D9113CF933A2575BC0A9629C8B63&sec=health&spon=). Manvell *et al.* (1998) reported that there were no clinical signs in young ostriches experimentally infected with a highly pathogenic avian influenza virus of the H5N2 subtype. However, the virus was found for several days in Manvell *et al.* (1998) experiment. Capua *et al.* (2000) reported that ostriches are susceptible to highly pathogenic avian influenza (H7N1). Clinical signs of young birds were anorexia, depression, nervous and enteric, which resulted in 30% mortality of the affected birds. The remaining birds recovered to normality within 1 week.

Newcastle disease (ND) in ostriches was found in zoo birds in the 1950s, in commercial ostriches in Israel in 1989 and in southern Africa during the 1990s (Alexander 2000). Both live and inactivated ND poultry vaccines can be used for ostriches, but are usually given more frequently and at much higher doses than recommended for poultry (Alexander 2000). Challenge experiment carried out by Verwoerd *et al.* (1997) showed that vaccinated ostriches were not affected by ND, but non-vaccinated birds suffered from ND. Clinical sign of ND diseases consists of general depression involved with the central nervous system.

Frequent vaccination is recommended when ND is a high risk. The methods to vaccinate ostriches recommended by Huchzermeyer (1994*b*) are; a) primary live vaccine by eye-drop; b) inactivated oil emulsion (twice the recommended chicken dose) 3 weeks later; 3) inactivated oil emulsion (twice the recommended chicken dose) every 6 months in growing birds every year in breeding birds. However, Madeiros (1997) recommended different methods for birds with and without maternal immunity should be used since maternal antibodies affected the effectiveness of vaccination. The methods he recommended were (doses relative to the poultry dose) for no maternal antibodies: a) 2 weeks old, live vaccine (x 5) eye-drop plus inactivated oil emulsion vaccine (x 1); b) 1 month old, inactivated (x 2); c) 2 months old, inactivated (x 6); d) 6 months old, inactivated (x 6); e) 12 months old, inactivated (x 10); and f) annually, inactivated (x 10). For maternal antibodies: a) 45 days old, inactivated oil emulsion (x 6); b) 70 days old, inactivated oil emulsion (x 6); c) 6 months old, inactivated oil emulsion (x 6); d) 12 months old, inactivated oil emulsion (x 10); e) annually, inactivated oil emulsion (x 10).

Summary

With the increase of ostrich farming around the world, more information is needed on methods to reduce ostrich chick mortality. This review provides information on a few aspects including managing breeders, egg handling, incubation, chick brooding and rearing, stocking density, handling, transport and bird health. In general, hygiene and proper housing and feeding are crucial points and to have healthy flocks in farm. The following issues should be addressed in order to reduce chick mortality. These include:

- Collecting eggs soon after lay and keeping them under proper storage conditions results in good hatchability since ratite eggs can be easily contaminated by bacteria,
- Proper setting up of incubator and hatcher parameters and keeping both areas clean,
- Ostrich chicks are sensitive to cold and susceptible to infection and disease. Good brooding systems including keeping brooding area clean, proper bedding, not over stocking, proper heating and exercise also is very important to maintain chick health,

- Proper nutrition and feeding, adequate exercise and allowing chicks to forage outside as early as possible results in good chick health,

- Spending time with chicks after hatching will help chicks condition themselves to human presence and make it easy to handle birds later,

- Proper facilities, gentle restraint, handling and transporting of ostriches reduces bird stress, injuries and improves animal welfare,

- Good biosecurity, good hygiene and proper vaccination will reduce the bird infection of diseases.

Good management and husbandry will reduce ostrich chick mortality. However, more research is required in standardising egg handling and incubation conditions, improving chick rearing and feeding and defining optimal stocking density for young chicks.

References

Adams J, Revell BJ (1998) Ostrich farming: a review and feasibility study of opportunities in the EU. School of Management, Harper Adams University College. http://www.macaulay.ac.uk/livestocksystems/feasibility/ostrich.htm.

Alexander DJ (2000) Newcastle disease in ostriches (*Struthio camelus*) –a review. *Avian Pathology* **29**, 95-100.

Angel CR (1993). Research update: Age changes in digestibility of nutrients in ostriches and nutrient profiles of ostrich and emu eggs as indicators of nutritional status of the hen and chick. In 'Proceedings of Association of Avian Veterinarians'. Lake Worth. pp. 275-281. (AAV Publ. Office)

Animal Welfare Advisory Committee (1998) Code of Recommendations and minimum standards for the welfare of ostrich and emu. Code of Animal Welfare No. 21, ISBN 0-478-07476-X, Ministry of Agriculture and Forestry, PO Box 2526, Wellington, New Zealand.

Anon (1998) Prescribing for Birds. In 'Veterinary Formulary'. (Ed. Y Bishop) pp. 40-42. 4th edn. (London, Pharmaceutical Press)

Anon (1992) Report on Priorities for Animal Welfare Research and Development. Farm Animal Welfare Council, Ministry of Agriculture, Fisheries and Food, Surbiton, UK.

Ar A (1996) Requirements for successful artificial incubation of ostrich eggs. In 'Proceedings of the Ratite Conference, Improving our understanding of ratites in a farming environment'. Manchester. (Ed. DC Deeming) pp. 131-144. (United Kingdom)

Ar A, Meir M, Aizik N, Campi D (1996) Standard values and ranges of ostrich egg parameters as a basis for proper artificial incubation. In 'Proceedings of the Ratite Conference, Improving our understanding of ratites in a farming environment'. Manchester. (Ed. DC Deeming) pp. 144-146. (United Kingdom)

Ashash E, Malkinson M, Meir R, Perl S, Weisman Y (1996) Case report-causes of losses including a Borna disease paralytic syndrome affecting young ostriches of one breeding organization over a five-year period (1989-1993). *Avian Diseases* **40**, 240-245.

Astley HD (1907) Polyandry in the Rhea. *Aviculture Magazine* **5**, 267-269.

Barri FR, Navarro JL, Maceira NO, Martella MB (2005) Rearing Greater Rhea (Rhea americana) chicks: is adoption more effective than the artificial intensive system? *British Poultry Science* **46**, 22-25.

Berge P, Lepetit J, Renerre M, Touraille C (1997) Quality traits in the emu *(Dromaius novaehollandiae)* as affected by muscle type and animal age. *Meat Science* **45**(2), 209-221.

Bertram BCR (1979) Ostriches recognize their own eggs and discard others. *Nature* **279**, 233-234.

Bezuidenhout AJ, Penrith M-L, Burger WP (1993) Prolapse of the phallus and cloaca in the ostrich (*Struthio camelus*). *Journal of the South African Veterinary Association* **64**, 156-158.

Bezuidenhout AJ, Burger WP, Reyers F, Soley JT (1994) Serum and bone mineral status of ostriches with tibiotarsal rotation. *Onderstepoort Journal of Veterinary Research* **61**, 203-206.

Blache D, Barrett CD, Martin GB (2000) Social mating system and sexual behaviour in captive emus *Dromaius novaehollandiae*. *Emu* **100**, 161-168.

Black D (1995) Trouble shooting leg problem. In 'Ostrich Odyssey '95, Proceedings of the Fifth Australian Ostrich Association Conference'. Gold Coast. pp. 41-47. (Gold Coast, Queensland, Australia)

Bornett-Gauci HLI, Martin JE, Arney DR (2006) The welfare of low-volume farm animals during transport and at slaughter: a review of current knowledge and recommendations for future research. *Animal Welfare* **15**, 299-308.

Brand Z, Brand TS, Brown CR (2003*a*) The effect of different combinations of dietary energy and protein on the composition of ostrich eggs. *South African Journal of Animal Science* **33**(3), 193-200.

Brand Z, Brand TS, Brown CR (2003*b*) The effect of dietary energy and protein levels on production in breeding female ostriches. *British Poultry Science* **44**(4), 598-606.

Brand Z, Brand TS, Brown CR, van Schalkwyk SJ (2000) Preliminary results on the effect of dietary energy and protein levels on the production of male breeding Ostriches. *South African Journal of Animal Science* **30**(Supplement 1), 21-22.

Brand Z, van Schalkwyk SJ, Cloete SWP, Blood JR (1997) The effect of pre-heating of ostrich eggs prior to storage and setting in commercial hatcheries. In 'Proceedings of the Second International Ratite Congress'. Oudtshoorn. pp. 152-154. (Ratite in a Competitive World, Oudtshoorn, South Africa)

Broom, DM (1991) Animal Welfare. Concepts and measurement. *Journal of Animal Science* **69, 4167-4175**

Brown CR, Peinke D, Loveridge A (1996) Mortality in near-term ostrich embryos during artificial incubation. *British Poultry Science* **37**, 73-85.

Bruning DF (1973) The Greater Rhea chick and egg delivery route. *Natural History* **82**, 68-75.

Bruning DF (1974) Social structure and reproductive behaviour of the Greater Rhea. *Living Bird* **13**, 251-294.

Bubier NE, Paxton CGM, Bowers P, Deeming DC (1998) Courtship behaviour of ostriches (*Struthio camelus*) towards humans under farming conditions in Britain. *British Poultry Science* **39,** 477-481.
Burger AE, Bertram BCR (1981) Ostrich eggs in artificial incubators: could their hatching success be improved? *South African Journal of Science* **77**, 188-189.
Capua I, Mutinelli F, Bozza MA, Terregino C, Cattoli G (2000) Highly pathogenic avian influenza (H7N1) in ostriches (*Struthio camelus*). *Avian Pathology* **29**, 643-646.
Chang PH, Chang CF, Liu MRS, Wang KP (1988) Bow leg syndrome in ostrich (Struthio camelus). *Journal of Chinese Society Veterinary Science* **14**, 17-21.
Chang Reissig E, Robles CA (2001) Case report-gizzard impaction in Lesser Rhea chicks (*Pterocnemia pennata*) raised on farms in Patagonia, Argentina. *Avian Diseases* **45**, 240-244.
Chang Reissig E, Terzolo H, Armando S, Roge A (2004) Hatching success and embryonic mortality on lesser rhea (Pterocnemia pennata) farms in northern Patagonia, Argentina. *British Poultry Science* **45**, 471-475.
Chang Reissig E, Uzal FA, Schettino A, Robles CA (2002) Case report-pulmonary aspergillosis in a Great rhea (*Rhea americana*). *Avian Diseases* **46**, 754-756.
Charnley J **(**1999) Diseases and welfare of farmed ostriches in the UK. *Veterinary Practice Nurse Summer* pp. 23-25.
Christensen VL, Davis GS, Lucore LA (1996) Egg shell conductance and other functional qualities of ostrich eggs. *Poultry Science* **75**, 1404-1410.
Christensen JW, Nielsen BL (2004) Environmental enrichment for ostrich, Struthio camelus, chicks. *Animal Welfare* **13**, 119-124.
Codenotti TL, Alvarez F (1998) Adoption of unrelated young by greater rheas. *Journal of Field Ornithology* **69**(1), 58-65.
Cooper RG (2000) The management of ostrich (*Struthio camelus*) chicks. *World's Poultry Science Journal* **56,** 33-44.
Cooper RG (2001). Handling, incubation, and hatchability of ostrich (*struthio camelus var. domesticus*) eggs: a review. *Journal Applied Poultry Research* **10**, 262-273.
Cooper RG (2005) Bacterial, fungal and parasitic infections in the ostrich (*Struthio camelus* var. *domesticus*). *Animal Science Journal* **76**, 97-106.
Cornetto T, Angel R, Estevez I (2003) Influence of Stocking Density and Dietary Energy on Ostrich (*Struthio camelus*) Performance. *International Journal of Poultry Science* **2**(2), 102-106.
Craig TM, Diamond PL (1996) Parasites of ratites. In 'Ratite Management, Medicine and Surgery'. (Ed TN Tully) pp. 115-126. (Malabar, Kreiger Publishing)
Crowther C, Davies R, Glass W (2003) The effect of night transportation on the heart rate and skin temperature of ostriches during real transportation. *Meat Science* **64**(4), 365-370.
Crowther C, Davies R, Glass W (2001) Ratite transportation in New Zealand: an assessment of practices and implications for welfare. Ministry of Agriculture and Forestry, Wellington, New Zealand.
Crowther C, Davies R, Glass W (2003) The effect of night transportation on the heart rate and skin temperature of ostriches during real transportation. *Meat Science* **64**, 365-370.
Davis GS (2006) Commercial Ostrich Production. Cooperative Extension Service, College of Agriculture and Life Sciences, North Carolina, USA.
Dawson TJ, Read D, Russell EM, Herd RM (1984) Seasonal variation in daily activity patterns, water relations and diet of Emus. *Emu* **84**, 93-102.
de Kock JA (1996) Natural rearing of chickens up to three months of age. In 'Guidelines for Successful Ostrich Farming'. pp. 24-27. (Little Karoo Agricultural Development Centre, Oudtshoorn, South Africa)
Deeming DC (1993) The incubation requirements of ostrich (*Struthio camelus*) eggs and embryos. In 'Ostrich odyssey: Proceedings of the Meeting of the Australian Ostrich Association Inc.' Victory. (Ed DI Bryden) pp. 1-66. (217, Post Graduate Committee in Veterinary Science, University of Sydney, Australia)
Deeming DC (1995) Factors affecting hatchability during commercial incubation of ostrich (Struthio camelus) eggs. *British Poultry Science* **36**, 51-65.
Deeming DC (1996*a*) Production, fertility and hatchability of ostrich (*Struthio camelus*) eggs on a farm in the United Kingdom. *Animal Science* **63**, 329-336.
Deeming DC (1996*b*) Microbial spoilage of ostrich (*Struthio camelus*) eggs. *British Poultry Science* **37**, 689-693.
Deeming DC (1997) Ratite egg incubation-a practical guide. Ratite conference, Buckingham Shire, UK.
Deeming DC, Angel CR (1996) Introduction to the ratites and farming operations around the world. In 'Improving our Understanding of Ratites in a Farming Environment. Ratite Conference'. Oxfordshire. (Ed DC Deeming). pp. 1-4. (Oxfordshire, UK)

Deeming DC, Ar A (1999) Factors affecting the success of commercial incubation. In 'The Ostrich: Biology, production and health'. (Ed DC Deeming) pp. 159-190. (CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom)
Deeming DC, Ayres L (1994) Factors affecting the rate of growth of ostrich (*Struthio camelus*) chicks in captivity. *Veterinary Record* **135**, 617-622.
Deeming DC, Ayres L, Ayres FJ (1993) Observations on the first commercial production of ostrich (*Struthio camelus*) eggs in the UK: incubation. *Veterinary Record* **132**, 602-607.
Deeming DC, Bubier NE (1999) Behaviour in natural and captive environments. In 'The Ostrich: Biology, production and health'. (Ed DC Deeming) pp. 83-104. (CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom)
Deeming DC, Dick ACK, Ayres L (1996) Rearing ostrich chicks-a stockman's guide. Ratite Conference, Oxfordshire, UK.
Degen AA, Kam M, Rosenstrauch A (1989) Time-activity budget of ostriches *(Struthio camelus)* offered concentrate feed and maintained in outdoor pens. *Applied Animal Behaviour Science* **22**, 347-358.
Department for Environment, Food and Rural Affairs (DEFRA) (2003) Guidance on the slaughter of ostriches welfare. http://www.Defra.gov.uk/animalh/welfare/farmed/slaughter/slaugh-ostrich.htm.
Dick ACK, Deeming DC (1996) Veterinary problems encountered on ostrich farms in Great Britain. In 'Improving our understanding of ratites in a farming environment, ratite conference'. Oxfordshire. (Ed DC Deeming) pp. 40-41. (Oxfordshire, UK)
Dingle JG (1996) The effect of production factors on emu meat quality. In 'World emu conference Australia 1996'. Adelaide. pp. 62-66. (Adelaide Convention Centre, Australia)
du Preez JJ (1991) Ostrich nutrition and management. In 'Recent Advances in Animal Nutrition in Australia'. (Ed DJ Farrell) pp. 279-292. (Armidale, University of New England)
Dunn S (1995) Ostrich chick rearing. In 'The ratite encyclopedia. ratite records'. San Antonio. (Ed C Drenowatz) pp. 139-147. (San Antonio, Texas, USA)
Earle R (1994) Successful Ostrich farming in Southern Africa and Australia. Canberra, Australian Ostrich Association.
Essa F, Cloete SWP (2004) Differentiation between females of ostrich breeding trios based on egg weights. *South African Journal of Animal Science* **34**(Supplement 2), 20-22.
Fernandez GJ, Reboreda JC (1998) Effects of clutch size and timing of breeding on reproductive success of Greater Rheas. *The Auk* **115,** 340-348.
Fernandez GJ, Reboreda JC (2007) Costs of large communal clutches for male and female Greater Rheas *Rhea Americana*. IBIS. British Ornithologists' Union.
Foggin CM (1992) Veterinary problems in ostriches. In 'The topaz introduction to practical ostrich farming'. (Ed MG Hallam) pp. 61-96. (The Producers Association of Zimbabwe, Harare)
Foggin CM, Honywill J (1992) Observations on the artificial incubation of ostrich (*Struthio camelus var. domesticus*) eggs with special reference to water loss. *Zimbabwe Veterinary Journal* **23**, 81-89.
Frasca SJr, Khan MI (1997) Multiple intussusceptions in a juvenile rhea (Rhea americana) with proventricular impaction. *Avian Diseases* **41**, 475-480.
Frazier KS, Herron AJ, Ii MEH, Gaskin JM, Altman NH (1993) Diagnosis of enteritis and enterotoxemia due to Clostridium difficile in captive ostriches (*Struthio camelus*). *Journal of Veterinary Diagnostic Investigation* **5**, 623-625.
Gamble KC, Honnas CM (1993) Surgical correction of impaction of the proventriculus in ostriches. Compend Contin Educ Pract Vet 15, 235-244.
Glatz PC (2000*a*) A benchmark study of husbandry, transport, lairage and slaughter methods to improve skin quality of ratites; Vol 1 Ostriches. A report for the Rural Industries Research and Development Corporation. Australia.
Glatz PC (2000*b*) A benchmark study of husbandry, transport, lairage and slaughter methods to improve skin quality of ratites; Vol 2 Emus. A report for the Rural Industries Research and Development Corporation, Australia.
Glatz PC (2001) Effect of declawing on behaviour of farmed emus. *Asian-Australasian Journal of Animal Science* 14(2), 288-296.
Glatz PC (2003) Husbandry and genetic strategies to improve hide quality of ostriches. A report for the Rural Industries Research and Development Corporation, Australia.
Glatz PC (2005*a*) Quality assurance procedures to improve skin quality in ostriches. In 'Proceedings of the 3rd international ratite science symposium and XII world ostrich congress'. Madrid. (Ed E Carbijo) pp. 385-389. (Madrid, Spain)

Glatz PC (2005*b*) Best practice methods to declaw ostriches to improve skin quality. In 'Proceedings of the 3rd international ratite science symposium and XII world ostrich congress'. Madrid. (Ed E Carbijo) pp. 397-400. (Madrid, Spain)
Glatz PC (2005*c*) Effect of declawing on behaviour and skin quality of ostriches. In 'Proceedings of the 3rd international ratite science symposium and XII world ostrich congress'. Madrid. (Ed E Carbijo) pp. 157-162. (Madrid, Spain)
Glatz PC (2007) Ratite Toe-trimming Training Manual-A resource to support the training of toe-trimmers. A report for the Rural Industries Research and Development Corporation, Australia.
Gonzales A, Satterlee DG, Moharer F, Cadd GG (1999) Factors affecting ostrich egg hatchability. *Poultry Science* **78**, 1257-1262.
Grandin T (1997) Assessment of stress during handling and transport. *Journal of Animal Science* **75**, 249-257.
Gupta BN, Trapp AL (1971) Case history-traumatic proventriculitis in a rhea (*Rhea americana*). *Avian Diseases* **15**(2), 408-412.
Hallam MG (1992) The topaz introduction to practical ostrich farming. Zimbabwe, Superior Print.
Hamilton EC, Hunter DB, Smith DA, Michel P (1999) Artificial incubation of trumpeter swan eggs: selected factors affecting hatchability. *Zoo Biology* **18**, 403-414.
Harms RH, Buresh RE, Wilson HR (1984) The influence of the grower diet and fat in the layer diet on performance of turkey hens. *Poultry Science* **63**(8), 1634-1637
Harris TC (1996) AATA - Manual for the transport of live animals by road. Redhill, Animal Transportation Association.
Hassan SM, Siam AA, Mady ME, Cartwright AL (2004) Incubation temperature for ostrich (*Struthio camelus*) eggs. *Poultry Science* **83**, 495-499.
Hassan SM, Siam AA, Mady ME, Cartwright AL (2005) Egg storage period and weight effects on hatchability of ostrich (*Struthio camelus*) eggs. *Poultry Science* **84**, 1908-1912.
Hastings MY (1991) Ostrich farming. University of New England Printery, Armidale, NSW, Australia.
Heckert RA, McIsacc M, Chan M, Zhou E-M (1999) Experimental infection of emus (*Dromaiius novahollandia e*) with avian influenza viruses of varying virulence: clinical signs, virus shedding and serology. *Avian Pathology* **28**, 13-16.
Hewitt L (1996) Welfare aspects of the commercial slaughter of ostriches. MSc thesis, University of Bristol, UK.
Hicks K (1992) Ostrich pediatric disorders. Ostrich Report August. pp. 13-18.
Hicks KD (1993) Ostrich reproduction. In 'Zoo and wild animal medicine. Current therapy 3' (Ed ME Fowler) pp. 203-209. (W.B. Saunders, Philadelphia)
Hicks-Allredge KD (1993) Ostrich chick management and nutrition. In 'Ostrich Odyssey: Proceedings of the meeting of the Australian Ostrich Association, Inc (Vic)'. (Ed DI Bryden) Vol. **217,** 155-158. (Postgraduate Committee in Veterinary Science, University of Sydney, Sydney, Australia)
Hicks-Allredge KD (1996) Reproduction. In 'Ratite Management, Medicine and Surgery'. (Eds TN Tully Jr., SM Shane) pp. 47-57. (Krieger Publishing Company, Malabar, Florida USA.)
Hoefer HL (1997) Diseases of the gastrointestinal tract. In 'Avian Medicine and Surgery'. (Eds RB Altman, SL Clubb, GM Dorrestein, K Queensbury). 1st edn. pp. 419-453. (W. B. Saunders, Philadelphia)
Honnas CM, Jensen J, Cornick JL, Hicks K, Kuesis BS (1991) Proven triculotomy to relieve foreign body impaction in ostriches. *Journal of American Veterinary Medical Association* **199**, 461-465.
Horbanczuk JO (2002) The history and current status of ostrich farming in Poland. In 'Proceedings of world ostrich congress'. pp. 7-13. (26-29 September, Warsaw, Poland)
Huchzermeyer FW (1994a) Metazoan parasites. In 'Ostrich diseases'. (Ed FW Huchzermeyer) pp. 8-45. (Onderstepoort, Onderstepoort Veterinary Institute, South Africa)
Huchzermeyer FW (1994b) Ostrich diseases. Agriculture Research Council, Onderstepoort Veterinary Insitute, South Africa. pp. 11-12.
Huchzermeyer FW (1996) High mortality in ostrich eggs and hatching due to egg washing. *Journal of the South African Veterinary Association* **67**, 3.
Huchzermeyer FW (1998) Disease of ostrich and other ratites. Agricultural Research Council, Onderstepoort Veterinary Institute, South Africa.
Huchzermeyer FW (1999) Veterinary problems. In 'The Ostrich: Biology, production and health'. (Ed DC Deeming) pp. 293-320. (CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom)
Hudson WH (1920) Birds of La Plata. **2**, 230-236. (J. M. Dent and Sons Ltd. London)
Iordanidis PI, Papazahariadou MG, Georgiades GK, Papaioannou NG, Frydas SE (2003) Cloacal prolapse in ostrich chicks with histomoniosis. *Veterinary Record* **153**, 434-435.
Ipek A, Sahan U (2004) Effect of breeder age and breeding season on egg production and incubation in farmed ostriches. *British Poultry Science* **45**(5), 643-647.

Jarvis MJF, Keffen RH, Jarvis C (1985) Some physical requirements for ostrich egg incubation. *Ostrich* **56**, 42-51.
Jensen JM, Johnson JH, Weiner ST (1992) Husbandry and Medical Management of Ostriches, Emus and Rheas. College Station, Texas: Wildlife and Exotics Animal Teleconsultants. pp. 124-127.
Junqueira SP, Colares EP, Bertacco LL (2007) Effect of a sunflower seed supplemented diet in the reproduction of ostrich (*Struthio camelus*) (Abstracts) *Comparative Biochemistry and Physiology, Part A* 148, S137
Kaleta EF, Baldauf C (1988) Newcastle disease in free-living and pet birds. In 'Newcastle Disease'. (Ed DJ Alexander) pp. 197-246. (Boston, MA: Kluwer Academic Publishers)
Kamau JM, Patrick BT, Mushi EZ (2002) The effect of mixing and translocating juvenile ostriches (*Struthio camelus*) in Botswana on the heterophil to lymphocyte ratio. *Tropical Animal Health and Production* **34**, 249-256.
Kenny D, Cambre RC (1992) Indications and technique for the surgical removal of the avian yolk sac. *Journal of Wildlife Medicine* **23**, 55-61.
Kocan AA, Crawford JA (1994) An ostrich farmers handbook. The Ostrich News, Cache, Oklahoma.
Komnenou AT, Georgiades GK, Savvas I, Dessiris A (2003) Surgical Treatment of Gastric Impaction in Farmed Ostriches. *Journal of Veterinary Medicine A* **50**, 474-477.
Labaque MC, Navarro JL, Martella MB (1999) A note on chick adoption: a complementary strategy for rearing rheas. *Applied Animal Behaviour Science* **63**, 165-170.
Labaque MC, Navarro JL, Martella MB (2003) Microbial contamination of artificially incubated Greater Rhea (Rhea americana) eggs. *British Poultry Science* **44**, 355-358.
Labaque MC, Navarro JL, Martella MB (2004) Effects of storage time on hatchability of artificially incubated Greater Rhea (Rhea americana) eggs. *British Poultry Science* **45**, 638-642.
Lambooij E (1998) Captive needle improves ostrich meat quality. *Meat International* **8**(7), 733-735.
Lambooij E, Potgieter CM, Britz CM, Nortje GL, Pieterse C (1999a) Effects of electrical and mechanical stunning on meat quality in ostriches. *Meat Science* **52**, 331-337.
Lambooij E, Pieterse C, Potgieter CM, Snyman JD, Nortje GL (1999b) Some neural and behavioural aspects of electrical and mechanical stunning in ostriches. *Meat Science* **52**, 339-345.
Lambrechts H, Swart D, Cloete SWP, Greyling JPC, van Schalkwyk SJ (2004) The influence of stocking rate and male:female ratio on the production of breeding ostriches (*Struthio camelus* spp.) under commercial farming conditions. *South African Journal of Animal Science* **34**(2), 87-96.
Levy A, Markowittz E, van Creveld C, Tagil R (1996) Water metabolism of laying ostriches. In 'Improving our understanding of ratites in a farming environment'. (Ed DC Deeming) pp. 127-129. (Oxfordshire, Ratite Conference)
Ley DH, Morris RE, Smallwood JE, Loomis MR (1986) Mortality of chicks and decreased fertility and hatchability of eggs from a captive breeding pair of ostriches. *Journal of the American Veterinary Medicine Association* **189**, 1124-1126.
Lumeij J (1994) Avian clinical enzymology, in Seminars. *Avian and Exotic Pet Medicine* **3**, 14-24.
Lunam CA, Glatz PC, O'Malley P (1996) The anatomy of the emu toe. In 'Proceedings of World Emu Conference-Australia, 1996'. pp. 90-92. (Adelaide Convention Centre, Australia)
Lunam CA; Glatz PC (2000) Declawing of Farmed Emus-Harmful or Helpful? A report for the Rural Industries Research and Development Corporation, Australia.
Madeiros C (1997) Vaccination of ostriches against Newcastle disease. *Veterinary Record*, **140**, 188.
Manvell RJ, Jørgensen PH, Nielsen OL, Alexander DJ (1998) Experimental assessment of the pathogenicity of two avian influenza A H5 viruses in ostrich chicks (*Struthio camelus*) and chickens. *Avian Pathology* **27**, 400-404.
Martin GR, Katzir G (1996) Visual fields, foraging and sunshade in ostriches. In 'Improving our understanding of ratites in a farming environment'. (Ed DC Deeming) pp. 10-12. (Oxfordshire, Ratite Conference)
McDougald LR (1997) Other protozoan diseases of the intestinal tract. In 'Diseases of poultry. (Eds BW Calnek, HJ Barnes, CW Beard, LR McDougald, YM Saif) 10th edn. pp. 890-900. (Ames, Iowa State University Press, USA)
McMillan EG, Zellen G (1991) Histomoniasis in a rhea. *Canadian Veterinary Journal* **32**, 224.
Minnaar P, Minnaar M (1995) The emu farmer's handbook. NYONI Publishing Co. Groveton, Texas, USA.
Mitchell MA (1999) Welfare. In: The Ostrich: Biology, production and health. Ed. Deeming, D. C. CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom. pp.217-230.
Mitchell MA, Kettlewell PJ, Sandercock DA, Maxwell MH, Spackman D (1996) Physiological stress in ostriches during road transportation. In 'Improving our understanding of ratites in a farming environment'. (Ed DC Deeming) pp. 79-80. (Oxfordshire, Ratite Conference)
Moody R (1992) Focus on ostrich farming-a new enterprise in the United Kingdom. *State Veterinary Journal* **2**, 7-10.

Mouser D (1996) Restraint and handling of the emu. In ‘Ratite Management, Medicine and Surgery’. (Eds TN Tully Jr., SM Shane) pp. 41-45. (Krieger Publishing Company, Malabar, Florida USA.)
Mukaratirwa S, Cindzi ZM, Maononga DB (2004) Prevalence of Libyostrongylus douglassii in commercially reared ostriches in the highveld region of Zimbabwe. *Journal of Helminthology* **78**, 333-336.
Musa HH, Suleiman AH, Lanyasunya TP, Olowofeso O, Mekki DM (2005) Feeding practices, growth rate and management of ostrich chicks in Sudan. *Pakistan Journal of Nutrition* **4**(3), 154-157.
Mushi EZ, Isa JFW, Chabo RG, Binta MG, Modisa L, Kamau JM (1998) Impaction of the Stomachs in Farmed Ostriches (Struthio camelus) in Botswana. *Avian Diseases* **42**(3), 597-599.
Nahm KH (2001) Effects of Storage Length and Weight Loss During Incubation on the Hatchability of Ostrich Eggs (*Struthio camuelus*). Research Note. *Poultry Science* **80**, 1667-1670.
Navarro JL, Martella MB, Cabrera MB (1998) Fertility of greater rhea orphan eggs: conservation and management implications. *Journal of Field Omithology* **69,** 117-120.
Navarro JL, Martella MB (2002) Reproductivity and raising of Greater Rhea (*Rhea americana*) and Lesser Rhea (*Pterocnemia pennata*)-a review. *Archiv fur Geflugelkunde* **66**, 124-132.
Navarro JL, Barri FR, Maestri DM, Labuckas DO, Martella MB (2003) Physical characteristics and chemical composition of Lesser Rhea (Pterocnemia pennata) eggs from farmed populations. *British Poultry Science* **44**, 586-590.
Navarro JL, Lopez ML, Maestri DM, Labuckas DO (2001) Physical characteristics and chemical composition of Greater Rhea (*Rhea americana*) eggs from wild and captive populations. *British Poultry Science* **42**, 658-662.
Noy Y, Uni Z, Sklan D (1996) Routes of yolk utilisation in the newly-hatched chick. *British Poultry Science* **37**, 987-996.
O’Malley P (1996) Bird handling and handling facilities. In ‘World Emu Conference Australia 1996’. pp. 97-103. (Adelaide Convention Centre, Australia).
Parker Z, Greaser GL, Harper JK (1994) Agricultural alternatives. College of Agricultural Sciences, PennState, The US Agriculture Department, USA.
Payne H (1993) Welfare of ostriches and other ratites during transport. *State Veterinary Journal* **3**, 8-12.
Payne H (1994) Welfare of ostriches and other ratites during transport. Live Animal Trade and Transport Magazine. September. pp.45-48.
Peace C (2004) Ostrich control. http://www.ontarioratite.com/handling_ostrich.htm.
Perelman B (1999) Health management and veterinary procedures. In ‘The Ostrich: Biology, production and health’. (Ed DC Deeming) pp. 321-346. (CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom)
Philbey AW, Button C, Gestier AW, Munro BE, Glastonbury JRW, Hindmarsh M, Love SCJ (1991) Anasarca and myopathy in ostrich chicks. *Australian Veterinary Journal* **68**, 237-240.
Pollok KD, Hale DS, Miller RK, Angel R, Blue-McLendon A, Baltmanis B, Keeton JT (1997) Ostrich slaughter and by-product yields. American Ostrich April, pp. 31-35.
Rahn H, Ar A, Paganelli CV (1981) How bird eggs breathe. Proceedings of the Avian Egg: Structure, Function, Environment Symposium, Buffalo, NY, pp. 282-291.
Raikow RJ (1969) Sexual and agonistic behavior of the common rhea. The Vilson Bulletin 81(2), 196-206.
Sahan U, Altan O, Iipek A, Yilmaz B (2003) Effects of some egg characteristics on the mass loss and hatchability of ostrich (Struthio camelus) eggs. *British Poultry Science* **44(3)**, 380-385.
Sales J (1999) Slaughter and Products. In ‘The Ostrich: Biology, production and health’. (Ed DC Deeming) pp. 232-233. (CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom)
Sales J, Smith WA (1995) Incubation and Management. In: Practical Guide for Ostrich Management and Ostrich Products. Republic of South Africa, Stellenbosch University Printers.
Samson J (1996) Targets of performance in ostriches. *Proceedings of Annual Conference Association Avian Veterinary* **14**, 1-147.
Samson J (1997) Prevalent diseases of ostrich chicks farmed in Canada. *Canadian Veterinary Journal* **38**, 425-428.
Satteneni G, Satterlee DG (1994) Factors affecting hatchability of ostrich eggs. *Poultry Science* **73(**Suppl. 1**)**, 38.
Sell R (1993) Ostrich. Department of Agricultural Economics, North Dakota State University of Agriculture and Applied Science, and U.S. Department of Agriculture cooperating.
Shane SM (1996) Hatchery Management in Emu Production. In ‘Ratite Management, Medicine and Surgery’. (Eds TN Tully Jr., SM Shane) pp. 69-73. (Krieger Publishing Company, Malabar, Florida USA.)
Shane SM, Minteer L (1996) Biosecurity and Control of Disease. In ‘Ratite Management, Medicine and Surgery’. (Eds TN Tully Jr., SM Shane) pp. 31-36. (Krieger Publishing Company, Malabar, Florida USA.)
Shane SM, Tully TNJr (1996) Infectious Diseases. In ‘Ratite Management, Medicine and Surgery’. (Eds TN Tully Jr., SM Shane) pp. 127-146. (Krieger Publishing Company, Malabar, Florida USA.)

Shivaprasad HL (2003) Hepatitis associated with Clostridium difficile in an ostrich chick. *Avian Pathology* **32**, 57-/62.
Skadhauge E, Dawson TJ, Prys-Jones R, Warui CN (1996) The role of the kidney and the gut in osmoregulation. In 'Improving our understanding of ratites in a farming environment'. (Ed DC Deeming) pp. 115-122. (Oxfordshire, Ratite Conference)
Smith WA, Cilliers SC, Mellett FD, van Schalkwyk SJ (1995) Ostrich production-a South African perspective. In 'Biotechnology in the Feed Industry, Proceedings of the 11th Alltech Annual Symposium'. (Eds TP Lyons, KA Jacques) pp. 175-197. (Nottingham University Press. Nottingham)
Soley JT, Groenewald HB (1999) Reproduction. In 'The Ostrich: Biology, production and health'. (Ed DC Deeming) pp. 129-158. (CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom)
Sotiraki ST, Georgiades G, Antoniadou-Sotiriadou K, Himonas CA (2001) Gastrointestinal parasites in ostriches (Struthio camelus). *Veterinary Record* **148**, 84-86.
Speer BL (1996) Developmental problems in young ratites. In 'Ratite Management, Medicine and Surgery'. (Eds TN Tully Jr., SM Shane) pp. 147-154. (Krieger Publishing Company, Malabar, Florida USA.)
Stewart JS (1989) Husbandry and medical management of ostriches. Proceedings of the Association of Avian Veterinarians. pp.208-212.
Stewart JS (1994) Ratites. In 'Avian Medicine: Principles and Application'. (Eds BW Ritchie, GJ Harrison, LR Harrison). pp. 1284-1326. (Fort Worth, Florida: Wingers Publishing Inc., USA)
Stewart JS (1996) Hatchery Management in Ostrich Production. In 'Ratite Management, Medicine and Surgery'. (Eds TN Tully Jr., SM Shane) pp. 59-66. (Krieger Publishing Company, Malabar, Florida USA.)
Swart, D., Rahn, H., and De Kock, J. (1987). Nest microclimate and incubation water loss of eggs of the African ostrich (Struthio camelus var. domesticus). *Journal of Experimental Zoology* **Suppl. 1**, 239-246.
Taylor MA, Hunt KR, Smith G, Otter A (2000) Deletrocephalus dimidiatus in greater rheas (Rhea americana) in the UK. *Veterinary Record* **146**, 19-20.
Tuckwell C (1997) The New Rural Industries-A handbook for farmers and investors. Rural Industries Research & Development Corporation, Australia.
Tully TN (1998) Health examinations and clinical diagnostic procedures of ratites. *Veterinary Clinics of North America –Food Animal Practice* **14,** 401-402.
Uhart M, Aprile G, Beldomenico P, Solis G, Marull C, Beade M, Carminati A, Moreno D (2006) Evaluation of the health of free-ranging greater rheas (*Rhea americana*) in Argentina. *Veterinary Record* **158,** 297-303.
Van den Akker P (1996) How to achieve the best out of your incubator. In 'World Emu Conference Australia 1996'. pp. 110-112. (Adelaide Convention Centre, Australia).
Van Heyst FCA (1950) Rhea breeding. *Aviculture Magazine* **16**, 202-205.
Van Schalkwyk SJ (1998) Improvement of fertility and hatchability of artificially incubated ostrich eggs in the Little Karoo. M Sc dissertation, Rhodes University, Grahamstown.
Van Schalkwyk SJ, Brand Z, Cloete SWP, Blood JR **(**1997) The influence of different disinfection protocols on the hatching performance of ostrich eggs. In 'Proceedings of 2nd international ratite conference'. pp. 157-158. (Oudtshoorn, South Africa)
Van Schalkwyk SJ, Cloete SWP, Brown CR, Brand Z (2000) Hatching success of ostrich eggs in relation to setting, turning and angle of rotation. *British Poultry Science* **41**, 46-52.
Van Schalkwyk SJ, Cloete SWP, Brown CR (1999) The effect of temperature on the hatching performance of ostrich chicks and its implications for artificial incubation in forced draught incubators. *South African Journal of Animal Science* **29**(2), 92-99.
Van Schalkwyk SJ, Hoffman LC, Cloete SWP, Mellett FD (2005) The effect of feed withdrawal during lairage on meat quality characteristics in ostriches. *Meat Science* **69**, 647-651.
Verwoerd DJ, Deeming DC, Angel CR, Perelman B (1999) Rearing environments around the world. In 'The Ostrich: Biology, production and health'. (Ed DC Deeming) pp. 163-206. (CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom)
Verwoerd DJ, Gerdes GH, Olivier A, Williams R (1997) Experimental infection of vaccinated slaughter ostriches with virulent Newcastle disease virus. *Onderstepoort Journal of Veterinary Research* **64**, 213-216.
Wade J (1992) Ratite pediatric medicine and surgery neonatal problems. *Proceedings of Annual Conference Association Avian Veterinary* pp. 343-353.
Wade J (1995) Chick rearing principles. In: Ostrich Odyssey '95, Proceedings of the Fifth Australian Ostrich Association Conference, Gold Coast, Queensland. pp. 25-27.
Wade JR (1996) Restraint and handling of the ostrich. In 'Ratite Management, Medicine and Surgery'. (Eds TN Tully Jr., SM Shane) pp. 37-40. (Krieger Publishing Company, Malabar, Florida USA.)
Wahoski M (1996) Latest incubation and egg candling systems. In 'World emu conference Australia 1996'. pp. 113-115. (Adelaide Convention Centre, Australia)

Westendorf M (1997) Ostrich, emu, and rhea production. Rutgers Cooperative Research and Extension, NJAES, Rutgers, The State of University of New Jersey, USA.
Wilson HR (2003) Incubation and Hatching of Ratites. one of a series of the Animal Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu.
Wilson HR, Eldred AR, Wilcox CJ (1997) Storage time and ostrich egg hatchability. *Journal of Applied Poultry Research* **6**, 216-220.
Wotton SB, Hewitt L (1999) Transportation of ostriches - a review. *Veterinary Record* **145**, 725-731.
Wotton S, Sparrey J (2002) Stunning and slaughter of ostriches. *Meat Science* **60**, 389-394.
Yagil R, van Creveld C, Markowitz E, Levy A (1996) Urine production and health status in ostriches. In 'Improving our understanding of ratites in a farming environment'. (Ed DC Deeming) p. 59. (Oxfordshire, Ratite Conference)

Reducing Mortality Rates in Ostrich Chicks

by Phil glatz and Zhihong Miao
RIRDC Publication No. 08/187

This project involved a review that examined factors both prior to hatch and after hatch that could lead to high mortality rates in chicks.

Appropriate breeder management, fertile egg handling and storage and incubation can improve hatchability and survival rates of chicks.

Ostrich chick mortality can also be reduced by correct housing, feeding and health management of chicks at hatch and during the brooding period. Low mortality (10-15%) can be achieved by good hygiene, proper feeding and housing and good management.

This report is targeted at Australian and overseas ostrich farmers.

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