HANDLING, INCUBATION, AND HATCHABILITY OF OSTRICH (*STRUTHIO CAMELUS VAR. DOMESTICUS*) EGGS: A REVIEW

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Primary Audience: Researchers, Commercial Producers

SUMMARY

Ostrich production is highly management intensive. Losses to producers commonly arise from infertile eggs, poor egg handling, and incorrect storage and incubator settings (temperature, relative humidity, and air flow). Early chick mortality is also a significant factor influencing successful ostrich management. Microbial infection of ostrich eggs, caused by contaminated nests, inadequate egg cleaning, and poor incubator and hatcher sanitation, results in low hatchability. Adequate breeder nutrition is vital for ensuring fertility, increasing the number of eggs laid, and ensuring good survival rates of hatched chicks. The producer must work closely with veterinary extension officers, health laboratories, ostrich producer associations, researchers, and other farmers so that ostrich egg production is molded into a process of excellence.

Key words: Egg, handling, hatchability, incubation, management, ostrich
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INTRODUCTION

The ostrich (*Struthio camelus var. domesticus*) is the largest of all birds and belongs to a small order of birds known as the ratitae or running birds (ostrich, emu, cassowary, rhea, and kiwi). Ostriches and emus are raised commercially, and, although it is easier to raise because of its tolerance to cold and humid conditions and early sexual maturity, the emu has a lower egg production and a longer egg incubation period [1]. The ostrich, however, has been farmed for more than 100 yr in South Africa [2], and the importance of ostrich production has been shown by its global growth over the past few years [3]. This increased production has necessitated improvements in farm practices to ensure adequate and increased breeding and survivability success [4]. The main constraints in ostrich production are infertile eggs, embryonic mortality, and posthatching leg deformity [5]. According to Van Zyl [6], the artificial incubation of ostrich eggs is characterized by low hatchability and is, therefore, a major source of loss to the producer. Low hatchability is a result of bad management practices [7], possibly temperature control and relative humidity in the incubator [8]. Other factors thought to influence successful egg management include egg weight, yolk quality, nutrition of breeders, age of the breeders, the ratio of hens to cocks, the management of egg hatchability, egg washing, fumigation, and storage of eggs [9, 10, 11].

Adult hens start laying at 2 to 3 yr of age and remain fertile for about 40 yr. During this

period, annual egg production varies between 20 and 70 eggs [12]. Thus, selective breeding and good breeder nutrition are vital for ensuring good production performance of the egg, embryo, and chick. Van Schalkwyk et al. [13] demonstrated that the phenotypic correlation between total egg production and hatching egg production was in decreasing order of egg production performance (r = 0.81), hatchability (r = 0.73), embryonic deaths (r = –0.21), and infertility (r = –0.58). Breeder performance is reported to be best with a dietary inclusion of 35% dried lucerne (alfalfa) and a diet containing 14% protein [14].

The aim of this article, therefore, is to appraise critically the literature concerning the factors necessary in the successful management of ostrich eggs. This work essentially forms an extension of previous work by Cooper [15].

Collection of Eggs

Trained workers should watch breeding hens so that eggs are collected 10 to 15 min after laying, especially on warm days, to allow sufficient time for the cuticle to dry. Quick collection prevents damage of the embryo in hot temperatures, microbial spoilage, and loss from theft or predation. Button et al. [16] showed that 39.5% of 114 fertile eggs with early to midterm embryonic death were infected, a finding that was significantly ($P < 0.01$) greater than the 19.6% infection rate of 240 infertile eggs. This study demonstrated that microbial infection is an important cause of embryonic death; the principal microbes are environmental or fecal bacteria and fungi. The maintenance of nest hygiene is considered the simplest way of reducing microbial contamination [17]. Infection of eggs with *Streptomyces* from a soiled nest has been reported to arise from microbes that gain access to the egg contents on cooling [18]. The authors demonstrated that out of a batch of 78 eggs condemned because of failure to hatch, 7 were infected with *Streptomyces*. This study confirmed findings of Welsh et al. [19] that demonstrated that contamination of eggs with *Streptomyces* arises from contact with soil, water, or plant material.

Method of Collection

The egg should be carefully gathered and wiped with a dry cloth. Holding the eggs with sterile toweling helps to prevent possible contamination from the worker's hands. The eggs are then placed in a carrying basket lined with foam rubber to prevent breakage. Details of each egg laid are tabulated in a notebook [15].

Cleaning of the Eggs

Before cleaning, the worker should sanitize his or her hands in a warm iodine wash or other antibacterial solution at 40 °C. Common bacterial infestations arising from poor egg cleaning include *Escherichia coli*, *Aeromonas* sp., *Enterobacter* sp., *Acinetobacter* sp., *Citrobacter* sp., and *Streptococcus faecalis*. Fungal infestations include *Penicillium* sp. and *Fusarium* sp. [8]. Deeming [20] demonstrated high mortality in full-term embryos that failed to hatch because of infection of the yolk sac with bacteria, including *Staphylococci*, *E. coli*, *Bacillus licheniformis*, and *Achromobacter* spp. Welsh et al. [19] describes a study using 675 eggs where the shell membranes were swabbed. In that study, 18% of the nonviable eggs were infected with bacteria, and, of those infected, 68% were colonized by Gram-negative bacteria. *Escherichia coli* was the predominant bacterial isolate of infected eggs represented by 5% of infected egg samples and 19.4% of infected yolk sac samples. An earlier study [21] described the clinical signs observed in *Salmonella*-infected breeder birds, resulting in shell-less, infertile eggs and early embryonic death.

Vigorous egg washing is inadvisable because of the likelihood of increasing the diffusive resistance in the eggshell pores via an increase in the egg water vapor pressure and reduced gaseous exchange [22]. If the temperature of the antiseptic solution is lower than the temperature of the egg, a reduction in the volume of the egg contents occurs, causing a negative pressure and vacuum, which results in an increase in the movement of bacteria through the shell pores and contamination of the internal contents of the egg and subsequent infection of the embryo. Such a practice has lead to high embryo mortality and yolk sac infection. Chick deaths after hatching show typical lesions of yolk sac infection with and without navel abscesses. Eggs are best cleaned with a dry cloth

and then lightly mist-sprayed with 50 g/10 L water Virkon solution [23]. The use of a potassium permanganate-formalin mix for cleaning eggs has been reported [24], although the usefulness of this technique is questionable given the strong reaction resulting from strong potassium permanganate, the oxidizing agent [25]. Pouring formalin over permanganate crystals would be more useful for disinfecting incubators and hatchers given the rapid release of formaldehyde vapor.

One study determined the influence of different disinfection protocols on the hatching performance of eggs [26]. Batches of 25 to 55 eggs were randomly allocated to four treatments: control (eggs were not subjected to disinfectant), powder peroxigen compound egg wash, quaternary ammonium egg wash, and use of a UV (ultraviolet) cabinet disinfectant machine. Eggs were incubated at 36 °C with a relative humidity of 28% and rotated hourly through 60°. Using a completely randomized design, infertility was not significantly different among treatments. The percentage of live chicks hatched was significantly ($P < 0.01$) elevated, and late embryonic deaths were significantly ($P < 0.01$) lower, for eggs on the UV treatment than on the other two sanitizing treatments.

Sterilization of Storage and Incubator Rooms

A light spray of potassium permanganate and formaldehyde may be used to disinfect the room. Alternatively, UV light may be used, although formaldehyde and UV light are potential carcinogens and producers should only use these methods after implementing safe working practice guidelines.

Storage of Eggs

The eggs are normally stored for 7 d under UV lighting to eliminate bacteria. It is important to maintain a low relative humidity of about 35% to prevent the development of overhydrated chicks [8]. Temperatures of 17 to 21 °C should be maintained [27]. Wilson et al. [28] showed that storage of ostrich eggs over 7 d at 12.8 to 15.6 °C resulted in a probable ($P < 0.08$) linear decline in hatchability. Preheating ostrich eggs for 4 h at 36 °C prior to setting them in the incubator resulted in a significant ($P < 0.005$) reduction of mean embryonic deaths (n = 17.1) in comparison with eggs that were not preheated (n = 26.2) (SEM = 2.3) [29]. This method confirms the need to prevent condensation of water on the shell surface during incubation [30] given the possibility that egg temperature is lower than the dew point for humidity of the air in the incubator, especially when eggs are stored at temperatures lower than 20 °C.

Incubation and Hatching

According to Hoyt et al. [47], the hatching time for ostrich eggs is closely related to incubation temperature: 44 d at 35.5 °C and 47 d at 35.0 °C. Hygiene is critical in the incubator room and hatchery. Walk-in baths filled with chlorine solution prevent the introduction of pathogens on shoes, and hand basins should have disinfectant soap and disposable paper towels [15]. The incubator should have a controlled-temperature setting, a turning facility, humidity control, and good air circulation. A good air flow at about 45 L/h/egg in the incubator is vital to prevent the build up of carbon dioxide and rises in water vapor; air movement in the incubator room is also important. The incubator must be thoroughly disinfected after each hatching. One study suggests that eggs should be turned a minimum of five times per day to stimulate the growth of the embryo [31]. Other reasons for turning include preventing the embryo from becoming attached to the inner shell membrane and ensuring a uniform temperature [27]. The author advocates a minimum turning period of five times every 24 h, although there are some indications that turning ostrich eggs 24 times per day gives superior results compared with turning five times per day. Indeed, van Schalkwyk et al. [32] demonstrated improved hatchability of fertile ostrich eggs turned through 60° hourly in eggs set in horizontal positions for 2 to 3 wk and vertically for the remainder of the period. In this study, the hatchability of fertile eggs set in the horizontal position without any turning was very low (27%). However, improvements in hatchability

to 80% were observed in eggs automatically turned through 60°, around the long axis in the incubator.

Malpositioning has been shown to be a significant cause of death of ostrich embryos (55% of 111 deaths during the last 10 to 14 d of incubation) [33]. The ostrich industry in Southern Africa experiences a high rate of embryo mortality mostly during the last 10 to 14 d of incubation. One study clearly showed that death in embryos was due to both severe oedema (45%) alone and in combination with malpositioning (55%) [34]. Poor hatchability of ostrich eggs may be related to malpositioning of the embryo in relation to the air cell if the egg is incubated horizontally, with the air cell down, or without adequate turning [34]. Other findings showed that oedema was correlated with the amount of water lost from the eggs, which was, in turn, correlated with egg size. A significantly ($P < 0.01$) low percentage of chicks hatched showed myopathy, gross lesions of internal organs, haemorrhage, bacterial infections, and congenital deformities [33]. This study confirmed earlier findings of Terzich and Van-Hooser [35] who reported oedema, aspergillosis, leg deformities, and impaction of the proventriculus in chicks less than 3 wk old. Philbey et al. [36] reported anasarca and acute degenerative changes in the complexus and pelvic limb muscles of chicks that died at or within 1 wk of hatching. The authors described a hatchability of 43 to 75% despite the fact that most eggs were fertile and embryos developed normally just before hatching. Farms with low hatchability had the most chicks with anasarca and myopathy. The authors suggested that myopathy occurred secondarily to oedema, hypoxia, exertion, metabolic acidosis, and other physiological imbalances or nutritional imbalances. Degeneration could contribute to muscular fatigue and failure to hatch.

A study comparing embryonic deaths (701 deaths of 3,341 fertile eggs) in artificially incubated ostrich eggs demonstrated that deaths were curve-linearly related to evaporative water loss up to 35 d of incubation [37]. Phenotypic correlation of water loss to 14 d of incubation with water loss to 21 and 35 d of incubation were 0.87 and 0.84, respectively. The corresponding correlation between water loss to 21 d of incubation and water loss to 35 d of incubation was 0.93. A quadratic equation fitted to the data accounted for 84.8% of the variation in embryonic deaths.

Deeming [17, 38] demonstrated low hatchability (37.5%) in a batch of 320 ostrich eggs because of high rates of infertility (22.2%) and contamination (22.8%). Embryonic mortality was shown to be high at the start and end of incubation; the latter was related to the percentage of water loss and mass specific water vapor conductance of the shell. The authors showed that a breeding ratio of cocks to hens of 1:1 or 1:2 resulted in an overall fertility of 78.7%, whereas larger ratios of hens had lower fertilities. However, mean weekly hatchability was 24.1%, and hatchability of fertile eggs was 31%, mainly because of microbial contamination of 32.6% of eggs laid. These findings confirmed previous work in which egg fertility was 81.8% and egg hatchability was 16.7 and 48.2%, respectively, for naturally hatched and artificially incubated eggs [39]. The author described how egg size (length and diameter) and weight had a significant ($P < 0.01$) effect on hatching rate and storage of eggs for 2 to 7 d prior to incubation improved hatchability. Maximum hatchability (85.7%) was attained for eggs incubated in a vertical position and turned eight times daily. Badley [40] compared the artificial incubation of 180 ostrich eggs horizontally or through the vertical on embryo survival and found no significant differences between the two. Jost [41] demonstrated that the avoidance of inbreeding significantly increased egg production; eggs weighing 1,300 to 1,700 g had the best hatchability. The author showed that the hatchability of eggs stored at 15 to 21 °C for 3 to 5 d before incubation was better than that of eggs stored for less than 3 or more than 5 d. Reiner and Dzapo [42] demonstrated that the hatching time of an ostrich embryo is proportional to its oxygen consumption. Maximum oxygen consumption was shown by Day 36, demanding about 240 L fresh air/egg/d. Oxygen consumption of embryos on Day 36 was significantly ($P < 0.01$) and positively correlated with their vitality.

Research to determine the optimum incubation temperature for ostrich eggs requires a large number of eggs in carefully controlled and replicated trials. There is currently nothing

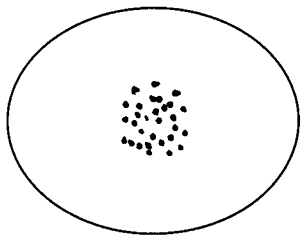
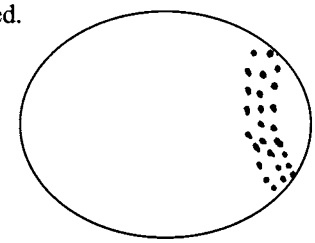
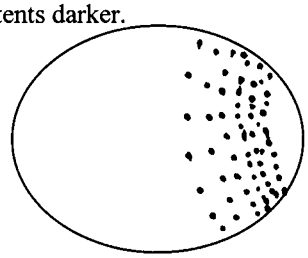
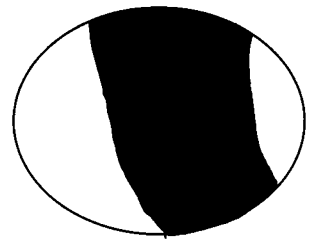
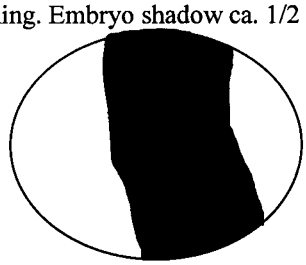
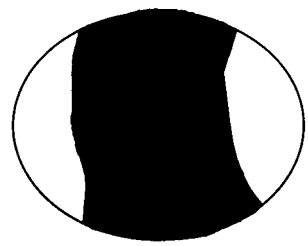
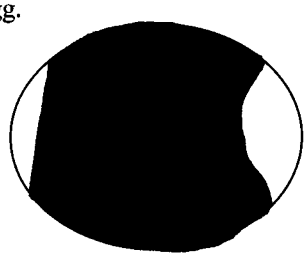
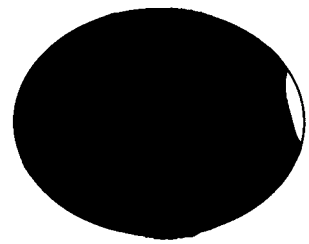
in the literature to support such work. However, successful incubation parameters recommended for ostrich producers in Zimbabwe are temperatures of 36.0 to 36.5 °C and relative humidities of 20 to 30% [8]. This was confirmed by Philbey et al. [36] who showed that, on farms in Australia, hatchability was improved by incubating eggs at 20 to 40% relative humidity. Indeed, some authors attribute reduced hatching times to temperatures above 40 °C [43]. Other investigators report temperatures of 36 °C [31] and varying relative humidities depending on altitude, some as high as 60%, although temperatures did not differ from those in Zimbabwe [34, 44]. However, Deeming et al. [43] demonstrated that average weight losses of 13.4% to 39 d of incubation, similar to those in wild nests with egg weight losses of 13.2% [45], can only be attained with relative humidities less than 30 to 35% (a wet bulb temperature lower than 23.5 °C at 36.0 °C). The temperature in the incubator is based on that measured naturally in the nest environment, varying from 32.9 to 37.1 °C, and a mean nest air temperature of 36.1 °C [45]. Complementing these findings, Swart and Rahn [46] demonstrated that the relative humidity of air in naturally incubated ostrich nests increases from Days 6 to 13 and then declines to Day 41. These findings demonstrated that eggs incubated naturally do not experience increases in relative humidity in the latter part of the incubation period. The incubation period is dependent on temperature; eggs incubated at 35.5 °C hatch in 44.1 days [44], whereas, at 35 °C, the incubation period is 47 d [47]. The temperature in the center of fertile eggs increases with incubation time as the embryo generates its own heat [46]. The temperature of the embryo is critical during development. Temperature and water vapor conductance of eggs are important for normal heart rate and, hence, survival of the embryo. Heart rate measured with a non-invasive condenser microphone for 36 eggs incubated at 36.3 °C showed the maintenance of heart rate of 185 beats/min during Days 19 to 23 [48]. Decreases in heart rate thereafter were associated with high water vapor conductance of the eggs in which heart rate decreased less during the last stages of incubation.

Multistage incubation systems allow proper interrelations of the eggs, i.e., new eggs require additional heat to counteract evaporative cooling during water loss [49] and older eggs need to lose heat generated by embryo metabolism [45]. The advantage of this system is that exchange of heat between these groups of eggs achieves both warming and cooling within one set point of incubation temperature [43]. Foggin and Honywill [8] report that, at a temperature of 36.0 °C and a relative humidity of 24.6%, the water vapor pressure gradient across an eggshell is 33.6 torr (torr = 133.322 PA). Such an egg would lose approximately 0.293% of its initial mass per day. Other authors suggest that the optimal incubator humidity for ostrich eggs is less than 25% to allow a 15% loss of initial egg mass during a 45-day incubation period. More [50] demonstrated, using random effects logistic regression modeling, that, in infertile eggs or those failing to hatch, there was no association between egg fertility and egg weight at the start of incubation, the season of lay, or the duration of egg storage prior to incubation. There was, however, a relationship between egg fertility and farm level factors, including genetics, management, nutrition, disease, and environment. Wilson et al. [28] demonstrated that egg weight loss to Day 38 of incubation approximated 13.2%, and chick weight at hatching averaged 63.6% of initial egg weight. Chicks were shown to lose body weight at 1.35 g/h if not removed immediately from the incubator after hatching. Lowereing incubation temperatures allows a longer development time for the embryo, so that it attains an adequate level of maturity during the plateau stage of oxygen consumption, that is the stage just prior to pipping when the partial pressure of oxygen in the egg is the lowest [51]. Hsu et al. [52] showed that high ambient temperatures above 34 °C in chicken houses resulted in inferior egg quality because of influences on shell weight, shell thickness, shell breaking strength, and specific gravity. The inability of ostrich eggs to lose sufficient weight during incubation is a major cause of low hatchability [53]. The authors found that hatchability was significantly ($P < 0.01$) increased by more than 25% in eggs with high eggshell porosity. The numbers of pores were shown to be positively corre-

lated more toward egg weight loss during incubation than to hatchability as indicated by a higher correlation coefficient of r = 0.64 as opposed to r = 0.25, respectively. Deeming [38] suggested that mortality of late stage embryos is related to the percentage lost and to the mass specific water vapor conductance of the shell. Embryonic deaths have been demonstrated as curve-linearly related to evaporative water loss up to 35 d of incubation in which 84.8% of the variation in embryonic deaths was accounted for by quadratic regression. Higher percentages of embryonic deaths occurred from eggs showing very little (less than 10%) or excessive (more than 19%) water losses [54]. These studies confirm the findings of other investigators who described the proper water balance of eggs during incubation in turkey eggs [55] and gaseous exchange dependent on the number of pores in avian eggshells [56, 57].

The monitoring of embryo development during incubation is done by a process called candling and the use of a candling chart [40, 58]. Candled eggs should be compared against charts to determine the stage of development of the embryo by the amount of shadow in the egg (Figure 1). The air cell becomes more pronounced as development proceeds [27]. The eggs are checked after 14 days, and, if there is no change, they are assumed to be infertile and blown (a procedure whereby the internal contents are removed and the shell is sold for decoration) [59]. An infertile egg will begin to decompose and, thus, be a potential source of infection to other eggs in the incubator. Infected eggs can be detected during candling, as the appearance of dark patches indicates infection of shell membranes [38]. Deeming [58] demonstrated that, during candling of ostrich eggs, there is a progressive increase in dark shadowing within the egg. Although Stages 1 through 8 (Figure 1) are not unique to the ostrich, candling was assessed by Hallam [27] as being an important method for monitoring development of ostrich eggs during incubation. However, the hatching position adopted by the ostrich embryo during the hatching sequence is unique and different from that in the fowl. During internal pipping, the air space is pulled toward the beak in ostriches; in fowl embryos, the beak moves to the air space. In the ostrich, the right foot is used in unison with the beak to break the shell, a unique adaptation to an egg with a hard, brittle shell. A further adaptation in the ostrich embryo is the distal tip of the upper mandible, which is covered by an amorphous layer, the right side of which disappears during hatching [60]. The authors described this layer as acting to protect the beak during the rubbing process, which creates a hole in the inner shell membrane during hatching. Candling should be done once a week for 40 d. Once it is observed that the chick is pipping, the egg should be transferred to a hatchery [27]. During hatching, one should not be too anxious to help a chick out of its shell as this may harm it [61]. Misconceptions among producers arise under the false impression that the incubation period of eggs is 42 d, beyond which hypoxia occurs. This notion leads farmers to drill holes into and crack open shells to help the chick hatch [62]. Commonly, in such instances, stand-alone attitudes by ostrich producer associations predominate, and advice on the best way to manage egg performance is lacking. Once hatched, the umbilical cord is disinfected with gentian violet spray [23] or cleaned with iodine solution until it has completely dried up. The hatching weight of chicks is highly correlated with egg size at setting [63]. Factors influencing hygiene in the hatchery include overcrowding and previous occupancy. Problems with hatchability are often related to factors such as infertility, faulty breeder nutrition, disease status, or poor egg handling and hygiene [64]. The hatchery must be completely disinfected between batches of hatched chicks to prevent microbial contamination [65].

Another factor affecting hatchability is the nutritional status of breeders; egg-laying hens require twice the concentration (from 0.8 to 1.5% to 2.0 to 2.5% [27]) of total calcium for the formation of the shell and shell membranes of the egg. These observations have been demonstrated in other studies in poultry in which calcium, phosphorus, and protein are required throughout the day for the formation of egg components [66]. Ullrey and Allen [67] report that ostrich hens laying a normal annual clutch of eggs do not significantly increase the dietary calcium requirement. However, by continually removing eggs, the producer is encouraging egg

Stage 1 Air cell not formed. Yolk shadow very mobile, small and oval contents pale/slightly mottled. 	**Stage 2** Air cell formed or partially complete embryo shadow surrounds air cell (ca. 1/5 of egg). Limits of embryo shadow may be hard to define. Embryo shadow heavily mottled. 
Stage 3 Air cell clearly defined. Embryo shadow darkening (ca. 1/3 of egg). Limits of embryo shadow clearly defined. Remainder of egg contents darker. 	**Stage 4** Air cell enlarging and well defined. Embryo shadow dark and sits at 45° across egg. Limits of embryo shadow clear (< 1/2 of egg). 
Stage 5 Air cell large (ca. 1/6 of egg). Embryo shadow dark, across egg. Remainders of egg darkening. Embryo shadow ca. 1/2 of egg. 	**Stage 6** Air cell boundary dark and clearly defined. Embryo shadow ca. 2/3 of egg. 
Stage 7 Embryo shadow very dark ca. 7/8 of egg. 	**Stage 8** Embryo movement may occur. No pale margins visible around egg. Egg feels very warm to the touch. 

Source: Sharp [75]

FIGURE 1. Development of an embryo as shown with candling

TABLE 1. The influence of nutrient and deficiencies on egg hatchability[A,B]

NUTRIENT	NUTRIENT EFFECT	DEFICIENCY SIGNS
Vitamin A	Egg production, hatchability, fertility	Death within 48 h of incubation; failure to develop circulatory system; deformities of kidneys, eyes, and skeleton
Vitamin D	Egg production, hatchability, fertility, shell quality	Death by 18 to 19 d of incubation with malpositioning, soft bones, and/or a defective upper beak
Vitamin E	Hatchability	Death by 84 to 96 h of incubation with haemorrhaging and circulatory failure
Vitamin K	Hatchability	Mortality occurs between 18 d and hatch with variable haemorrhaging
Thiamin	Hatchability	High embryo mortality during hatch; no other obvious symptoms
Riboflavin	Egg production, hatchability, chick quality	Mortality peaks at 60 h, 14 d, and 20 d of incubation, with peaks prominent early as deficiency becomes severe; altered limb and beak development
Niacin	Egg production, egg yield, hatchability	Various beak and bone malformations can occur during incubation
Biotin	Egg production	High death rate at 19 to 21 d of incubation; embryos have parrot beak or skeletal deformities
Pantothenic acid	Egg production, hatchability, viability of offspring	Death appears at 14 d of incubation in severe cases; variable haemorrhaging and oedema with wiry feathers
Folic acid	Egg production, hatchability	Mortality at 20 d of incubation; the dead appear normal except for beak malformations
Vitamin B12	Hatchability	Mortality at 20 d of incubation, oedema, haemorrhaging, fatty organs, and head between thighs malpositioned
Manganese	Egg weight, egg production, hatchability, shell quality	Peak deaths prior to hatch, oedema, malformations, abnormal feathering
Zinc	Egg yield, hatchability, feather condition of offspring	Deaths prior to hatch, underdeveloped eyes, or missing limbs
Copper	Shell quality	Deaths at early blood stage; no malformations
Iodine	Hatchability	Prolongation of hatching time; incomplete abdominal closure
Iron	Hatchability	Low blood haemoglobin; poor embryonic circulation in candled eggs
Selenium	Egg production, hatchability	High incidence of embryo death early in incubation

[A]Source: NRC Nutrient Requirements of Poultry [69].
[B]Reflects values for chickens, as NRC does not report such values for ratites.

production for which increased calcium requirements are met by inclusion of 16 g/kg (1.6%) calcium in the feed or by providing granulated calcium carbonate or oyster shells. It should be noted that this level of calcium is below that which was recommended by Hallam [27]. Scheideler and Angel [68] emphasize the need for vitamin E and selenium as essential nutrients in breeder diets for egg production. A high potency feed should not be restricted to the protein content but to the overall ability of the ration to provide reserves of all nutrients, including minerals, vitamins, and trace elements. Good nutrition ensures egg productivity through improved hatchability, an increase in healthy embryos, survivability of hatched chicks, earlier breeding, higher fertility rates, better egg quality and porosity, and higher egg yolk nutrient reserves [69]. The importance of nutrients and the deficiencies thereof in egg hatchability are shown in Table 1.

Parallel studies in White Leghorns demonstrated an increased deposition of fat and energy during the laying period, but protein deposition decreased [70]. This result is due to the metabolizable energy utilization for fat energy deposition, which is higher than that for protein energy deposition in the egg. Related studies of ostrich eggs are currently unavailable. However, Reiner et al. [71] compared the cholesterol content, fatty acid profiles, and nutrients of ostrich eggs with other poultry species. Cholesterol content in ostrich yolk was in the upper range of that in chicken yolk with lower amounts of monounsaturated fatty acids and increased proportions of saturated and polyenoic fatty acids. The appropriate levels of these components can only be achieved through good breeder nutrition.

Posthatch Survival of Chicks

The importance of maintaining correct relative humidities in the incubator has a bearing on the subsequent normal growth and survival of ostrich chicks. High relative humidities of 67 to 83% have been attributed to the development of anasarca and myopathy in chicks [36]. The study examined 20 chicks that died from farms with low hatchabilities (43 to 75%). Most chicks had anasarca, and death occurred in the shell at the point of hatch and 1 week after hatching. Ley et al. [34] also demonstrated poor hatchability associated with high relative humidities and the hatching of weak oedematous chicks with high mortality in the early posthatching period. The authors attributed excessive relative humidity, causing reduction in the loss of moisture from the egg and interfering with respiratory exchange through the air cell, to the ability of the chick to penetrate the air cell during hatching. This process allowed them to breathe the air before the shell was pipped. Hoyt et al. [47] showed that the oxygen tension in the air cell of ostrich eggs is higher than that in poultry, potentiating hypoxia associated with a decreased rate of diffusion of oxygen through the cell at high relative humidities [36].

Failure to absorb the yolk sac during the first few days after hatching is a common observation in ostrich chicks, leading to poor development and growth. This phenomenon has been associated with poor husbandry, high ambient temperatures, energy-rich diets, and lack of exercise [62]. Indeed, poor nutrition has been cited as the primary cause of high chick mortalities; overcrowding, overheating, and poor ventilation have contributed to nutritional stress and disease [72]. Poor hygiene and maintenance in incubators and hatchers result in pathogenic microbial infections, and the posthatch survivability of chicks is severely reduced. Sick chicks are generally lethargic and anorexic, and there are commonly concurrent bacterial, yeast, and viral infections [73, 74].

Conclusions and Applications

1. Ostrich egg production is management intensive. Improving the hatchability rates of ostrich eggs requires team effort of the producer and his or her workers to maximize survivability and hatchability rates. Veterinary extension officers should visit farms regularly to give advice to producers on the integration of best practices.

2. Infection of fertile ostrich eggs is associated with the death of an appreciable number of embryos and, consequently, reduced hatchability. Nests should be sited away from feeding and usual congregation sites to minimize fecal contamination. Sand should be replaced regularly. Strict maintenance of hygiene and sanitation is important to eliminate microbial infection in the incubator and hatchery. Microbial culture is useful for identifying the microbe present in an infected egg and establishing its source. If there is an unacceptably high number of eggs that fail to hatch, they should be submitted to a veterinary research laboratory for investigation of fertility status.
3. The temperature and relative humidity of eggs during storage (17 to 20 °C and 35% RH) and incubation (36 to 36.5 °C and 20 to 30% RH) must be maintained within narrowly defined parameters if survivability is to be maximized. The use of a constant power source, trained personnel, and daily recordings of temperature and relative humidity are indicative of good management practice.
4. Breeder nutrition is a key element of good egg fertility and hatchability.
5. Local ostrich producer associations should provide funds for research on ostrich egg production to identify problem areas fully and make improvements. Best practices on ostrich egg management should be compiled into a manual evaluated annually and made available to producers at an affordable price. Funding should facilitate research via trials on both normal and abnormal eggs and chicks to determine the factors contributing to embryonic death at each stage of development and posthatching.

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