Incubation temperatures and humidity requirements of ostrich (*Struthio camelus*) eggs, and effects on hatchability

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INTRODUCTION:

The ostrich (*Struthio camelus*), is a member of the ratite family of flightless birds. It is the world's largest living bird, and a native of the African continent. Ostriches have been raised to produce usable products such as leather, meat, feathers and eggs, with these products fulfilling established markets throughout the world.

Intensive farming of ostriches originated in South Africa around hundred and fifty years ago. The Austratian industry was established shortly thereafter in the mid-1870's. The number of ostrich farms, in Australia, steadily grew until the onset of World War I, in 1914, when the industry suffered a dramatic decline in response to diminishing world markets for ostrich-based products. It has only been since the late 1970's that the ostrich industry, in Australia, has once again begun to expand (Hastings, 1994; Tuckwell and Rice, 1993).

The Australian ostrich market is at present going through a transition period. The industry is on the verge of ending its breeding phase and becoming commercial. The commercial industry supplys world-wide demand for ostrich produce, such as feathers, leather and meat. In a recent publication of the Australian Ostrich Association Journal, Black (1996) suggested that "many more thousands of breeding birds" needed to be bred in Australia before the Australian ostrich industry would be able "to provide commercial sustainability".

This transition from a breeder-based market into a commercial-based market, creates a new environnment with different determinants of profitability. These new factors need to be identified and evaluated in order to sustain commercial profitability. One very important aspect will be the ability to produce ostriches efficiently i.e. maximise fertility of the breeding stock, the hatchability of eggs and the survival of chicks.

It will be the purpose of this essay to concentrate on the aspect of hatchability of ostrich eggs, in particular how humidity and temperature affect the hatchability of eggs incubated. This discussion will elaborate on the interactions between water loss of eggs during incubation, humidity and temperature. These factors will individually be discussed and how they affect

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the embryo development and subsequent hatching of the chicks. Practical aspects of artificial incubation and the effects of altering their environmental conditions on the incubating eggs will be addressed later.

The Hatchability of Ostrich Eggs

The hatchability of ostrich eggs serves as an important index when considering the production of ostrich chicks. Hatchability, in this essay will be defined as the number of eggs that successfully hatch, divided by the number of fertile eggs, multiplied by one hundred i.e. hatchability is expressed as a percentage. Hatchability can also be expressed as a percentage of eggs hatched compared to number of eggs set, but unless stated the former definition of hatchability will be used for the purpose of this essay.

In Australia, the hatchability of ostrich eggs are reported, by many ostrich breeders, to be below 50% (Philbey, Button, Munro, Glastonbury, Hindmarsh and Love, 1991). A limited survey, conducted by Button (1993a), of seven Australian breeders, revealed an average hatchability of 54.3%. Smith (1993) comments that similar breeding difficulties are encountered in the United States ostrich industry.

In order to achieve higher hatchabilities, it can readily be deduced that the level of embryonic mortality needs to be minimised. To obtain this goal, egg quality needs to be high. Genetical influences from parent birds, the reproductive tract of the hen, the nutritional state of the hen, sanitation, storage conditions et cetera, are just a number of the many factors which will influence egg quality prior to incubation (Deeming, 1993; Hastings, 1994; Tuckwell and Rice, 1993). What constitutes high egg quality in ostriches still remains largely unresearched worldwide (Deeming, 1993).

During incubation, there is a dynamic interaction between the developing embryo and the external environment. It is this environment that the ostrich producer can manipulate will relative ease. By changing the temperature, humidity, oxygen and carbon dioxide levels within the incubator, the producer can markedly alter embryonic development, hence the hatchability of the eggs.

In order to achieve high hatchability, it is essential to understand what environmental conditions are required for normal ostrich egg development. The following discussion will be limited to the effects of temperature and humidity on ostrich eggs. What temperature and humidity levels constitute an 'optimal' incubator environment for ostrich eggs will be elaborated on shortly. Problems which arise, should the incubation environment be inadequate will also be addressed, as well as what practical changes can be made to correct these problems.

Humidity and Water Loss in Ostrich Eggs

During incubation, all bird eggs lose weight (Deeming, 1993). The egg is essentially a sealed container, from which only air can enter (Rahn, Ar and Paganelli, 1979). This 'sealed container' provides all the essential nutrients, minerals, energy sources and water for the developing embryo to utilise. Therefore the only requirement from the environment is warmth, which is provided by the parent bird under natural conditions, and oxygen. Eggs also need to be periodically turned to prevent adhesion of the embryo to shell membranes (Rahn *et al*., 1979).

Oxygen, essential for embryonic survival, diffuses through thousands of microscopic pores in the shell (Rahn *et al*., 1979). Gas moves through the pores due to passive diffusion from an area of relative high concentration (surrounding air) to an area of relative low concentration (inside the egg) (Rahn *et al*., 1979).

Conversely, the water content within the egg is higher than the air surrounding the egg. Water molecules are smaller than oxygen molecules, therefore the same pores which allow oxygen to diffuse into the egg, allow water molecules to diffuse out of the egg (Rahn *et al*., 1979). . It is this water loss from the egg that is responsible for the normal weight loss of eggs during incubation.

The developing embryo cannot control the rate of water loss, as it is purely a mechanical process. The rate of water loss will be determined by the relative difference in humidity (water content) between inside the egg and outside, as well as the porosity of the eggshell. Deeming (1993) described this relationship between egg weight loss, porosity and humidity as follows:

Water loss = Eggshell porosity x (Humidity in the egg - Humidity in air)

This relationship is a simplified version of Fick's first law of diffusion.

(A) Humidity and Ostrich Eggs

For any particular egg, eggshell porosity will remain constant, as will the humidity inside the egg (remains saturated). This means that the only variable in this expression to affect water loss will be humidity in the air. Simply stated, humidity is an expression of the amount of water molecules in a gaseous environment, such as the atmosphere. It is this variable that producers can control in artificial incubators, hence controlling water loss in ostrich eggs. Humidity is however not the sole determinant of water loss. Temperature and air flow also determine the rate of water loss.

The most common expression of humidity is %relative humidity. %relative humidity is expressed as a percentage of water vapour in air compared to the amount when air can not hold anymore water vapour, i.e. when the air is saturated. %relative humidity can be determined from psychrometric charts. Psychrometric charts relate dry bulb temperature and wet bulb temperature to moisture content of dry air, as well as the relative humidity (Deeming, 1993). Dry bulb temperature is the temperature of dry air i.e. ambient temperature of the environment (Deeming, 1993). Wet bulb temperature is determined by a thermometer whose probe is maintained moist via a wick from a distilled water reservoir. The water is continually being evaporated from the surface of the probe and wick. This evaporative process cools the probe, hence the reading of the wet bulb thermometer will be lower than the dry bulb thermometer (Deeming, 1993). The difference between the dry and wet bulb thermometers indicates the relative humidity , as well as the amount of water in the air. As previously stated, standard psychrometric charts allow the determination of relative humidity, once the wet bulb and dry bulb temperatures are known. Dry and wet bulb thermometers are simple, effective equipment that can be readily installed in artificial incubators. This allows the producers to determine the relative humidity inside the incubator.

What is the optimal humidity for artificial incubators? In the wild, the relative humidity in ostrich nests vary quite considerably. Bertram and Burger (1981) recorded mean relative humidities of 43%, with the nest air temperature being 32.2^{o}C, in one group and a mean relative humidity of 41% (nest temperature being 33.6^{o}C), in another group. However, Bertram and Burger (1981) recorded that the relative humidities within the nests ranged between 30% to 72%. This variation in relative humidities in wild ostrich nests was attributed to natural variation during the day, as well as changes over the entire incubation period.

It is generally accepted than the relative humidity of artificial incubators should remain below 35% (Deeming, 1993), but relative humidity levels are often modified by farmers to achieve a constant weight loss from the incubating eggs. The reasons for this practice will be discussed shortly.

(B) Water Losses from Ostrich Eggs

What is the optimal water loss from the ostrich egg during incubation? Ar and Rahn (1980) were able to show, over a wide range of avian species, egg masses and incubation periods, that water loss is on average 15.0% of the initial egg mass. Meir and Ar (1987) were able to demonstrate, using large samples, that eggs losing more than 20% or less than 10% of their mass of water was significantly associated with reduced hatchability.

Bertram and Burger (1981) measured the weight loss of ostrich eggs incubated under natural conditions and found that they lost on average 11 to 12% of their weight. Swart, Rahn and de Kock. (1987) demonstrated similar results measuring ostrich egg weight losses of 13.4% during the incubation period. Smith (1993) recommends that eggs should lose 14% of their initial weight. Minnaar and Minnaar (1994) suggested emu eggs should lose 10 to 20% of their initial weight during incubation, with an 'ideal' range being between 13% to 15%. Deeming (1993) states that an optimal level of water loss, from the start of incubation to the point at which the shell is broken, is 15% of the eggs initial mass. However Deeming suggests that further research be undertaken before adjusting this 15% goal - something which still has yet to be presented.

When the incubating eggs are losing too much water i.e. greater than 20%, then changes need to be implemented. Dehydration of egg contents will increase the risk of embryonic death and ultimately reduce the hatchability of the batch. When water loss is occurring at this high a level, the shell porosity may be too great, or the incubator humidity too low (see Fick's Law above). It is important to rule out excessive temperatures or excessive air flow as a possible contributing factor. This problem is easily correctable, if identified early, by either painting an area of the eggs with a special non-toxic acrylic paint (reduces the porosity), or increasing the relative humidity inside the incubator.

Eggs that are not losing enough water i.e. less than 10% may be incubating in incubators with excessive relative humidities or have low eggshell porosities. Counteracting low shell porosities is difficult (Deeming, 1993). Water retention due to low eggshell porosity may be corrected simply by reducing the relative humidity in the incubator. However the problem of low porosity remains and this makes the egg susceptible to hypoxia and death (Deeming,1993).

Temperature Requirements of Ostrich Eggs

Optimal temperature conditions support normal ostrich embryo development. Incubation conditions are considered to be ideal when the eggs are incubated under natural conditions (Deeming, 1993). Successful artificial incubation of ostrich eggs is dependant on careful control of incubator temperature. Small deviations away from optimum have a major effect on embryo development, growth rate and survival (Deeming and Ferguson, 1991; Hastings and Farrell, 1991; Wilson, 1991).

Temperature has two major effects on avian egg development. Firstly, it determines the rate of embryonic development, and secondly it determines the length of incubation (Deeming, Ayres and Ayres, 1993; French 1994; Minnaar and Minnaar, 1994).

The rate of embryo development is entirely dependant on temperature levels. Growth efficiency of the embryo is affected by temperature and appears to be most efficient at the optimal temperature for hatchability (Wilson, 1991). Below a temperature of 15^{o}C, embryonic cells are unable to develop and remain in a stable, but suspended state of development (Deeming, 1993). Below optimum temperature, embryonic development is slowed resulting in a greater incidence of embryonic death (Deeming, 1993). Likewise, temperatures above optimum temperature will cause the embryo to develop too rapidly (Deeming, 1993). Increasing the temperature above normal incubation levels caused turkey embryos to increase the level of malposition and deformities, subsequently reducing hatchability (French, 1994). Similar findings for broiler breeder chickens were found by Scott and MacKenzie (1993). An exception to rapid development of the embryo at elevated temperatures were observed by Deeming *et al.* (1993) where eggs in early incubation appeared to develop more slowly than egg that were incubated at a lower temperature.

However this finding may be erroneous, as the rate of embryonic development was determined via visual observation using candling techniques.

The second effect of temperature on incubating ostrich eggs is its effect on the length of incubation. Under natural conditions, the incubation period for ostrich eggs is commonly quoted as forty two days (Button, 1993b; Deeming, 1993; Hastings, 1994). The incubation period will decline as the incubation temperature increases.(Thornberry, 1989).

The question that still remains unanswered, is what temperature constitutes the optimum temperature for hatchability. Incubation under natural conditions is still considered optimal (Deeming, 1993).

The major heat source for naturally incubated eggs comes from the male and female ostrichs' brood patch. The brood patch is a special area, on the underside, that is devoid of feathers (Swart *et al*., 1987). Heat is conducted across to the egg via direct contact with the brood patch. The brood patch also warms the air surrounding the eggs via convection transfer. Swart *et al*. (1987) demonstrated that at the start of the incubation process a considerable temperature gradient exists between the brood patch and the bottom of the egg (4.6^{o}C). Should artificial incubators attempt to reproduce this temperature gradient when incubating ostrich eggs? Similar situations occur with other avian species under natural conditions, for example fowl. However the success of forced-draft incubators, which maintain uniform temperatures, would tend to suggest that reproducing such temperature gradients is unnecessary (Wilson, 1991).

The transfer of heat from the brood patch maintains the embryo at a temperature conducive with development whilst the embryo's own circulatory system is developing. The temperature at which incubation proceeds under natural conditions is not static, but rather it changes over time (Swart and Rahn, 1988). Once the embryonic circulatory system has developed the temperature within the egg becomes more uniform (Turner, 1991). As embryonic development progresses, metabolic heat becomes another important source of heat (Turner, 1991). It is this embryonic heat which is responsible for the difference in mean egg temperatures of fertile and infertile eggs. Should artificial incubators be adjusted to compensate for the heat generated by the embryo later in the incubation period, in order to maintain a uniform temperature for the developing embryo? Deeming *et al*. (1993) conducted incubation studies where the temperature was gradually decreased as incubation proceeded. In one trial, the temperature was reduced from 36.0^{o}C to 34.8^{o}C, achieving a hatchability 69.2%. In the other trial, the temperature of the incubator was reduced from 37.0^{o}C to 35.5^{o}C, achieved a hatchability of 58.2%. Further investigation will need to be conducted to assess the effect of this procedure on hatchability.

Due to the large size of ostrich eggs, their thermal properties are markedly different from the smaller sized poultry eggs. Larger eggs retain heat for longer than smaller eggs because larger eggs have lower surface area to volume ration (Deeming 1993). This ability to retain heat is known as thermal inertia. Ostrich eggs have a higher thermal inertia than poultry eggs. This higher thermal inertia plays an important part when considering artificial incubation. Preheating eggs after storage will take 16 hours longer than poultry eggs, assuming same incubator temperature conditions (Deeming 1993). However ostrich eggs cool at a slower rate, than do poultry eggs, when removed from the incubator. This property allows managerial process, such as candling and weighing the eggs, to be carried out, whilst minimising the temperature decline inside the egg.

Due to the complex interaction, under natural conditions, between the brood patch, air temperature within the nest, thermal gradients across the egg (in the early stages of incubation), embryonic heat production et cetera, it is difficult to determine the ideal artificial incubator temperature. As previously stated, small deviations away from optimum have a major effect on embryo development, growth rate and survival.

Current recommendations for incubation temperatures are as follows:

(a) Tuckwell and Rice (1993)= 36.4 deg C, wet bulb temperature 21.5 -22^{o}C.
(b) Deeming *et al*. (1993)= 36.0-36.5^{o}C
(c) Smith (1993) = 36.1 - 36.7^{o}C (humidity 20 - 25%)

A common industry misperception is that eggs that have been incubated longer than the 'natural incubation period' of forty two days must contain chicks that are having difficulty hatching. The farmer perceive that the chicks are 'suffocating' inside their shells and hence assist the chicks to hatch (Deeming *et al*. 1993). Chicks that have been assisted to hatch often have very low survival rates (Hastings, 1994; Deeming *et al*., 1993; Minnaar and Minnaar, 1994). Tuckwell and Rice (1993) advise farmers against this practice of assisting 'late' chicks to hatch. The problem most likely is a result of too low an incubator temperature, which causes the incubation period to be extended longer than forty two days.

Embryonic Mortality Patterns

When investigating causes of poor hatchability in ostrich eggs, it is useful to identify at what stage in the incubation process did mortalities occur at, and investigate what factors were involved in bringing about these mortalities.

There are two peaks of mortality during incubation, that are common to many avian species (Deeming, 1993). There is an initial peak during the first week of incubation. This early mortality was attributed by Deeming (1993) to genetical abnormalities, but elevated temperatures also play a significant role (Scott and MacKenzie, 1993), as discussed earlier.

A second peak in mortality occurs shortly before hatching. This later peak not only occurs in ostrich incubation (Philbey *et al*., 1991; Button, 1993a; Deeming, 1993; Miller and Sullivan, 1995) but also in other avian species (French, 1994; Romanoff, 1972).

Button (1993a) found that the most common period of embryonic mortality occurred late in the incubation period. In this study, all the chicks that died in the late embryonic period suffered from anasarca (extensive subcutaneous oedema), and many had myonecrosis of

pipping and leg muscles.
Terzich and Vanhooser (1993) conducted a review of one hundred and twenty-one ostrich necropsies. Within this group, sixteen chicks had failed to hatch after a forty two day incubation period. Fourteen of the ostrich chicks in this group were afflicted with a generalised subcutaneous oedema. All the oedematous chicks had been incubated at relative humidity levels greater than 25%. These findings conflict with findings by Javis, Keffen and Jarvis (1985) who found that incubation was most successful, in relation to hatching and chick health, at relative humidities of 40% to 50%.

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The pattern of ostrich embryonic mortality was common between Philbey *et al*. (1991), Button (1993a), Terzich and Vanhooser (1993), and Miller and Sullivan (1994) with the peak period of embryonic mortality occurring late in the incubation period. Terzich and Vanhooser (1993) attributed the cause of these deaths to incubating the eggs at relative humidities greater than 25%. However Button (1993a) rejected that anasarca in these chicks is entirely the result of excessive incubator humidities, as many of the chicks with anasarca in his study were incubated at relative humidities below 20%. Javis *et al.* (1985) study also tends to reject high relative humidities as the sole cause of anasarca, with the highest hatchability of eggs in this study were incubated at relative humidities between 40% to 50%.

These findings emphasise that weight loss, rather than the relative humidity at which the eggs are incubated, play a more important role in modulating the incubator environment.

The above findings present a common theme. Firstly, there are two identifyable peaks in mortality. The increased mortality early in the incubation period has been attributed to genetical defects, elevated temperatures, improper storage of eggs prior to incubation, solar damage, et cetera. (Deeming, 1993; Scott and MacKenzie, 1993; French, 1994; Hastings, 1994; Miller and Sullivan, 1994). Then there is a second peak, in the late embryonic stage. The overwhelming finding is a high incidence of anasarca in the chicks (Philbey *et al*. 1991; Button, 1993; Deeming, 1993; Smith, 1993; Terzich and Vanhooser, 1993; Miller and Sullivan, 1994; Hastings, 1994). Once again, the aetiology of this disease is debatable. Possible contributing factors include: (1) excessive incubator humidity which inhibits normal water loss; (2) nutritional deficiences, such as Vitamin E and perhaps selenium and (3) hypoxia from low shell porosity with reduced oxygen transport. At present there has been no definitive clinical trial performed, and much research is needed on the aetiology of anasarca of chicks in the late embryonic stage.

Conclusion

With the Australian ostrich industry on the brink of becoming commercialised, the need for high hatchability of ostrich eggs, from commercial stock, is paramount. Natural incubation in the commercial environment would not be of any economical benefit, hence farmers will rely heavily on the use of artificial incubators. In order to achieve profitable hatchability levels, it is important for farmers to have sound guidelines for correctly setting up their incubators as to provide a favourable environment for the developing eggs. The incubator environment is not the only determinant of sound hatchability, with other factors such as egg quality, sanitation procedures and pre-incubation protocol's, all influencing the hatchability of the eggs.

However, incubator environmental conditions, such as temperature and humidity, do have profound effects on the developing ostrich. It is these factors which the farmer can readily alter to successfully achieve higher hatchability from their incubated eggs.

This essay has attempted to define these requirements, as well as demonstrate how problems can be identified, and solved. Unfortunately, research into the inter-relationship of environmental conditions and defining optimal levels for incubating ostrich eggs, is still relatively in its infancy. If the Australian ostrich industry, is to become a commercial success, further research into optimal conditions for artificial incubators of ostrich eggs needs to be carried out.

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