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The critical importance of incubation temperature

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INTRODUCTION

Incubation is defined as the process of applying heat to eggs and control of this process is critical for successful hatching. Most birds apply heat to their eggs by sitting on them, although there are some notable exceptions such as the megapodes, which use heat from rotting vegetation or volcanic activity. However, it is the purpose of this chapter to discuss the third method of incubation as used by man for poultry and other avian species, artificial incubation.

Before proceeding incubation temperature must first be defined. For most hatchery managers it is the temperature that they set their machines to operate at and is shown on the outside of the incubator. However, for the developing embryo it is the temperature it experiences inside the egg that is the incubation temperature and as this is what determines the development of the embryo this must be considered the real incubation temperature. Machine operating temperature and embryo temperature are by no means necessarily the same thing (French, 1997).

RELATIONSHIP BETWEEN INCUBATOR AND EGG TEMPERATURE

Measurements of air temperature around the eggs within incubators have shown that, depending on the design of the machine, temperatures can differ between 0.4 and 3.0°C from the set temperature (Kaltofen, 1969; Mauldin and Buhr, 1995; French, 1997). Similarly, studies have shown that as incubation progresses the internal egg temperature changes from being slightly cooler than the surrounding air in the first half of incubation to being hotter than the surrounding air in the second half of incubation (Tazawa and Nakagawa, 1985; French, 1997). Understanding why these temperature differences occur between egg and incubator requires an understanding of how heat is transferred within the system.

The temperature experienced by an embryo during incubation depends on: (1) the metabolic heat production of the embryo itself which in turn is dependent on the size of the embryo, (2) the slight cooling effect of water lost from the egg during incubation, (3) the temperature of the incubator and (4) the ability of the heat to transfer from embryo to incubator air. Several authors have produced thermal energetic models describing how these four factors interact to determine the temperature within the egg during artificial incubation (Kashkin, 1961; Sotherland *et al.*, 1987; Meijerhof and van Beek, 1993; French, 1997).

While incubators are designed with heating and cooling systems to control the temperature within the machine, the eggs within the machine also have an important effect on temperature. Embryos at the start of incubation are very small and so generate very little metabolic heat and so incubation heat needs to be supplied to the embryo by the incubator. Indeed, the internal egg temperature at this stage is slightly cooler than the incubator air as there is a slight evaporative cooling effect due to water being lost from the egg (Figure 1). At the end of incubation, the embryo is large and generates a significant amount of metabolic heat, approximately 130 mW in a chicken egg (Romijin and Lokhorst, 1960), that must be removed from the egg. In a study of temperatures within a turkey tunnel incubator, French (2001) showed that there was a strong correlation between the estimated total metabolic heat production of the eggs within the machine and the air temperature around the eggs. The total metabolic heat production of the eggs was dependent of the size of the egg and their fertility so that as either egg mass or fertility increased so did the temperature within the machine.

How effectively heat is transferred from the egg to the surrounding incubator air and control system is mainly determined by the rate of airflow over the eggs (Sotherland *et al.*, 1987; Owen, 1991). The greater the airflow over the egg the more efficiently heat is transferred either to or from the egg. Variations in rates of airflow are a major reason for temperature variations within incubators. Monitoring temperatures within commercial incubators have found variations of up to 1.2°C within machines (French, 2002) and reducing this temperature variation requires a more uniform airflow over the eggs in all locations within the incubator.

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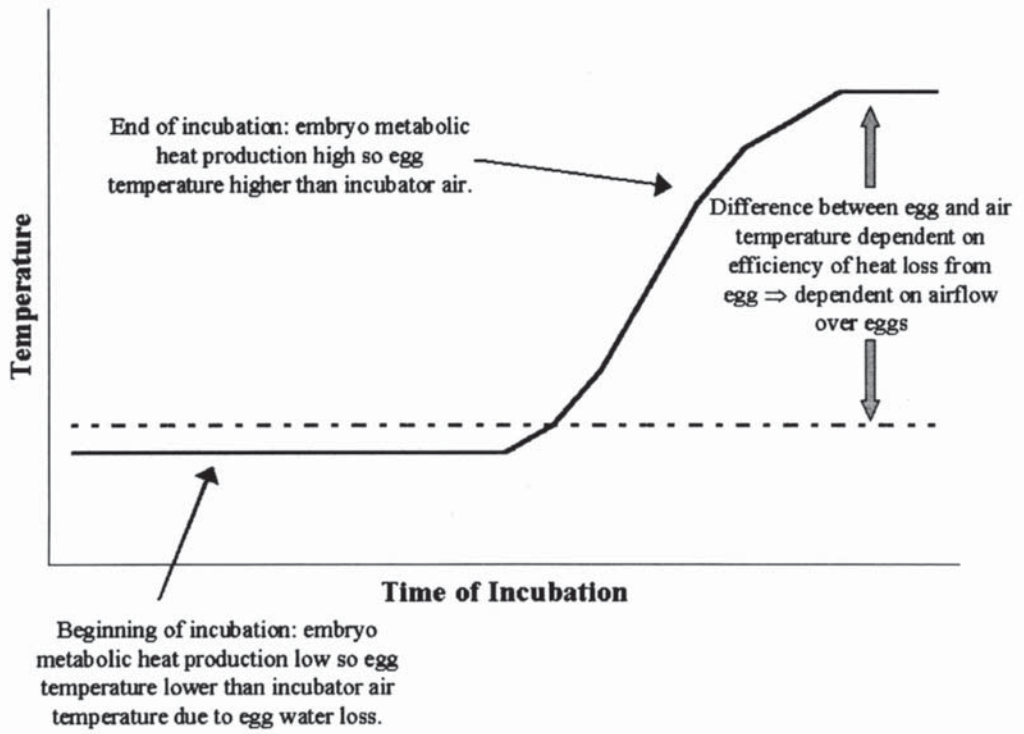

Figure 1 The relationship between egg temperature (–) and incubator air temperature (– – –) in an artificial incubator.

Other factors that can influence the uniformity of temperature within a machine are the heater and cooler units, evaporative cooling from humidifiers and cool air entering the machine through the ventilation system. A well-designed incubator will ensure that the localised air heating or cooling caused by these elements will not effect the eggs by ensuring good mixing of the air before it reaches the eggs.

Where multi-stage incubation is used, *i.e.* incubating eggs at different stages of incubation together within the same machine, there are some additional considerations to ensure uniform temperatures. Multi-stage incubators rely on the metabolism of the embryos at the end of incubation to heat the eggs at the start of incubation. For this to work successfully it is important to ensure that there are equal numbers of embryos at each stage of incubation and different stages of incubation are equally spaced apart. Major hatch problems can occur if there are too many eggs at either the end or the start of incubation within the machine. Multi-stage incubators also rely on good airflow amongst the eggs to ensure efficient heat transfer between the eggs.

INCUBATION TEMPERATURE TOLERANCE OF POULTRY EMBRYOS

Many studies have investigated the optimum incubation temperature for poultry species but most have reported the effects of incubator operating temperature rather than embryo temperature on hatching success. As the operating and embryo temperatures are not necessarily the same and the difference will depend on incubator design, it is very difficult to summarise results between different studies. Optimum operating temperatures for poultry species appear to be between 37–38°C and deviations from this optimum can have a major impact on hatching success (Wilson, 1991). For example, French (1994) showed that increasing the incubation temperature of turkey eggs from 37.5 to 38.5°C resulted in a 30–60% decline in hatchability.

Recent studies have also shown that incubation temperature will not only affect hatching success but also post hatching performance (*e.g.* Lourens and Middelkoop, 2000; Gladys *et al.*, 2000; Hulet *et al.*, 2000). It is therefore important to consider all the effects when determining the correct incubation temperature for poultry species (Decuypere and Michels, 1992).

Rather than using a single optimum incubation temperature, it would be better to define a temperature range over which incubation will be successful. Ideally this would be the temperature at the embryo level, although it may be more practical to use the temperature of the air immediately surrounding the egg. The degree of temperature tolerance will depend on whether the temperature is high or low, the length of time applied and the stage of embryo development.

So what happens as incubation temperature changes away from the optimal temperature range for successful development? The first effect of high or low incubation temperature is to alter the rate of embryo development resulting in an altered time of hatch (French, 1997). High incubation temperatures will advance the hatch whereas low incubation temperatures will delay hatch time and this can be a useful early indicator for the hatchery manager that temperature is sub-optimal. However, it should be noted that if incubation temperature continues to increase further it can also slow down development (Romanoff, 1935).

If incubation temperature further increases above the optimum, then the next effect would be to alter the embryo's development so that post-hatch performance is affected. A further increase in temperature would result in a delayed mortality: French (2000) showed that incubating turkey eggs at 38.0°C in the second week of incubation resulted in an increase in mortality in the fourth week of incubation. Immediate embryo death occurs when the internal egg temperature reaches 46.5°C (Ono *et al.*, 1994).

The effects of decreasing incubation temperature are less dramatic. Embryos are able to tolerate quite long periods of low incubation temperature without adverse effects. Lancaster and Jones (1988) showed that broiler embryos were able to tolerate cooling to 21°C for 24 hours after day 13 of incubation without any adverse effect on hatchability. Indeed embryos were able to tolerate 22°C for up to 48 hours on day 16 of incubation without any adverse effect on hatch, although exposure for more than 30 hours increased the incidence of hatched chicks with down abnormalities. These experiments were carried out at temperatures below 27°C, the temperature at which embryonic development stops (Wilson, 1991). Prolonged incubation at temperatures between 27–35°C are more of a problem and will cause abnormal development of the embryo (Wilson, 1991). Immediate embryonic death at low temperatures will only occur if internal egg temperature drops below freezing and allows ice crystals to form inside the egg (Lundy, 1969).

The effects of temperature on embryo development are summarised in Table 1. The temperature ranges shown are not exact and may vary between poultry species, eggs of different sizes (French, 1997) and stage of embryo development. Studies in both chickens (Romanoff *et al.*, 1938; Morgan and Tucker, 1967; Moreng and Shaffner, 1951; Ande and Wilson, 1981) and turkeys (French, 2000) have found that the tolerance of embryos to high incubation temperature varies with the stage of incubation.

Table 1 Typical effects of temperature on development of the avian embryo–temperature ranges shown are estimates based on available evidence

Incubation Temperature (°C)	Effect on Embryo
47	Immediate mortality
39–47	Mortality dependent on length and timing of exposure
38–40	Altered rate of development and post hatch performance
37–38	Normal embryo development
35–37	Altered rate of development and post hatch performance
27–35	Mortality dependent on length and timing of exposure
14–27	Embryo development stops, no adverse effects of holding for 24 hours in embryos in last third of incubation
0–14	Mortality dependent on length and timing of exposure
<0	Immediate mortality

IDENTIFICATION OF INCUBATION TEMPERATURE PROBLEMS

In commercial hatcheries the rapid identification and correction of incubation temperature problems is essential for maximising hatchability. There are two techniques that are routinely used in the hatchery to ensure that the correct incubation temperature is being used: (1) monitoring hatch time and (2) measuring incubation temperature within incubator.

As noted above, an early indication that incubation temperature may be sub-optimal is an alteration in hatch time. Hatching early can indicate high incubation temperatures whereas late hatching can indicate low or very high incubation temperatures. It should be noted that other factors can also influence the length of the incubation period, such as length of pre-incubation egg storage and age of breeder flock, and so a change of incubation time does not necessarily indicate a change of incubation temperature.

Monitoring hatch time can be done in several ways, assessing chick quality (thin chicks–hatched early, fat chicks–hatched late), counting how many chicks have hatched 18 hours before take-off and by weighing chicks. The simplest method to check that the chicks are hatching at the right time is to weigh the chicks and express this weight as a percentage of the fresh egg weight (chick yield). If hatch time is correct then chicks yield should be between 66–68% when they are removed from the hatcher. If the weight is too low, it is an indicator that the chicks have been hatched a long time before removal from the hatcher. If the weight is too high it indicates that the hatch is late. Chick yield will also be affected by how much water is lost from the egg during incubation although the effect is relatively small in comparison to the effect of changing hatch time.

Recently it has been suggested that measuring chick length at hatch is an indicator of normal or abnormal embryo growth and could be a useful technique for identifying high incubation temperature problems (Hill, 2001). Further studies are required to determine how chick length is affected by incubation temperature but if a relationship is demonstrated then this could be a very useful tool for the hatchery manager.

Measuring temperatures within incubators can also be very useful for solving hatch problems. This can be done with thermisters attached to data-loggers so that temperatures can be recorded at several locations within an incubator throughout the incubation cycle. There is a wide range of data-logging equipment available on the market but whatever system is chosen it is important that the thermister should be able to read to 0.1°C as a minimum and to be as accurate as possible.

Measuring internal egg temperatures would be the ideal situation but practically difficult to achieve within commercial incubators. Measuring eggshell surface temperature is less problematic as it does not require placing a thermister within the egg and has been shown to be similar to measuring internal temperature (Sotherland *et al.*, 1987). Measuring air temperature in amongst the eggs within the incubator will not be as close to internal egg temperature as measuring shell surface temperature but can still be a useful method of checking temperature within the machine.

THE FUTURE

Whilst the importance of temperature for the successful incubation of poultry eggs has been long understood it is only in recent years that the clear distinction between egg temperature and incubator temperature been made. An improved understanding of how egg temperatures with incubators are controlled has resulted in improvements in incubator design resulting in less within machine temperature variation. What are now required are guidelines as to what are the maximum and minimum egg temperatures that the poultry embryo can tolerate without adverse effect on hatch or post-hatch performance. The temperature tolerance of embryos may not only vary between poultry species but also between breeds or types within species (Decuypere and Michels, 1992). Determining embryo tolerance to temperature will be essential if hatchery managers are to maximise hatchability.

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