INCUBATION FOR UNIFORMITY

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Summary

It is becoming increasingly apparent that for efficient broiler management the vitality and uniformity of day old chicks and poults at placement is crucial. The performance and growth of broilers to slaughter weight depend on egg quality and incubation conditions. Single-stage incubation can maximize hatchability and chick uniformity for each egg type. In this review the prerequisites for optimal single stage incubation will be discussed. Firstly, the three phases of embryonic development will be discussed: a phase of cell differentiation, growth and maturation. Secondly, tools to optimize single stage incubation for optimum chick vitality are presented. Tools are: a systematic analysis of egg shell temperature and the Pascargscore, an objective score for chick vitality. Thirdly, the prerequisites for the design of single stage incubators for modern breeds will be discussed.

I. INTRODUCTION

It is becoming increasingly apparent that the vitality and uniformity of day old chicks and poults at placement is crucial for efficient broiler management. Generally, however, producers take vitality and uniformity of the received day old chicks for granted. The reason for this, on the one hand, is the limited exchange of information between the farmer and the hatchery manager about chick growth rates and performance data. On the other hand, it is only recently accepted that incubation related factors influence the performance and growth of broilers to slaughter weight (Decuyper et al., 2001; Tona et al., 2005).

The management of day old chick production has changed greatly during recent decades. First of all the size of hatcheries has changed such that a production of more than 2 million chicks per week is not an exception and secondly we notice a gradual transition from multistage to single stage incubation. Although the multistage incubation is still very common, the advantages of single stage incubation are being increasingly recognised. In the multi-stage incubator the climate among the eggs depends on the age of the different batches of embryos in the incubator and, therefore, fluctuates from day to day (French and Houlbrooke, 2004). Consequently, climate conditions in multi-stage incubators can not support optimal and uniform embryonic development. Single stage incubation offers the opportunity to adjust the incubation conditions to the requirements of the eggs and the embryos growing in them. Single-stage incubation can maximize hatchability and chick uniformity for each egg type. Another major advantage of single stage incubation is that after each incubation cycle the incubators can be cleaned and thereby minimize the risks of spreading microbial contamination.

To take the full advantage of single stage incubation three conditions have to be met. Firstly, knowledge must be available of those conditions needed to support embryonic development of modern breeds most optimal. Secondly, the hatchery manager must have the tools to find the appropriate incubation set points for temperature, humidity and ventilation and, thirdly, incubators must be designed to provide a homogeneous climate among all the eggs in each section of the incubator. In this review each of the prerequisites for optimal single stage incubation will be discussed as a management instrument for the incubation of uniform chicks of high vitality.

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II. THE DIFFERENT PHASES OF EMBRYONIC DEVELOPMENT

The rate of development and the vitality of the embryo depend on storage (Fasenko et al., 2002) and on maternal age (Applegate, 2002), while genetic selection influences important physiological systems (Christensen et al., 1995). The development of the avian embryo is a complex process that can roughly be divided into three phases: a phase of cell differentiation, growth and maturation. These phases are recognized through specific physiological details. From empirical data we learned that these different egg types need specific incubation protocols.

a) Embryonic differentiation

Embryonic differentiation is characterised by the formation of different tissues that will develop into the chicken’s final organs in the growth phase. This first phase of cell differentiation starts in the hen, when the single-cell oocyte divides many times so that, in the un-incubated egg the embryo consists of about 30,000 cells. These 30,000 cells are organised as a plate of cells, known as the early gastrula, which floats on the top of the yolk.

After laying, the temperature of the egg decreases and the development of the embryo ceases or stops completely if the temperature falls below the physiological zero (25-27°C; Lundy, 1969). Embryonic differentiation continues only when the temperature of the egg rises. The differentiation phase is further characterised by a ‘folding’ of the early gastrula, to form a three dimensional structure in which premature organ structures of the head and heart can be recognised within 36 hours. Movement of cells mediates this folding process, whereby the cells in the early gastrula ‘travel’ from one side to the other, and this process is highly temperature dependent.

In the differentiation phase, it is not only the embryonic structures that develop, but also the extra-embryonic tissues - such as the amnion and chorio-allantois, both essential structures in the transport of oxygen and nutrients from the yolk to the embryo.

In this stage of development, the embryo floats to the top of the egg, where it is nearest to the eggshell, and normal, synchronised differentiation occurs only when the eggshell temperature is in the range of 37-38°C. If the temperature is in the range from 27°C to 36°C, uneven differentiation of the various tissues results and abnormal development occurs as a consequence (Romanoff, 1960). Embryonic differentiation is even less tolerant to temperatures above 38°C for longer periods, when exposed brains and eye abnormalities have been recorded. Interestingly, it has been shown that broiler embryos are even more sensitive to high temperatures during the differentiation phase than layer embryos (Decuypere and Michels, 1992).

b) Embryonic growth

During differentiation the premature organs are formed and the basic body pattern is laid down. Relatively minor changes in the size of the embryo are seen in this phase of development. Embryonic growth is characterized by an increase in mass while the development of the organs continues. The shape of the organs and, finally, the embryo is determined by the rate of growth at a specific time in the different parts of the embryonic body. Temperatures below the optimum incubation temperature of 37.5-37.8°C might result in disproportional growth: some embryonic cells and structures may grow while others do not grow. The result of a disproportional growth might be a malformed embryo (Romanoff, 1960). Temperature has a profound effect on the growth and the development of the left/right symmetry of skeletal parts and the lungs, as shown when broiler embryos were exposed to heat (39.6°C) and cold (36.9°C) for periods as short as six hours each day (Yalcin and Siegel, 2003).
The increase in mass during the growth phase is the result of a high metabolic activity and cell proliferation. The fuel for this activity is delivered by the nutrients from the egg and oxygen via the eggshell. The produced carbon dioxide and metabolic heat are by-products of embryonic metabolism.

Growth rates decline when the porosity of the eggshell becomes the limiting factor in the supply of sufficient oxygen. The growth rate and thereby the length of the incubation period depend mainly on temperature and is influenced by flock age and the length of the storage period (Lundy, 1969; Tona et al., 2003).

c) Embryonic maturation

During the final phase of development the embryo undergoes a series of events that enable it to survive outside the protective environment of the shell. The rate of metabolism stabilizes and reaches the so-called plateau phase at about the 19th day of incubation in chicken and 25th day for turkey. At the plateau phase the growth rate declines because the embryo needs more oxygen than the porosity of eggshell can deliver. To be able to use yolk fat as energy source the availability of oxygen is essential. At the plateau phase the embryo suffers from anaerobic conditions. Therefore the embryo depends on carbohydrates, sugars, as energy source during the hatching period. The healthy and vital embryo is prepared for this condition because it has sufficient energy stores, in the form of glycogen, to survive the anaerobic conditions in the plateau phase. Vital tissues like heart and liver accumulate glycogen to ensure embryonic survival during the energy demanding process of maturation and hatching (Dietz et al., 1998). It has been suggested that lines selected for growth or egg production differ in glycogen metabolism and accumulation of glycogen stores during the maturation phase. These line specific differences might explain the different responses of the genetic lines on varying incubator climates.

A vital day old chick is an active chick that has the physiological potential to grow at the best rates with the lowest feed conversion ratios. Vitality is the result of optimum differentiation, growth and the maturation of all organs and physiological controlling circuits. The process of maturation starts shortly before hatching, the so called peri-natal period, and continues during the first week post-hatch. It has been shown that during this short timeframe, the emerging chick is equipped to cope, within certain limits, with the acute change in environmental conditions. In recent years, significant research has been undertaken on the development of the thermoregulatory system of the chick embryo and hatchling (Nichelmann and Tzschenke, 2002). This research has shown that with the development of the thermoregulatory system, the hatchling develops the capability to maintain its body temperature under changing environmental temperatures. Changes in incubation temperature at the end of embryonic development induce epigenetic adaptation, which results in a post-hatch long-lasting cold or heat adaptation. The maturation of the thermoregulatory system during the first week also includes the development of the regulation and response of heart rate baseline to changing environmental temperatures. By adapting the incubation environment throughout the last phases of incubation, and by adapting the newly hatched chick’s environment during the first days post hatch, we can manage the growth development and temperature adaptation of the embryo - while it is still in the egg.

d) Metabolic heat production by modern poultry breeds

It is widely recognised that genetic improvements in poultry have resulted in an enormous diversification of breeds – all of which require specific incubation conditions (Decuyper et al., 2001). It is clear that embryo metabolism is changing as a result of selection for production traits. The rate of embryonic as well as post-natal growth (growth at
the farm) is determined by the rate of bio-synthesis of tissue which depends on the availability of nutrients and oxygen. A strong physiological relationship exists between the rate of bio-synthesis and metabolic heat production. In collaboration with the Humboldt of Berlin we showed that at day 18 metabolic heat production, based on oxygen consumption, is about 26% higher for Ross 308 compared to a white leghorn breed (Table 1).

Table 1. Metabolic heat production (W/1000 eggs) of a modern layer hen breed (Lohman white) and a broiler breed (Ross 308) compared to heat production (W/1000 eggs) (Janke et al., 2004) produced by the North Holland Blue breed (traditional) (Romijn and Lokhorst, 1960).

<table>
<thead>
<tr>
<th>Days of incubation</th>
<th>Metabolic heat production W per 1000 eggs</th>
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<tr>
<td></td>
<td>Ross 308</td>
</tr>
<tr>
<td>17</td>
<td>151.2</td>
</tr>
<tr>
<td>18</td>
<td>156.6</td>
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<tr>
<td>19</td>
<td>164.4</td>
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<td>20</td>
<td>252</td>
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Metabolic heat production of the modern broiler breeds Ross 308 and the Ross 508 is about 20 % higher compared to the metabolic heat production by a North Holland blue breed a more traditional meat producing breed used in the sixties (Table 1). The higher metabolic heat production by modern broiler breeds as compared to a slower growing breed, is the result of the higher growth potential. With respect to this it is interesting to note that, at all time points measured, the Ross 508 embryo produced slightly less metabolic heat, although not significant. This might be unexpected since there is an idea that breast meat producing breeds like the Ross 508 produces more metabolic heat during incubation. From our results we conclude that a high heat production by the broiler embryo is determined by the high growth rate and not by carcass quality.
III. TOOLS FOR OPTIMIZING CHICK VITALITY AND UNIFORMITY

a) Tool: single stage incubation

Based on excellent scientific research, Lundy (1969) summarised the incubation conditions needed for optimum chick development. When he wrote his review in 1969, it was common to set eggs of several embryonic ages in one incubator: the so-called multi-stage incubation. In multi-stage incubators, the temperature, humidity and ventilation are set at a fixed point. The advantage of multi-stage incubation is its simplicity both with respect to the control system of the incubator as well as the management of incubation. The main disadvantage however, is that the multi-stage incubation environment cannot, by its nature, create optimum conditions for every egg set. For example, in a multistage incubator, the average eggshell temperature may vary from 37.5°C for the youngest embryos, to 39.5°C for the later embryonic stages; so it is difficult to find a temperature set point such that eggshell temperature is correct for each embryonic stage. Consequently, in multi-stage incubation, it is impossible to optimise both hatchability and chick quality, especially when dealing with variable egg quality. The single stage incubator is filled at one setting and, thus, contains eggs at one embryonic stage. To avoid overheating the set points of the different climate parameters have to be adjusted as embryonic development proceeds (Figure 1): for each day of incubation the set points are defined.

Figure 1. Two examples of temperature program for layer strains: the relation between temperature set points (lines) and average eggshell temperature (dotted lines) of at least 45 eggs is shown. Green lines: LOW incubation program; blue lines: HIGH incubation program.

For optimum chick and poult quality, fine-tuning of the incubation program might be necessary for each specific batch of eggs based on chick vitality and uniformity. These tools are respectively the Pasgarscore for objective scoring of chick vitality and a systematic analysis of egg shell temperature to find the optimum incubation temperatures.
b) Tool: Pasgarscore for chick vitality

Daily hatchery practice shows us that poor incubation conditions result low hatchabilities and poor chick vitality. For example, Pas Reform’s studies, in collaboration with Wageningen University and Research centre, have shown that broiler chicks with red hocks develop significantly more leg problems at 30 to 40 days of age (De Jong et al., 2004).

The size of the residual yolk sac is dependent on incubation humidity and temperature, so it is clear that the vitality of an individual day old chick can be described using different aspects of the chicks’ morphology. These morphological criteria have been used to develop the so-called Pasgar score (Boerjan, 2002) and, separately, researchers from the Catholic University of Leuven in Belgium (Tona et al., 2003) have developed a more detailed score for chick vitality, known as the Leuven score. In both scoring systems, chicks lose points from a total of 10 (Pasgar score) or 100 (Leuven score) for abnormalities seen in navels, beaks, legs and yolk sac volume.

The Pasgar score has proven its worth in current hatchery practice. For example we applied the Pasgarscore on eggs from the same flock but stored for either 3 or 11 days before incubation. Of both lots 4,800 eggs (one trolley) were incubated in the same setter and hatchery. The Pasgarscore was determined on a sample of chicks of both groups. The mean Pasgarscore for the eggs stored for 3 days was 9.4 compared with a means value of 8.9 for eggs stored for 11 days (P<0.05) (Table 2). This result is in accordance with the anticipated chick quality after prolonged storage (Tona, 2003).

Because the Pasgarscore is easy to teach to hatchery personnel, it is currently in widespread use to improve incubation programmes around the world. The Pasgarscore is intended to express chick quality using a number. To gain a representative quality score of a flock of chicks, a sample of at least 30 chicks must be assessed and the average Pasgarscore calculated.

<table>
<thead>
<tr>
<th>Number of storage days</th>
<th>Mean Pasgarscore (n= number of chicks)</th>
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<tbody>
<tr>
<td>3</td>
<td>9.4 (27)*</td>
</tr>
<tr>
<td>11</td>
<td>8.9 (29)*</td>
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* P<0.05

c) Tool: Eggshell temperature as the leading parameter

We recognised the importance of temperature for optimum embryonic development and defined eggshell temperature as the leading parameter for the design of incubation programs (Boerjan, 2004). For optimum hatchability and chick quality we have found, and therefore advise that the average eggshell temperature follows a pattern within a range of 36.6-37.9°C during the first two-thirds of incubation and should not exceed 38.8 °C during the last days in the setter (Figure 1). It must be kept in mind that the larger eggs are less tolerant to higher incubation temperatures.

A way to improve the incubator’s temperature program is to measure the temperature of a specific number of eggs during the different phases of the incubation process. Because embryo temperature can not be measured without destroying the egg, the temperature of the eggshell is used as a reference. The cheapest and easiest way to measure eggshell temperature is with an infrared ‘fever thermometer’. The Braun Thermoscan is a practical instrument for such measurements, provided the instrument is used properly. To get a good idea of actual eggshell temperature in a specific incubator, a representative sample of at least 30 eggs must be measured.
IV. THE SINGLE STAGE INCUBATOR

a) Separate sections

For incubator manufacturers today, the challenge is to design incubators that can support optimum embryonic development for each egg at each stage of development. Single stage incubation requires incubators to be equipped with heating, cooling, ventilation, humidifier and turning mechanisms that are controlled accurately and independently. The uniformity and power of heat transfer from the incubator’s temperature to the mass of eggs is a key aspect of incubator performance, because to achieve a uniform hatch, the eggs must be warmed rapidly and homogeneously. Homogenous temperature is best facilitated in an incubator divided into separate units, each with its own climate control.

b) Heating and cooling capacity

The heating capacity of the incubator must be sufficient to initiate embryonic development in every egg placed in one section of the incubator. Genetic selection has not only had an impact on production traits, but has also resulted in larger eggs with a decreased percentage of yolk volume. The greater volume of eggs produced by modern breeds means that a greater volume of eggs must be warmed and, therefore, the heating capacity of the modern incubator must be increased by 25% in comparison to the older, single stage incubators. In addition the preheating module facilitates a controlled and uniform preheating of eggs before setting. The cooling capacity of the incubator must also be sufficient to remove the heat produced by the older embryos, as the higher metabolic heat production of modern broiler embryos increases the risk of overheating.

In addition the temperature control system must be accurate so that unacceptably large deviations or fluctuation in temperature around the set point, or ‘overshoots’ are avoided. Again, the hatchery manager must have the facility to adjust the incubator temperature to keep eggshell temperatures at the desired level. In the design of the incubation program, the average eggshell temperature of a representative sample of eggs should be the leading parameter.

V. CONCLUSION

It is now understood that genetic improvements in poultry have resulted in an enormous diversification of breeds, all of which need specific incubation conditions. The embryo metabolism is changing through selection for production traits. For optimum cell differentiation and growth the embryo is dependent on a specific eggshell temperature. The importance of temperature for optimum embryonic development has been recognized and the eggshell temperature appeared to be a good reference. It is essential that the hatchery manager has the ability and facilities to control the set points of temperature, humidity and ventilation independently and as accurately as possible.

Single stage incubation facilitates optimum incubation programming, per batch and egg type. A single stage incubator should be facilitated in an incubator divided into small, separate units, each with its own climate control.

For optimum chick and poult quality, fine-tuning of the incubation program might be necessary. A tool for the objective scoring of chick vitality based on morphological criteria is the Pasgarscore. The Pasgarscore has proven its worth in current hatchery practice worldwide.
REFERENCES