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Embryonic Development In Chicks And Factors Affecting Egg Fertility And Hatchability

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Abstract

Chicken embryonic development is a highly coordinated biological process that begins with fertilization and progresses through a series of cellular, morphological, and physiological changes until hatching. The approximately 21-day incubation period involves cleavage, gastrulation, organogenesis, development of extra-embryonic membranes, tissue differentiation, growth, and maturation of the developing embryo. This review summarizes the major events of chick embryogenesis and presents the principal developmental changes occurring during different stages of incubation. It also examines the major factors influencing egg fertility, embryonic survival, hatchability, and chick quality, including genetic background, breeder age, male-to-female ratio, nutrition, semen quality, flock health, environmental conditions, stress, egg characteristics, storage, incubation temperature, relative humidity, ventilation, egg turning, sanitation, and hatchery management. In addition, practical measures for improving hatchability and reducing embryonic mortality are discussed. Proper management of breeder flocks, hatching eggs, incubation conditions, and hatchery hygiene is essential for improving reproductive efficiency and producing healthy and viable chicks. A comprehensive understanding of embryonic development and its influencing factors can contribute to improved hatchery performance, economic efficiency, and sustainable poultry production.

Keywords: Chicken embryo; embryonic development; egg fertility; hatchability; incubation; breeder flock; egg quality; embryonic mortality

1. INTRODUCTION

The chicken embryo develops within the egg and completes its development during an incubation period of approximately 21 days. During this relatively short period, the fertilized ovum undergoes rapid cellular multiplication, differentiation, tissue organization, organ formation, growth, and physiological maturation before hatching (Romanoff, 1960; Gilbert, 2019). Because the embryo is completely dependent on the egg and the surrounding incubation environment, the quality of the hatching egg and the conditions under which it is stored and incubated have a major influence on embryonic survival and hatchability (King'ori, 2011; Boleli *et al.*, 2016).

The chicken embryo is also an important biological model for understanding vertebrate development. The sequence of morphological changes occurring during incubation has been systematically described by Hamburger and Hamilton (1992), who established a standardized series of developmental stages based on external morphological characteristics. These stages provide a useful framework for identifying the progression of embryonic development and detecting developmental abnormalities.

The incubation period can broadly be considered in terms of early, middle, and late developmental phases. The early phase is characterized by rapid cellular differentiation and establishment of the basic body plan. Extensive organogenesis occurs during the middle phase, while the late phase is dominated by rapid growth, physiological maturation, preparation for pulmonary respiration, and positioning of the embryo for hatching (Hamburger & Hamilton, 1992; Romanoff, 1960).

The embryo is supplied with nutrients from the yolk and albumen and is protected by several extra-embryonic membranes. The amnion protects the embryo, the yolk sac participates in nutrient transfer, the chorion contributes to gaseous exchange, and the allantois plays important roles in respiration and waste management (Romanoff, 1960; Gilbert, 2019). Thus, embryonic development depends on the coordinated functioning of both embryonic and extra-embryonic structures.

Environmental conditions during incubation also have a major influence on embryonic development. Temperature, relative humidity, oxygen availability, carbon dioxide concentration, and egg weight loss interact throughout incubation and influence hatchability and chick quality (Molenaar *et al.,* 2010). The developing embryo is therefore highly responsive to its thermal and gaseous environment.

In natural conditions, the parent bird provides incubation through behavioral control of egg temperature and turning. In commercial poultry production, these requirements are reproduced using artificial incubation systems. Modern hatchery systems increasingly depend on precise environmental monitoring and control to provide appropriate conditions throughout incubation (Berckmans, 2017).

The interval between the emergence of the first and final chick from a group of eggs is commonly referred to as the **hatch window**. The timing of hatching is influenced by embryonic

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development, incubation conditions, physiological status, and communication between developing embryos and their environment (Molenaar *et al.*, 2010; Rumpf & Tzschentke, 2010). Therefore, successful chick production requires proper management from the breeder flock through egg collection, storage, incubation, hatching, and early chick handling.

2. EMBRYONIC DEVELOPMENT IN CHICKS

2.1 Fertilization and Cleavage

Embryonic development begins following fertilization of the ovum by a spermatozoon. In the domestic chicken, fertilization normally occurs in the infundibulum of the oviduct shortly after ovulation (Bakst & Long, 2010). Fusion of the male and female gametes restores the diploid chromosome number and initiates embryonic development. The avian egg contains a large quantity of yolk that serves as the principal nutrient reserve for the developing embryo. Consequently, cell division is restricted to a small disc of cytoplasm located on the surface of the yolk. This pattern of cleavage is known as **discoidal meroblastic cleavage** and is characteristic of birds (Gilbert, 2019; Romanoff, 1960). Following fertilization, repeated mitotic divisions produce a progressively organized blastoderm. The early embryonic disc subsequently undergoes major morphological changes that establish the basic body organization of the developing chick.

2.2 Gastrulation

Gastrulation is a critical developmental process during which the basic germ layers of the embryo are established. The primitive streak develops and cells migrate to form the three primary germ layers: ectoderm, mesoderm, and endoderm. These layers subsequently contribute to the formation of all major tissues and organs of the developing chick (Hamburger & Hamilton, 1992; Gilbert, 2019). Gastrulation establishes the fundamental body axis and provides the cellular organization required for subsequent organ development. Disturbances during this period can result in abnormal development or early embryonic mortality.

2.3 Organogenesis

Following gastrulation, the embryo enters a period of rapid organogenesis. Structures derived from the three germ layers differentiate into the nervous system, cardiovascular system, digestive tract, respiratory structures, musculoskeletal system, reproductive organs, and other body systems (Gilbert, 2019; Romanoff, 1960). The cardiovascular system develops particularly early because the growing embryo rapidly develops a requirement for oxygen and nutrient transport. The primitive heart begins functional activity during the early stages of incubation, followed by progressive development of the vascular system.

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2.4 Development of Extra-Embryonic Membranes

Extra-embryonic membranes are essential for the survival of the developing embryo. The **amnion** surrounds the embryo and provides mechanical protection. The **yolk sac** is involved in the mobilization and transfer of nutrients from the yolk. The **chorion** contributes to gaseous exchange, while the **allantois** participates in respiratory exchange and storage of metabolic waste (Romanoff, 1960). The development of these membranes is closely associated with embryonic growth and changing metabolic requirements. Their proper development is therefore essential for maintaining embryonic viability throughout incubation.

3. DAY-WISE EMBRYONIC DEVELOPMENT

Hamburger and Hamilton (1992) described a standardized series of morphological stages for chicken embryonic development. The following table provides a simplified day-wise description for practical and educational purposes. The exact timing of individual developmental events may vary slightly with genetic background, egg characteristics, and incubation conditions.

Table 1. Major morphological changes during chicken embryonic development

Incubation day	Major developmental changes
Day 1	Gastrulation progresses, the primitive streak becomes established, and early blood islands begin to develop.
Day 2	Neural development progresses, the primitive heart becomes functional, and early blood circulation is established.
Day 3	Vascular development becomes prominent, the amnion develops, and early limb buds become visible.
Day 4	Eye development becomes more prominent, pigmentation increases, and the allantoic membrane begins developing.
Day 5	Limb differentiation progresses, early gonadal development occurs, and spontaneous embryonic movements become more evident.
Day 6	The developing beak becomes more distinct and early feather follicle development begins.
Day 7	Digits become more clearly differentiated and the embryo increasingly assumes the basic body form of a chick.
Days 8–10	Feather germs become prominent, eyelids develop, and skeletal development and ossification progress.

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Days 11–14	Claws become distinct, feather development increases, and rapid embryonic growth occurs.
Days 15–18	The embryo enlarges considerably, the intestine retracts into the abdominal cavity, and the embryo gradually assumes the hatching position.
Day 19	Most of the yolk is transferred into the abdominal cavity and the embryo prepares for internal pipping.
Day 20	Internal pipping has occurred and pulmonary respiration becomes established; external pipping of the shell begins.
Day 21	The chick completes hatching, residual yolk is absorbed, the umbilical region closes, and post-hatch life begins.

4. FACTORS AFFECTING EGG FERTILITY

Egg fertility refers to successful fertilization of the ovum following mating or artificial insemination. It is an important reproductive parameter because fertility determines the proportion of eggs that are potentially capable of producing embryos. Fertility is influenced by genetic, physiological, nutritional, environmental, health, and management factors (King'ori, 2011; North & Bell, 1990).

4.1 Genetic Factors

Genetic background influences reproductive performance through its effects on sexual maturity, reproductive organ development, gamete quality, mating behavior, and overall reproductive efficiency. Different breeds and strains may exhibit differences in fertility because of inherited reproductive characteristics (North & Bell, 1990; Bell & Weaver, 2002).

Selection programs that emphasize rapid growth or high production without adequate consideration of reproductive fitness may adversely affect reproductive performance in some breeding populations (Decuypere *et al.*, 2001). Therefore, genetic improvement programs should consider both productive and reproductive traits.

4.2 Age of the Breeder Flock

Breeder age is an important determinant of fertility. Fertility generally increases after sexual maturity and remains relatively high during the productive period. However, reproductive efficiency may decline as birds become older because of changes in semen quality, mating activity, egg characteristics, and reproductive physiology (Wilson, 1991; Leeson & Summers, 2001).

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Older males may show reductions in sperm concentration and motility, which can reduce fertilization efficiency (Bakst & Long, 2010). Similarly, changes in egg quality and reproductive performance may occur in aging females.

Field observations also demonstrate that breeder age and egg weight can influence fertility and hatchability. Singh *et al.* (2018) reported differences in reproductive performance associated with hen age and egg size in Vanaraja birds.

4.3 Male-to-Female Ratio

An appropriate male-to-female ratio is essential in naturally mated breeder flocks. Too few males may result in inadequate mating frequency and reduced fertility, whereas an excessive proportion of males may increase aggression, competition, and stress.

The appropriate ratio depends on breed, age, housing system, mating behavior, and management conditions. Maintaining a balanced mating structure is therefore important for maximizing fertilization efficiency (North & Bell, 1990; Bell & Weaver, 2002).

4.4 Nutrition

Adequate nutrition is essential for reproductive development and function in both male and female breeder birds. Protein and energy provide substrates required for reproductive tissue development, hormone synthesis, egg production, and sperm formation (Leeson & Summers, 2001).

Both nutrient deficiencies and excessive nutrient intake may impair reproductive performance. Excessive dietary energy can result in obesity and reduced reproductive activity, while inadequate energy and protein intake may impair reproductive development and production.

Vitamins and minerals are also important. Vitamins A, D, and E contribute to normal reproductive function, antioxidant protection, and embryo development. Selenium and zinc participate in antioxidant defense, sperm quality, reproductive function, and eggshell formation (Surai, 2002). Appropriate breeder nutrition is therefore essential for maintaining fertility and producing high-quality hatching eggs.

4.5 Semen Quality

Semen quality is one of the major determinants of fertility, particularly in breeding systems using artificial insemination. Important semen characteristics include sperm concentration, motility, viability, morphology, and membrane integrity (Bakst & Long, 2010). Poor semen quality reduces the probability of successful fertilization. Proper nutrition, environmental management, male health, semen collection, and handling are therefore important for maintaining reproductive efficiency.

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4.6 Health Status

The health of the breeder flock directly affects reproductive performance. Healthy birds generally exhibit better fertility and hatchability than birds affected by infectious or metabolic diseases. Diseases affecting the reproductive tract can interfere with egg production, sperm quality, fertilization, and embryonic survival. Infectious diseases such as Newcastle disease and infectious bronchitis may adversely affect reproductive performance and hatchability (Jordan *et al.*, 2001). Effective vaccination, biosecurity, disease surveillance, hygiene, and appropriate veterinary management are therefore essential components of breeder flock management.

4.7 Environmental Conditions

Environmental conditions can substantially influence reproductive performance. High ambient temperature and heat stress can reduce feed intake, semen quality, egg production, mating activity, and fertility (Decuypere *et al.*, 2001). Environmental factors may also influence endocrine regulation and reproductive behavior. Adequate ventilation, suitable lighting, appropriate stocking density, and effective temperature management are therefore necessary to maintain breeder performance (Bell & Weaver, 2002). The physiological relationship between environmental conditions, endocrine regulation, development, and reproduction has also been discussed in avian species by McNabb (2007).

4.8 Stress

Stress can negatively influence reproductive efficiency through alterations in endocrine function and reproductive behavior. Overcrowding, transportation, excessive handling, sudden environmental changes, poor ventilation, and inappropriate management can increase stress in breeder birds. Persistent stress may reduce mating activity, egg production, and semen quality (Decuypere *et al.*, 2001). Minimizing unnecessary disturbance and maintaining consistent management practices can therefore contribute to improved reproductive performance.

4.9 Artificial Insemination

Artificial insemination is used in several poultry breeding systems, particularly when genetic improvement and controlled mating are important. It allows semen from selected males to be efficiently utilized and can overcome some limitations associated with natural mating (Bakst & Long, 2010). Successful artificial insemination depends on semen quality, collection procedures, dilution, handling, insemination frequency, and timing relative to ovulation. Properly managed artificial insemination can improve reproductive efficiency in appropriate breeding systems.

5. Factors Affecting Hatchability of Eggs

Hatchability is generally expressed as the percentage of fertile eggs that successfully produce viable chicks. It is an important indicator of hatchery efficiency and is influenced by egg quality, breeder flock management, egg storage, incubation conditions, embryonic viability, sanitation, and hatchery practices (King'ori, 2011).

High fertility does not necessarily result in high hatchability. Fertile eggs may fail to hatch because of embryonic abnormalities, prolonged storage, poor egg quality, inadequate incubation conditions, microbial contamination, or improper hatchery management.

Hatchability of fertile eggs.

Hatchability (%) = (Number of chicks hatched / Number of fertile eggs set) × 100

Singh *et al.* (2018) demonstrated that season, breeder age, egg weight, and source of eggs can influence fertility and hatchability. Therefore, hatchery performance should be evaluated in relation to both breeder and incubation factors.

5.1 Egg Storage

Egg storage conditions before incubation can influence embryonic viability and subsequent hatchability. Prolonged storage is generally associated with deterioration in embryonic quality and reduced hatchability (King'ori, 2011). Storage temperature, relative humidity, duration of storage, and pre-incubation handling should therefore be carefully controlled. Eggs should be collected frequently and handled gently to minimize contamination and physical damage. The relationship between egg storage and subsequent embryonic development is particularly important because the developmental state of the embryo before incubation can influence hatchability and chick quality (Molenaar *et al.*, 2010).

5.2 Egg Size and Weight

Egg weight affects embryonic development because the egg supplies the embryo with its major nutrient reserves. Extremely small eggs may contain relatively limited nutrient reserves, while excessively large eggs may create additional challenges during incubation and hatching. Egg size has also been associated with reproductive performance in practical poultry production. Singh *et al.* (2018) reported better fertility and hatchability for medium-sized eggs compared with other egg-weight groups in Vanaraja birds.

5.3 Eggshell Quality

The eggshell provides mechanical protection and regulates the exchange of gases and water between the egg and the external environment. Shell thickness, strength, integrity, and porosity therefore influence embryonic development and survival (Romanoff, 1960). Cracked or weak-shelled eggs are more susceptible to microbial contamination and abnormal moisture loss. Adequate dietary calcium, phosphorus, and vitamin D are important for proper eggshell formation (Leeson & Summers, 2001).

5.4 Incubation Temperature

Temperature is one of the most important environmental factors affecting embryonic development. Chicken embryos require a relatively narrow thermal range for normal development. In conventional forced-air incubation systems, an eggshell temperature around 37.5–38.0°C is commonly associated with favorable embryonic development, although the optimum condition depends on incubator design and other environmental factors (Molenaar *et al.*, 2010). Excessively high temperature may accelerate embryonic metabolism and result in developmental abnormalities or mortality. Low temperature slows embryonic development and may delay hatching. Both the magnitude and duration of temperature deviations are important considerations.

5.5 Relative Humidity

Relative humidity regulates moisture loss from the egg during incubation. Appropriate water loss is necessary for normal air-cell development and successful hatching. Excessively low humidity can cause excessive water loss and embryo dehydration, whereas excessive humidity can restrict appropriate moisture loss. Humidity should therefore be considered together with egg weight loss, eggshell characteristics, ventilation, and incubator design rather than as an isolated parameter (Tullett, 1990; Boleli *et al.*, 2016).

5.6 Egg Turning

Regular turning is important during the majority of the incubation period. It helps prevent abnormal adhesion of the embryo to the shell membranes and supports appropriate development of extra-embryonic membranes. In commercial systems, eggs are commonly turned automatically at regular intervals. Turning is normally discontinued near the end of incubation, commonly around day 18 in chicken eggs, when the embryo assumes the appropriate hatching position. Inadequate turning may increase embryonic mortality and reduce hatchability. Therefore, turning frequency and angle should be appropriate for the type of incubator being used (King'ori, 2011; Boleli *et al.*, 2016).

5.7 Ventilation

Developing embryos continuously consume oxygen and release carbon dioxide and metabolic heat. Adequate ventilation is therefore necessary to maintain suitable gaseous conditions within the incubator.

Poor ventilation may result in inadequate oxygen availability, excessive carbon dioxide accumulation, abnormal embryonic development, and increased mortality. Ventilation also

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contributes to maintaining uniform temperature and humidity throughout the incubation chamber (Molenaar *et al.*, 2010).

5.8 Egg Sanitation and Hatchery Hygiene

Microbial contamination is an important cause of embryonic mortality and poor hatchability. Eggs should be collected frequently and handled using appropriate hygiene procedures. Excessively dirty or cracked eggs should generally be excluded from incubation.

Hatchery equipment, trays, incubators, hatchers, chick handling areas, and associated equipment should be cleaned and disinfected according to an effective sanitation program. Good biosecurity and hygiene practices reduce microbial contamination and improve hatchery performance (Jordan *et al.*, 2001).

5.9 Embryonic Mortality

Embryonic mortality may occur during any stage of incubation. Early mortality can be associated with poor fertility, prolonged egg storage, genetic abnormalities, or breeder nutritional problems. Mortality during the middle period may be related to infection, developmental abnormalities, or unsuitable incubation conditions. Late embryonic mortality may be associated with inadequate ventilation, inappropriate temperature or humidity, poor turning, contamination, or weak embryos (Romanoff, 1960; Molenaar *et al.*, 2010).

Examination of unhatched eggs and dead embryos can provide useful information about the timing and probable causes of embryonic mortality. Hatch residue analysis is therefore an important diagnostic tool for improving hatchery management.

6. HATCH WINDOW AND EMBRYONIC COMMUNICATION

The period between the emergence of the first chick and the final chick within a group of incubated eggs is known as the **hatch window**. Hatch timing is influenced by embryo temperature, egg characteristics, incubation conditions, and developmental stage (Molenaar et al., 2010). Embryonic communication may also contribute to hatching behavior. Developing embryos can produce vocal and other signals before hatching, and these signals may facilitate communication between embryos and influence behavioral responses around the time of hatch (Rumpf & Tzschentke, 2010). Variation in hatching time within a clutch is therefore a biological phenomenon influenced by both developmental and environmental factors rather than being solely a result of incubation equipment.

7. METHODS FOR IMPROVING HATCHABILITY

Improvement of hatchability requires an integrated management approach covering breeder flock management, egg collection, storage, incubation, hatching, and sanitation.

The following practices are recommended:

1. Maintain healthy and reproductively efficient breeder flocks.
2. Provide balanced diets according to breeder age and physiological requirements.
3. Maintain an appropriate male-to-female ratio.
4. Monitor breeder body condition and reproductive performance.
5. Collect hatching eggs frequently.
6. Select eggs with appropriate size, shape, shell quality, and cleanliness.
7. Avoid incubating cracked or severely contaminated eggs.
8. Minimize the duration of egg storage.
9. Maintain appropriate storage temperature and humidity.
10. Maintain accurate incubation temperature.
11. Monitor humidity and egg weight loss where appropriate.
12. Turn eggs regularly until the recommended stage of incubation.
13. Provide adequate ventilation and gaseous exchange.
14. Maintain strict hatchery sanitation and biosecurity.
15. Calibrate temperature and humidity monitoring equipment regularly.
16. Maintain accurate fertility and hatchability records.
17. Examine unhatched eggs and dead embryos to identify causes of mortality.
18. Review hatchery performance periodically and implement corrective measures.

Modern hatchery systems can benefit from improved environmental monitoring and data-based management. Precision livestock approaches emphasize continuous monitoring of environmental and production variables to support better management decisions (Berckmans, 2017).

8. INCUBATION REQUIREMENTS

Table 2. General incubation requirements for chicken eggs

Parameter	General recommended condition
Incubation temperature	Approximately 37.5–38.0°C, depending on incubator system
Relative humidity during setting	Approximately 50–60%, adjusted according to egg weight loss and incubator conditions
Relative humidity during hatching	Approximately 65–70%, depending on hatchery conditions
Egg turning	Regular turning during incubation
Turning frequency	Commonly 6–8 times/day or according to incubator design
Turning angle	Approximately 45° on either side

Turning discontinued	Approximately day 18
Ventilation	Adequate oxygen supply and removal of carbon dioxide and excess heat
Incubation period	Approximately 21 days

The values presented are general guidelines. Actual requirements may vary according to incubator design, egg characteristics, breeder flock, environmental conditions, and manufacturer recommendations (Boleli et al., 2016; Molenaar et al., 2010).

9. ROLE OF INCUBATION CONDITIONS IN CHICK QUALITY

Successful incubation should not be evaluated solely on the basis of hatchability. The physiological quality of the newly hatched chick is also an important outcome. Conditions during incubation can influence embryonic growth, organ development, nutrient utilization, hatch timing, and post-hatch performance (Decuypere *et al.*, 2001; Molenaar *et al.*, 2010). Temperature and oxygen availability are particularly important during the later stages of incubation because embryonic metabolic requirements increase substantially. Alterations in eggshell temperature and oxygen concentration can influence embryonic development and the physiological condition of hatchlings.

Therefore, hatchery management should aim not merely to maximize the number of chicks hatched but also to produce vigorous, well-developed chicks with good physiological quality.

10. CONCLUSION

Chicken embryonic development is a highly coordinated process occurring over approximately 21 days and involving cell differentiation, organ formation, membrane development, growth, and maturation. Successful development depends on both pre-incubation egg quality and proper incubation conditions. Egg fertility is mainly affected by breeder genetics, age, nutrition, health, mating ratio, and environmental conditions. Hatchability depends on egg quality, storage, incubation temperature and humidity, ventilation, turning, sanitation, and embryo viability. High fertility does not necessarily result in high hatchability. Therefore, proper breeder management, egg handling, incubation, hygiene, and monitoring of embryonic mortality are essential for achieving good hatchability, chick quality, and efficient poultry production.

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