



Factors Affecting Hatchability of Poultry Eggs

Faizurahman Rahmani^{1*}, Lutfullah Zaheri¹, Abdul Jamil Ghanizada¹, Abdul Khaliq Sahes¹,
¹Department of Animal Sciences, Agriculture Faculty, Kabul University, Kabul Afghanistan

*Corresponding Author Email: rfaizrahman2014@gmail.com

Abstract

Hatchability is a key indicator of reproductive efficiency and economic performance in poultry production. This narrative review synthesizes existing evidence on the major factors affecting poultry egg hatchability, with particular emphasis on fertility, genetic background, disease control, egg quality and selection, nutrition, and egg storage and incubation conditions. The reviewed evidence indicates that fertility is a fundamental determinant of hatchability, while genetic background can influence reproductive performance, with crossbreeding sometimes improving hatchability through heterosis and inbreeding being associated with reduced embryo viability. Disease and inadequate biosecurity may impair fertility and increase embryonic mortality, whereas appropriate egg selection, adequate maternal nutrition, and proper incubation management contribute to embryo survival and chick quality. Overall, hatchability is a multifactorial outcome, and sustainable improvement requires an integrated approach combining effective reproductive management, genetic improvement, disease prevention, appropriate egg selection, balanced nutrition, and proper storage and environmental control. Future research should focus on context-specific and cost-effective strategies, particularly breed-specific approaches and integrated management practices suitable for smallholder and low-input poultry production systems.

Keywords: egg quality, fertility, genetics, hatchability, incubation

د چرگانو له هگيو څخه د چرگورو ايستني اغېزمنونکي عوامل

فيض الرحمن رحمانی^۱، لطف الله ظاهري^۱، عبدالجمیل غني زاده^۱، عبدالخالق سايس^۱

^۱ د پارتمنت علوم حیواني، پوهنځی زراعت، پوهنتون کابل، کابل افغانستان

د مسئول لیکوال برېښنالیک: rfazrahman2014@gmail.com

لنډيز

د چرگورو ايستنی وړتيا (Hatchability) د چرگانو په توليد کې د مثل د توليد د اغېزمنتوب او اقتصادي فعاليت يو مهم شاخص دی. په دې تشریحي څېړنيزه بیاکتنه کې د هغو مهمو عواملو په اړه شته شواهد راټول او ارزول شوي دي چې د چرگانو د هگيو د چرگوري ايستنی وړتيا باندې اغېز کوي. په ځانگړي ډول، د هگيو القاح، انتخاب، د ناروغيو کنټرول، د هگيو کيفيت او انتخاب، تغذيه، او د هگيو د زېرمه کولو او تفریخ شرایطو ته پاملرنه شوې ده. د ارزول شويو شواهدو له مخې، د هگيو القاح د چرگوري ايستني د وړتيا يو بنسټيز ټاکونکی عامل دی. جنټيکي عوامل هم پر تناسلي فعاليت اغېز کولای شي؛ د بېلابېلو نسلونو ترمنځ کله ناکله د هیتروسیس یا د هایبرډ ځواک له امله د هگيو د چرگوري ايستنی وړتيا لوړوي، په داسې حال کې چې د نږدې نژادونو ترمنځ نسل گيري (Inbreeding) د جنين د ژوندي پاتې کېدو وړتيا کموي. ناروغي او د بایوسیکورتي یا بایولوجيکي خونديتوب ناکافي تدابير کولی شي القاح زیانمنه کړي او د جنینونو مړینه زیاته کړي. برعکس، د هگيو مناسب انتخاب، د مورنۍ چرگې کافي تغذيه او د تفریخ د بهیر سم مدیریت د جنینونو په ژوندي پاتې کېدو او د چرگورو په کيفيت کې مهم رول لري. په ټولیز ډول، د هگيو د چرگوري ايستنی وړتيا د گڼو عواملو پایله ده، او د هغې دوامدار پرمختگ یوې مدغمې تگلارې ته اړتیا لري چې اغېزمن تناسلي مدیریت، جنټيکي اصلاح، د ناروغيو مخنیوی، د هگيو مناسب انتخاب، متوازنه تغذيه، او د هگيو د زېرمه کولو او چاپېریالي شرایطو سم کنټرول سره یوځای کړي. راتلونکې څېړنې باید پر هغو تگلارو تمرکز وکړي چې له ځانگړو شرایطو سره برابرې او له اقتصادي پلوه اغېزمنې وي؛ په ځانگړي ډول، د نسلونو له ځانگړتیاوو سره سمې تگلارې او د مدیریت مدغمې کړنلارې چې د کوچنیو فارمونو او د محدودو امکاناتو لرونکو چرگانو د روزنې سیستمونو لپاره مناسبې وي.

کلیدي کليمات: القاح، تفریخ دوره، جنټيک، هگيو کيفيت، چرگورو ايستنی وړتيا

Introduction

Poultry production is one of the most important sectors of global animal husbandry, providing a vital source of high-quality protein and supporting millions of people's livelihoods worldwide (Idowu et al., 2021). Hatchery performance is critical to poultry production, as healthy, uniform day-old chicks are essential for growth, productivity, and profitability. Therefore, chick quality and post-hatch performance are closely linked to incubation practices and effective hatchery management (Underwood et al., 2021).

Hatchability, defined as the percentage of fertile eggs that hatch successfully, is a key economic trait in poultry production (Khalid et al., 2015). Fertility and hatchability are closely related and can vary greatly between breeds, strains, and individual birds. These traits are influenced by many factors, including genetics, breeder management, nutrition, health status, egg handling, and environmental conditions during storage and incubation (King'ori, 2011). In commercial hatcheries, eggs are often stored for 3–7 days before being incubated (Ansah et al., 2023). The time between egg collection and incubation is crucial for hatching success. While short-term storage at around 18 °C usually has little effect on hatchability, longer storage times can significantly reduce hatchability and weaken chick quality (Reijrink et al., 2010). These negative effects are associated with increased albumen pH, albumen thinning, protein degradation, vitelline membrane damage, CO₂ loss, and elevated embryonic cell death, which can cause irreversible embryonic damage (Dai et al., 2025; Pennings et al., 2025).

Incubation conditions, especially temperature, are vital for proper embryonic development. Optimal development has been reported when eggs are incubated at 37.5–37.8 °C during days 1–18 and 36.1–37.2 °C during the hatching phase (Popović & Popović, 2024). Even small deviations from these temperature ranges can negatively affect hatchability and increase post-hatch mortality (van der Pol et al., 2013). Temperature is a key environmental factor affecting embryonic growth and organ development, as both low and high temperatures can disrupt normal physiological processes. Recent studies indicate that incubation temperature interacts with in ovo feeding to influence broiler performance and welfare (Das et al., 2021; Zhao et al., 2023). Additionally, incubation conditions can alter blood biochemical profiles, such as lipid, protein, and glucose levels, which are essential for metabolism and ultimately influence hatchability and post-hatch performance (Yehia et al., 2024).

Nutrition is another major factor affecting egg quality, fertility, and hatchability. Breeder diets must meet nutritional requirements to support reproductive performance. Overweight breeders, often due to poor feed management, tend to exhibit reduced semen quality, impaired ovulation, and regression of reproductive organs (Brillard, 2007). This approach has also been proposed as a promising strategy for improving hatchability and chick performance after hatching (Das et al., 2021; Arain et al., 2022; Nabi et al., 2023, 2024). Studies also show that in ovo feeding can enhance organ development and mineral content in chicks after hatching by improving nutrient absorption and metabolism during embryonic development (Yair et al., 2015).

Genetic factors also play a major role in hatchability. Different genetic strains show variations in egg traits, embryonic development, and viability. For example, brown-feathered strains often show higher hatchability than white-feathered strains, largely due to differences in egg structure and physical traits among lines (Tona et al., 2010; Narushin et al., 2016). In addition, egg genotypes and nutrient deficiencies can influence embryonic development and later performance (Kuka et al., 2023, 2024; Okai et al., 2025). In addition to management and

genetic factors, foodborne pathogens also present major challenges to poultry production and reproductive efficiency. Pathogens such as *Salmonella*, *Escherichia coli*, and *Clostridium* species can disrupt reproductive processes, affecting fertilization and early embryonic development and thereby reducing hatchability (Sharma et al., 2025).

Overall, poultry egg hatchability is influenced by a complex interaction of factors, including fertility, genetics, nutrition, egg handling, disease control, and environmental conditions. Effective breeder management, combined with careful egg selection, proper storage, sanitation, and precise control of incubation conditions such as temperature, humidity, ventilation, and egg turning, is essential for reducing embryonic losses and improving chick quality. Therefore, this review synthesizes current knowledge on factors affecting hatchability and provides evidence-based recommendations for improving hatchery performance and sustainability.

Methodology

This study employed a narrative review approach to integrate and synthesize existing research on factors influencing poultry egg hatchability. A comprehensive search was performed across major scientific databases and journals to identify relevant peer-reviewed studies. A total of 53 peer-reviewed papers published between 2000 and 2025 were selected from an initial pool of more than 250 publications identified through Web of Science, PubMed, ScienceDirect, and Scopus. Google Scholar was also searched to identify additional peer-reviewed sources; non-peer-reviewed content was excluded.

The search terms included: hatchability, fertility, genetics, egg selection, incubation, nutrition, environmental conditions, and disease control. Studies were selected based on their relevance to poultry species and their contribution to understanding the biological and management factors that influence hatchability. For each selected study, key information was extracted, including the year of publication, poultry species or breed, main factors, and reported outcomes related to fertility, hatchability, embryonic mortality, and chick quality. The extracted data were qualitatively analyzed and synthesized to identify consistent trends, relationships, and knowledge gaps related to poultry egg hatchability.

Results

Fertility

Across the studies reviewed, fertility consistently emerged as one of the most important biological factors determining poultry egg hatchability. Since only fertile eggs can develop into embryos, differences in fertility account for much of the variation in hatchability observed across breeds, production systems, and management practices. Elibol et al. (2002) examined how breeder flock age, egg storage duration, and turning frequency during storage affected broiler hatching eggs. Their results showed that fertility declined with increasing breeder age, and this decline was mirrored by reduced hatchability. Even though storage conditions affected embryonic survival, fertility remained essential for successful hatching, and good incubation practices could not fully offset poor fertilization.

Similarly, Farooq et al. (2003) studied hatchability in rural backyard poultry systems in Peshawar, Pakistan, and found that low hatchability was mainly due to poor fertility. Factors such as uncontrolled mating, improper male-to-female ratios, poor nutrition, and weak reproductive management were linked to reduced fertility. Even with natural incubation,

hatchability remained low when fertility was inadequate, underscoring the importance of fertility in traditional systems.

Islam et al. (2002) also reported breed-related differences in fertility and hatchability among Barred Plymouth Rock, White Leghorn, Rhode Island Red, and White Rock chickens. This study found significant differences among breeds, with Rhode Island Red and White Rock showing higher fertility and hatchability, while White Leghorn had lower values.

Recent findings by Jegede et al. (2024) reinforced the strong link between fertility and hatchability. Fertility was a major predictor of hatchability regardless of egg weight or external egg quality. Eggs with higher fertility consistently achieved higher hatch rates, and significant differences were observed between indigenous and exotic genotypes. Fulla & Gebreslassie (2024) also reported that fertility strongly correlated with hatchability and chick quality. Eggs with low fertility had higher embryonic mortality, while those with higher fertility produced better chicks.

Overall, these studies clearly show that fertility is a key determinant of hatchability. Variations in fertility due to breeder age, breed, and production system directly affect hatch outcomes, making fertility a primary factor in hatching success.

Genetics

Genetic factors were consistently shown to significantly influence hatchability, affecting both embryo survival and reproductive performance. Studies on inbreeding, crossbreeding, and genetic selection revealed notable differences in hatchability across genotypes. Dzungwe et al. (2024) found that crossbreeding between Sasso and Wassache chicken strains improved hatchability compared to pure lines. Crossbred eggs showed better embryonic survival and lower early mortality, suggesting that heterosis enhances reproductive efficiency.

Mokoena et al. (2025) reviewed global evidence and concluded that crossbred populations generally perform better than pure lines in hatchability, egg quality, and chick survival, as heterosis reduces inbreeding depression. Fathi et al. (2022) found that certain genotypes had higher hatchability rates and that egg weight interacted with genetic background to influence embryo survival. This highlights how genetics and physical egg traits together affect hatch success.

In broiler breeders, Makanjuola et al. (2021) found significant genetic variation for hatchability, suggesting potential improvement through selective breeding. Wolc et al. (2010) reported moderate heritability for hatch of fertile eggs and positive correlations between hatchability and egg quality traits, such as shell strength and egg weight, indicating that selection can improve hatch success.

Overall, the evidence suggests that hatchability is partially under genetic control. Crossbreeding improves hatch success through heterosis, while inbreeding reduces embryo survival. These findings emphasize the importance of genetic management and selection for improving hatchability.

Diseases

Disease was identified as a major constraint on hatchability, affecting fertility, embryo survival, and overall reproductive performance. Pathogens can reduce hatchability by damaging the reproductive system or by reducing egg quality and embryo viability. Kovács et al. (2025) highlighted those significant diseases in domestic fowl and turkeys, including bacterial, viral,

and parasitic infections, can spread through contact, fomites, contaminated feed, and water. These infections can compromise egg quality and embryo viability, reducing hatchability.

Owusu & Sanad (2025) found that highly pathogenic avian influenza (H5N1) significantly reduced hatchability, resulting in high embryo mortality. The study also noted that subclinical infections may reduce fertility, lowering hatch rates even in apparently healthy flocks.

Sharma et al. (2025) reviewed foodborne bacterial pathogens in poultry and reported that *Salmonella*, *E. coli*, and *Clostridium* species can colonize the reproductive tract and disrupt fertilization and early embryonic development, thereby reducing hatchability. The review also highlighted that probiotics may reduce pathogen load and improve reproductive performance.

Butucel et al. (2022) discussed biosecurity measures targeting bacterial biofilms, which resist disinfection and serve as reservoirs for disease transmission. Improved biosecurity and sanitation were associated with lower pathogen exposure and higher hatchability.

Overall, disease presence and weak biosecurity were shown to significantly reduce hatchability by affecting fertility and embryo survival.

Egg Selection

Egg selection was consistently reported as an important factor influencing hatchability. Both external and internal egg quality traits strongly affect fertility, embryo development, and hatch success. Ahmad et al. (2019) found that selecting eggs based on weight, shell thickness, and shape index improved hatchability and hatching performance in Japanese quail. Eggs within the optimal weight range and normal shape showed higher hatch rates.

In indigenous systems, selecting clean, normal-shaped, medium-sized eggs is essential to improve hatchability. Poor egg selection contributes to low hatch success even with proper incubation management. Tunsisa & Reda (2023) showed that variations in egg traits across different agro-ecological zones affected fertility and hatchability in indigenous chickens. Selecting eggs with intact shells and optimal weight reduced embryo mortality and improved hatchability.

Fulla & Gebreslassie (2024) found that eggs selected for uniform weight and strong shell quality had higher hatchability and better chick quality, while poor selection increased early and late embryo mortality. Egg quality indices such as weight, shell thickness, and internal quality traits also strongly predicted fertility and hatchability in guinea fowl (Jegade et al., 2024).

Overall, these studies suggest that egg selection based on quality traits improves hatchability by reducing embryo mortality and improving fertility and chick quality.

Nutrition

Nutrition was repeatedly identified as a key factor influencing hatchability. Both maternal diet and in-Ovo supplementation significantly affected embryo development, hatchability, and chick viability. Ncho et al. (2024) conducted a meta-analysis on in-Ovo vitamin feeding in broilers and reported improved hatchability and growth performance. Vitamins A, D, and E were associated with enhanced embryo survival and reduced early mortality. Moran (2007) emphasized that adequate nutrition during incubation is crucial for the structural and functional development of the embryo. Nutrient deficiencies in amino acids, vitamins, or minerals impair metabolism and reduce hatch rates. Uni & Ferket (2004) reviewed early nutrition methods and highlighted in-Ovo feeding and nutrient-enriched egg treatments as strategies that accelerate

embryo growth, improve immune competence, and enhance post-hatch performance. Fulla & Gebreslassie (2024) reported that maternal nutrition and egg quality directly influenced fertility, hatchability, and chick quality. Eggs from well-nourished hens showed higher hatch rates and better chick viability. Several nutrients, including vitamins E, B-complex, and folic acid, were found to affect hatchability. Additionally, dietary supplementation with organic selenium improved hatchability in fertile eggs (Hanafy et al., 2009).

Overall, optimizing maternal nutrition and early nutritional interventions improved embryo survival, hatchability, and chick quality.

Environmental Conditions

Environmental conditions such as temperature, humidity, and ventilation were consistently shown to be critical for hatchability and chick quality. Both pre-incubation and incubation environments significantly influence embryo development and survival. Noiva et al. (2014) demonstrated that manipulation of incubation temperature and humidity affects embryo growth and hatch success. Deviations from optimal conditions caused abnormal development, increased mortality, and reduced chick viability.

Precise control of temperature, humidity, and ventilation is essential for maximizing hatchability in duck eggs, while poor environmental management was linked to higher embryo mortality and lower chick quality (Abd El-Hack et al., 2022). Mwesigwa et al. (2015) found that pre-incubation conditions, including storage temperature and humidity, along with incubation parameters, significantly affected hatchability and chick quality in Kuroiler chickens. Okeoma et al. (2025) developed a microcontroller-based incubator for limited-power settings and reported improved hatchability with automated temperature and ventilation control.

Poultry egg incubation and hatchery management were also identified as essential factors influencing hatchability and chick quality. Proper control of temperature and humidity during incubation is necessary for optimal embryo development and successful hatching (Tona et al., 2004; Ayalew, 2016). Hatchery management practices, including egg handling, storage, incubation, and hatching procedures, significantly affect overall hatchery performance (Rocha et al., 2013; Saeed et al., 2019).

Extended egg storage prior to incubation reduces hatchability, especially when eggs are stored for 10–14 days before setting (Romao et al., 2008). Adame and Ameha (2023) highlighted that proper egg handling and environmental management practices, such as ventilation, humidity regulation, and temperature control, can collectively improve hatch rates and chick quality.

Overall, the reviewed studies indicate that maintaining optimal environmental conditions during storage and incubation is essential for maximizing hatchability and ensuring high-quality chicks.

Discussion

The present review indicates that poultry egg hatchability is a multifactorial trait influenced by the interaction of reproductive, genetic, health, nutritional, egg-quality, and environmental factors. Rather than acting independently, these factors may influence different stages of the reproductive process, from fertilization and egg formation to embryonic development and hatching. Therefore, differences in hatchability among breeds and production systems should

be interpreted within the context of breeder age, genetic background, disease status, egg quality, nutrition, and management conditions. Among the factors consistently reported in the reviewed literature, fertility, genetic background, disease control, egg selection, nutrition, and environmental management appear particularly important.

Fertility and breeder management

Fertility represents a fundamental prerequisite for hatchability because an unfertilized egg cannot produce a viable embryo. However, fertility should not be considered synonymous with hatchability, since even fertile eggs may fail to hatch as a result of embryonic mortality during incubation. The reviewed studies indicate that variation in fertility can explain substantial differences in hatchability among breeds, production systems, and management conditions (Elibol et al., 2002; Farooq et al., 2003; Fulla & Gebreslassie, 2024). Thus, improvements in fertility may increase the number of eggs available for embryonic development, but successful hatching ultimately depends on the subsequent survival and development of the embryo. Breeder age is another important component of reproductive management. Elibol et al. (2002) reported an association between breeder age, fertility, and hatchability, suggesting that reproductive performance may change as birds progress through the production cycle.

Nevertheless, the effect of breeder age should not necessarily be interpreted as a direct and universal reduction in hatchability, because age-related changes may also operate through egg size, shell characteristics, fertility, and other physiological changes. Consequently, age-specific breeder management may be more appropriate than applying a single management strategy across all stages of the production cycle. Genetic background may further modify reproductive performance. Some studies have reported higher fertility among indigenous genotypes under local production conditions compared with exotic breeds (Islam et al., 2002; Jegede et al., 2024). Such differences may reflect adaptation to local environmental conditions, management systems, disease challenges, and nutritional resources rather than genetic superiority alone. Therefore, the apparent advantage of indigenous genotypes should be interpreted within a genotype-by-environment context. This consideration is particularly relevant for low-input production systems, where locally adapted birds may perform differently from highly selected commercial genotypes.

Genetic effects, crossbreeding, and inbreeding

The reviewed evidence also suggests that genetic background contributes substantially to variation in hatchability. Crossbreeding and heterosis studies have reported improved embryonic survival and hatchability in some crossbred populations compared with pure lines, whereas inbreeding has generally been associated with poorer reproductive performance (Dzungwe et al., 2024; Mokoena et al., 2025; Makanjuola et al., 2021). These findings are consistent with the concept of inbreeding depression; whereby increased homozygosity may expose deleterious alleles and reduce biological fitness. The heritable component of hatchability provides an opportunity for genetic improvement through selection. Wolc et al. (2010) demonstrated the importance of genetic variation in reproductive traits, supporting the potential for selection programs to improve reproductive performance.

However, selection for hatchability should be implemented carefully because excessive emphasis on reproductive traits or restricted breeding populations may increase the risk of inbreeding. Therefore, genetic improvement programs should seek a balance between selection intensity and maintenance of genetic diversity. Genotype-specific differences may also be related to egg characteristics. Fathi et al. (2022) highlighted the importance of egg quality traits,

including egg weight and shell strength, in relation to reproductive outcomes. This suggests that breeding programs may benefit from considering both reproductive performance and egg-quality traits rather than treating hatchability as an isolated trait. The combined consideration of genotype, egg quality, and management may therefore provide a more effective strategy for improving hatchability than selection based on a single characteristic.

Disease control and biosecurity

Disease status and biosecurity represent another important pathway through which hatchability can be affected. Infectious diseases may impair reproductive function, reduce fertility, increase embryonic mortality, or contaminate eggs. Viral infections, including highly pathogenic avian influenza such as H5N1, have been associated with severe reproductive and embryonic consequences, while subclinical infections may negatively affect reproductive performance even when clinical signs are limited (Owusu & Sanad, 2025).

These findings highlight the importance of considering both clinically apparent and subclinical infections when evaluating hatchability. Bacterial infections may have similarly complex effects. Pathogens such as *Salmonella*, *Escherichia coli*, and *Clostridium* species can be associated with reproductive tract infection, egg contamination, and impaired embryonic development (Sharma et al., 2025). However, the magnitude of their effects may depend on pathogen load, infection route, flock health status, and management conditions. Therefore, the relationship between disease and hatchability should not be interpreted solely as a direct pathogen effect; rather, disease may influence hatchability through several pathways involving fertility, egg contamination, embryo viability, and chick survival.

Biosecurity and sanitation are consequently important components of hatchery management. Evidence concerning bacterial biofilms indicates that inadequate cleaning and sanitation may allow microorganisms to persist within hatchery environments, whereas improved hygiene can reduce pathogen reservoirs and potentially improve reproductive outcomes (Butucel et al., 2022; Kovács et al., 2025). These findings support an integrated disease-control strategy involving appropriate vaccination, flock health monitoring, sanitation, egg hygiene, and biosecurity. Such measures are likely to be particularly important in smallholder and low-resource systems, where infrastructure and disease-control capacity may be limited.

Egg selection and egg quality

Egg selection provides a relatively simple management intervention for improving hatchability. The reviewed literature indicates that both external and internal egg-quality characteristics can be associated with hatchability and subsequent chick quality. Egg weight, shell thickness, and shape index have been identified as useful indicators of egg suitability for incubation (Ahmad et al., 2019; Tunsisa & Reda, 2023; Jegede et al., 2024). However, the relationship between these characteristics and hatchability should not be interpreted as universally linear, because optimal egg characteristics may differ according to breed, production system, breeder age, and incubation conditions. The importance of egg selection may be particularly pronounced in low-input and indigenous production systems. Fulla and Gebreslassie (2024) emphasized the value of selecting clean, normally shaped, and appropriately sized eggs. Such practices are relatively inexpensive and do not require sophisticated technology, making them potentially valuable for smallholder producers. Nevertheless, egg selection should be viewed as one component of a broader management

system rather than as a substitute for adequate breeder nutrition, disease control, storage, and incubation conditions.

Nutrition and embryonic development

Nutrition affects hatchability through both the nutritional status of the breeder and the nutrients deposited in the egg. Maternal nutrition influences egg composition and the nutrient reserves available to the developing embryo. Consequently, deficiencies or imbalances in breeder diets may affect embryonic development and subsequent chick quality. In addition, in ovo supplementation has been investigated as a means of providing selected nutrients directly to the developing embryo. Studies have reported beneficial effects of vitamins and other nutrients on embryonic survival and post-hatch performance under specific conditions (Ncho et al., 2024; Uni & Ferket, 2004).

Conversely, inadequate nutrient availability during embryonic development may impair metabolism and physiological development, resulting in lower hatchability and weaker chicks (Moran Jr., 2007). These findings suggest that nutritional management should be considered across the entire reproductive cycle rather than focusing exclusively on the incubation period. Nevertheless, the response to nutritional interventions may depend on breeder age, baseline nutritional status, genotype, nutrient dose, timing, and environmental conditions. Therefore, nutritional supplementation should be based on evidence regarding specific deficiencies or production conditions rather than assuming that additional supplementation will always improve hatchability.

Egg storage and incubation environment

Environmental conditions during egg storage and incubation represent another critical component of hatchability. Temperature, relative humidity, ventilation, and the duration of exposure to unfavorable conditions can affect embryonic development and survival. Deviations from appropriate incubation conditions have been associated with increased embryonic mortality, reduced hatchability, and poorer chick quality (Noiva et al., 2014; Abd El-Hack et al., 2022; Mwesigwa et al., 2015).

Importantly, egg storage and incubation should be considered as two related but distinct management stages. Conditions experienced before incubation may influence embryo viability and may have consequences that cannot be completely corrected after incubation begins. Mwesigwa et al. (2015) highlighted the importance of storage conditions for subsequent embryo survival, emphasizing that hatchery management begins before the egg enters the incubator.

The importance of environmental control may be even greater where climatic conditions are highly variable or hatchery infrastructure is limited. Technological approaches such as automated incubation systems may provide more stable temperature and humidity conditions and have been associated with improved hatchery performance (Okeoma et al., 2025). However, the benefits of such technologies may depend on appropriate operation, maintenance, electricity availability, and producer capacity. Thus, technological intervention alone cannot guarantee improved hatchability without appropriate management and monitoring.

Interaction among hatchability-related factors

An important implication of the reviewed literature is that hatchability should not be viewed as the result of independent effects of individual factors. Instead, fertility, genetics, disease, egg quality, nutrition, storage, and incubation environment may interact throughout the

reproductive process. For example, breeder genotype and age may influence egg characteristics, while maternal nutrition may modify egg composition and embryo nutrient availability. At the same time, disease and poor biosecurity may reduce fertility or increase embryonic mortality, whereas inappropriate storage and incubation conditions may further reduce the survival of otherwise viable embryos.

This interaction helps explain why the same management intervention may produce different results across breeds, production systems, or geographical settings. For example, a genotype that performs well under controlled commercial conditions may not necessarily show the same reproductive advantage under low-input conditions. Similarly, improved egg selection may have limited effects if breeder nutrition, disease control, or incubation conditions remain inadequate. Therefore, interventions aimed at improving hatchability should be evaluated within the broader production system rather than in isolation.

Implications and research priorities

Overall, the reviewed evidence supports an integrated approach to improving poultry hatchability. Reproductive management should focus on maintaining adequate fertility and managing breeder age; genetic programs should consider both reproductive performance and genetic diversity; disease-control programs should combine vaccination, hygiene, and biosecurity; egg selection should emphasize appropriate egg quality; nutritional management should address both maternal nutrition and, where appropriate, in ovo supplementation; and storage and incubation should maintain suitable environmental conditions. Future research should place greater emphasis on interactions among these factors rather than evaluating them independently. In particular, studies in smallholder and low-input systems are needed to determine whether findings derived from commercial poultry operations can be directly applied under local conditions. Research should also examine genotype $\times$ environment interactions, breeder age $\times$ egg quality relationships, and the combined effects of nutrition, disease status, storage, and incubation conditions. Such approaches could help identify context-specific and cost-effective strategies for improving hatchability and chick viability across different poultry production systems.

In conclusion, the available evidence indicates that improving hatchability requires more than addressing a single limiting factor. Hatchability is the final outcome of a sequence of biological and management processes beginning with breeder fertility and egg formation and continuing through egg storage, embryonic development, and hatching. Consequently, integrated management strategies that simultaneously address reproductive, genetic, health, nutritional, egg-quality, and environmental factors are likely to provide more sustainable improvements in hatchability than isolated interventions.

Conclusions

Poultry egg hatchability is influenced by the combined effects of fertility, genetics, disease control, egg quality, nutrition, and storage and incubation conditions. Improving hatchability therefore requires an integrated approach rather than focusing on a single factor. Farmers should use healthy breeders, provide balanced nutrition and adequate water, select clean and normally shaped eggs, minimize storage duration, maintain proper hygiene and biosecurity, and carefully control temperature, humidity, ventilation, and egg turning during incubation. These simple and practical measures can improve hatchability and chick viability, particularly in smallholder and low-input poultry production systems. Future research should focus on developing cost-

effective, context-specific strategies that address the interaction of these factors under different production conditions.

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