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Impact of Temperature on Embryonic Development Rates in Gallus Gallus Domesticus

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Abstract

An experiment was conducted to study the impact of temperature on embryonic development rates in Gallus gallus domesticus. For this purpose, 40 eggs were obtained and divided into four groups (10 eggs in each group): Group A was kept in a refrigerator at a temperature of approximately(9-10°C), Group B was kept at normal room temperature (28–36°C), Group C was buried in flour (30–32°C), and Group D was kept wrapped in cotton (33–46°C). The experiment lasted 15 days, during which the eggs were observed daily to note changes in their weight, color, odor, and internal development (through candling). The results showed that there was no embryonic development at all in groups A and B, which may be due to the low or inappropriate temperature. In group C, 40% of the eggs showed signs of partial development, while in group D, 60% of the eggs showed clear embryonic development, but no complete chicks hatched in any of the groups. The study concluded that suitable, constant and high temperature is essential for proper embryonic development of eggs. Although home-made methods such as flour or cotton may be partially successful, a suitable arrangement such as an artificial incubator is indispensable for complete and safe hatching of chicks. Moreover, indigenous eggs are better adapted to local temperatures, which may allow for some successful incubation even in local resources.

Keywords: Embryonic development, temperature effects, Gallus gallus domesticus, incubation conditions, egg development, **h**atchability, **e**nvironmental conditions, **r**efrigeration, cotton insulation, flour insulation, **t**emperature fluctuations, embryonic mortality, egg survival, **i**ncubation temperature

1. Introduction

The chicken (Gallus gallus domesticus) embryo serves as an excellent model organism for developmental biology because most of its development occurs inside an egg, independent of the mother.By creating a small hole in the egg shell, it becomes possible to directly access, observe, and manipulate the early stages of embryonic development (Jove Science Education Database, 2014).Incubation conditions have significant effects on embryonic development, hatchability,

chick quality, and post hatch performance (Han et al., 2022; Rocha et al., 2022; Fares et al., 2023; Al-Zghoul et al., 2023). Multiple investigations have been performed to identify solutions to improve these variables (hatchability and chick quality) and one of the most effective ways is temperature management (Tona et al., 2022; Al-Zghoul et al., 2023).

Three factors affect the temperature that the developing embryo experiences:1) the incubator temperature, 2) the embryo's capacity to transfer heat between the incubator and itself, and 3)the embryo's own metabolic heat generation.Temperature, an important environmental condition that influences several biological functions of eggs, is considered as the most critical incubation condition. Studies have shown that controlling the temperature during incubation can influence embryonic organ development, hatching parameters, and chick quality at hatch Han et al. (2022).The conditions during incubation must be regulated to satisfy the needs of the embryo in order to achieve the ideal incubation results (Meijerhof, 2009a).The optimum incubation temperature for most of poultry species is between 37 and 38 C, and even slight deviations from this can significantly affect the growth of the embryo and hatching success (Wilson, 1991).

French (2000) asserts that even a small temperature difference can have a substantial effect on an embryo's growth. The development of the embryo and its organs may be impacted by departures from the optimal incubation temperature. impacts both skeletal growth and hatching success (Yalcn and Tazawa et al., 2004; Siegel, 2003). It has been demonstrated that maintaining the appropriate embryonic temperature throughout incubation is more important than the incubator temperature settings because the temperature inside the egg, also known as the embryo temperature, is of the biggest relevance (Meijerhof, 2009a). Therefore, attempts to keep embryo temperatures within acceptable ranges will improve hatchability and chick quality (Meijerhof, 2009a).

It has been demonstrated that maintaining the appropriate embryonic temperature throughout incubation is more important than the incubator temperature settings because the temperature inside the egg, also known as the embryo temperature, is of the biggest relevance.While low temperatures have the opposite impact, high temperatures usually shorten incubation times and accelerate embryonic development (Kaplan et al., 1978; Black and Burggren, 2004). Additionally, if the incubation temperature is either too high or too low, an increase in embryonic mortality will result in a decrease in hatchability (Decuypere et al., 1979; Suarez et al., 1996).

However, calculating out the embryo's temperature requires the use of harmful methods that change the embryo's potential for development and hatching. Eggshell temperatures (ETS) are what we use. Eggshell temperature which measures the temperature of the embryo, can resolve this problem. Lourens (2001) found that the average eggshell temperature of commercial one-stage incubators was 37.8°C. A 5°C fluctuation in eggshell temperature was seen, nevertheless, and this changed depending on the position and the egg's maturation stage (Lourens, 2001). In particular multiple phases, it is reasonable to anticipate relatively low and high EST at the beginning and end of incubation, respectively, because to the imbalance between heat generation and transfer in embryos (Meijerhof, 2002).

Since the effects of varying eggshell temperature on these processes are unknown, an experiment was conducted to evaluate the effects of low eggshell temperature (36.7°C) during the first week of incubation and high EST (38.9°C) during the third week on embryo development, hatchability, and performance after hatching. The eggs in the control group were consistently incubated at 37.8°C (EST). Since the age of the parent stock significantly affects the development of an embryo and hatching, the experiment was repeated twice using eggs from varying ages of the stock (Gladys et al., 2000). Apart from evaluating the impact of eggshell temperature on hatchability and embryo development, post hatch performance was also evaluated in chicks housed at different temperatures (HT).

The primary objective of this study is to examine the causing of different incubation temperatures on the rate of embryonic development in Gallus gallus domesticus (domestic chicken). This research objective to determine the optimal temperature range for normal development, identify any developmental abnormalities caused by temperature fluctuations, and assess the correlation between incubation temperature and hatching success rate.

2. Material and Methods

2.1 Experimental Setup

The experiment was set up to examine the effect of temperature on embryonic development rates on Gallus gallus domesticus. We placed the eggs in four different environmental conditions. Each group was exposed to a specific temperature setting to observe change in development. First, condition eggs were placed in refrigerator at approximately 9°C to 10°C. Second, condition eggs were placed in room temperature at approximately 28°C to 30°C . Third, condition eggs were directly placed in flour. Fourth, condition eggs were placed in cotton. Each group contained an equal number of eggs (n = 40). The experimental duration was kept 15 days for all groups and environmental variables such as humidity and light exposure were kept consistent across all groups to ensure that temperature remained the primary factor influencing embryonic development.

2.2 Incubation

To ensure genetic uniformity, 40 eggs of the same size and weight were selected from the same parent flock (broiler breed) for this experiment. Before being incubated, each egg was cleaned with a disinfectant solution and allowed to dry at room temperature for two hours. Each egg was candled to verify fertility. The eggs were divided at random to form four experimental groups with varying temperatures.

Four groups of ten eggs each were randomly selected from the eggs. Group 1 had remained refrigerated. The second group was kept at the room temperature. Cotton was used to incubate Group 3. The last set was put straight into the flour. Prior to incubation, each egg started out at the same beginning temperature. Throughout the incubation period, the cotton group's temperatures were the highest and most consistent. In contrast, the refrigerator group stayed chilly all the time. Flour exhibits somewhat better heat retention than room temperature, whereas the flour and room temperature groups retain intermediate temperature.

Standard thermometers were used to measure the temperature in the incubation environment on days 5, 10, and 15. No additional humidity control or egg-turning mechanism was used, aside from the inherent properties of each incubation medium (flour or cotton). The experiment's primary focus was on how the four basic incubation methods varied in temperature.

Each of the four treatment groups showed different temperature profiles on the fifth day of the trial. The refrigerator group confirmed that the gadget was operating properly by maintaining the temperature at 10°C. The normal cold storage conditions that would promote embryonic growth are represented by this temperature. The average ambient temperature in the experimental setting, 28°C, was then recorded by the room temperature group. Although sluggish embryonic development is possible at this temperature, it is still a little below the ideal range for incubation. Cotton's ability to produce a warm, stable microclimate was demonstrated when the third cotton-insulated group reached and maintained 33°C. The temperature falls within the ideal range for the early stages of embryonic development. The fourth flour embedded group showed a moderate ability to retain heat, even though it stabilized at 30°C, which was warmer than room temperature but still within the optimal incubation range. The temperature falls within the ideal range for the early stages of embryonic development. The fourth flour embedded group showed a moderate

ability to retain heat, even though it stabilized at 30°C, which was warmer than room temperature but still within the optimal incubation range.

On the 10th day of observation, the refrigerator group kept a constant low temperature of 9.5°C, indicating stable cold conditions. The temperature of the eggs reach 29°C when they are kept at room temperature, suggesting that the environment is initially warm.The cotton-insulated group showed significant heat retention at 35°C, but the flour-embedded eggs registered 33°C, demonstrating moderate thermal stability.

Temperature variations become more noticeable on the fifteenth day of the final data toward the end of the study.The temperature in the group that was refrigerated stayed at 9°C the entire time. At normal temperature, the eggs' temperature rose marginally to 30°C. The cotton-incubation approach was the most effective; it reached 42°C, which is within the optimal hatching range. The flour group was able to retain heat at 32°C better than the ambient air, but not as good as cotton insulation.

2.3 Embryonic development

We took 40 eggs and kept them in different environmental conditions. No embryonic development was observed in the 10 eggs stored in the refrigerator . This means that the temperature did not affect the eggs that was stored in the refrigerator. Then, the 10 eggs that we kept at room temperature also showed no embryonic development. After seven days, the 10 eggs stored in cotton began to show development. This means fluctuations in temperature can affect the eggs (embryonic development). No development was observed in the 10 eggs that was stored in the flour.

2.4 Embryonic mortality and hatchability

Chicken (Gallus gallus domesticus) eggs were used in the experiment to study the effects of temperature in different environmental conditions. Chicken (Gallus gallus domesticus) 40 eggs were divided into four groups and incubated under different environmental conditions in the experiment.

The first group, consisting of ten eggs, were kept in the refrigerator for fifteen days.These eggs did not spoil and are still in good condition, with no embryonic development.The low temperature kept the eggs safe, but none of them hatched or developed into chicks.

The 10 eggs of the second group were kept at room temperature. Within a few days, all of these eggs were spoiled, indicating that without controlled incubation, normal temperatures were not suitable for preserving the eggs. In this group, embryonic mortality was 100% and none of the eggs hatched.

The third group of 10 eggs were placed in cotton to provide a natural insulation environment. The eggs in this group successfully started developing and showed clear signs of growth. This means that the cotton provided a moderately warm and stable environment, which was suitable for embryonic development. Some eggs in this group showed significant growth, indicating a partial hatching rate.

The final group of 10 eggs were placed in flour to create a more insulating environment. The results were mixed some eggs were damaged while others showed signs of growth. This indicates partial success, which was likely due to the uneven insulation and temperature imbalance in the flour. Therefore, partial embryonic mortality and hatching rates were also observed in this group.

Overall, the results show that there is a clear relationship between temperature and embryonic development. Eggs that were kept in suitable or insulating conditions showed growth and hatchability, while eggs that were kept at extreme or unbalanced temperatures showed complete or partial embryonic mortality.

2.5 Statistical analysis

To evaluate the effects of different temperatures and storage methods on embryo development and hatchability of Gallus gallus domesticus, data from four experimental groups were analyzed. The analysis included the total number of eggs, developing eggs, spoiled eggs, and hatchability and mortality percentages.

This descriptive statistical analysis helps us understand which environment is more suitable for successful embryo development. The following formulas were used:

Hatchability (%) = (Number of Developed Eggs / Total Eggs)×100

Embryonic Mortality (%) = (Number of Spoiled or Undeveloped Eggs / Total Eggs)×100

Table: Statistical Summary of Embryonic Development and Mortality

Group	Total Eggs	Developed Eggs	Spoil Eggs	Hatchability (%)	Embryonic Mortality (%)
Refrigerator	10	0	0	0%	100%
Room Temperature	10	0	10	0%	100%
Cotton	10	6	4	60%	40%
Flour	10	4	6	40%	60%

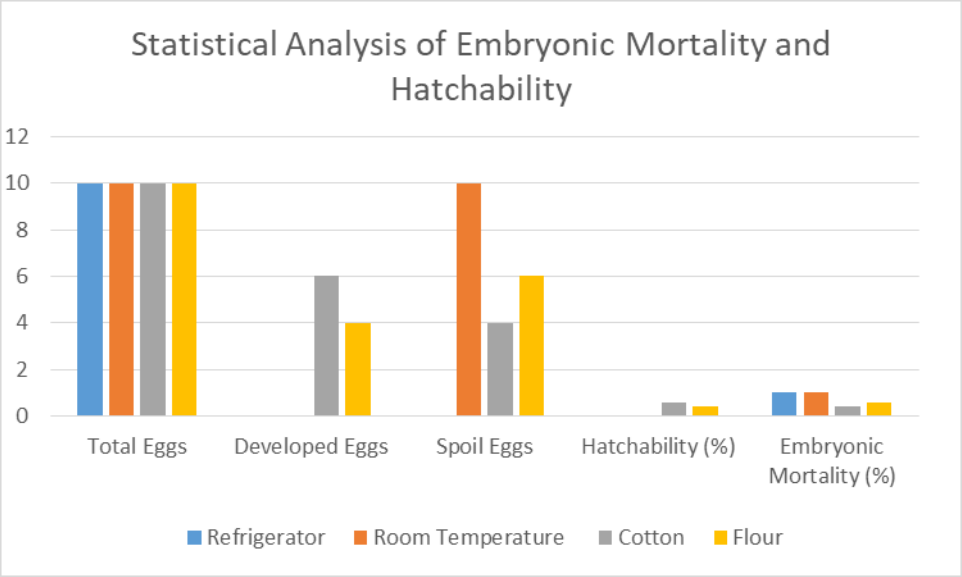


Figure:2.5.1 This figure presents a comparative analysis of embryonic development and hatchability rates of Gallus gallus domesticus eggs stored under different storage conditions refrigeration, room temperature, cotton, and flour. The highest success rate was observed in the cotton group, where 60% of the eggs developed. This indicates that a heat preserving environment is favorable for embryo genesis. The refrigerated and room temperature groups had zero hatchability, indicating complete embryonic mortality. The flour group had 40% hatchability, indicating partial success.

3. Results

In this experiment, eggs were placed in different environments (refrigerator, room, flour and cotton) and their temperature changes were recorded for 15 days. The results are as follows:

Eggs placed in the refrigerator the initial temperature of this egg was 28°C, which dropped to 10°C on the second day and remained between about 9 and 10°C for the remaining days. This shows that the refrigerator effectively kept the egg cool and kept the temperature stable.
Eggs placed at room temperature the temperature of the egg remained between 28 and 30°C in the initial days, but after the tenth day it increased, reaching 36°C by the fifteenth day. This indicates that the temperature increase was due to environmental influences or possible biological processes.
Eggs placed in a flour the temperature of this egg gradually increased and reached 32°C by the fifteenth day. The flour acted as a moderate insulator, partially preventing the outside temperature from reaching the egg.
Eggs placed in cotton showed the highest temperature increase. Starting from 28°C on the first day, it reached 46°C on the fifteenth day. This shows that the cotton acted as an effective insulator and retained the heat inside.

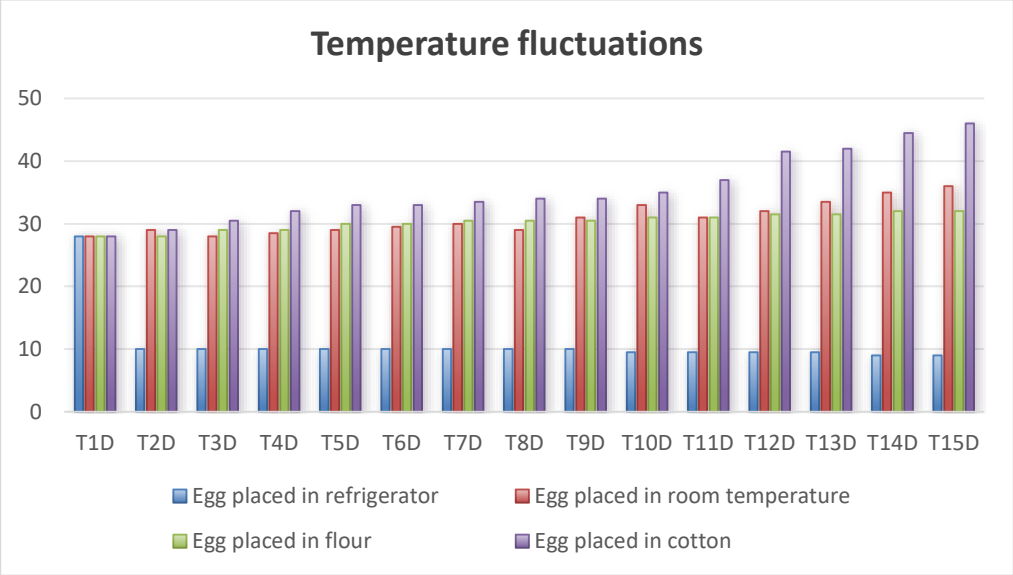
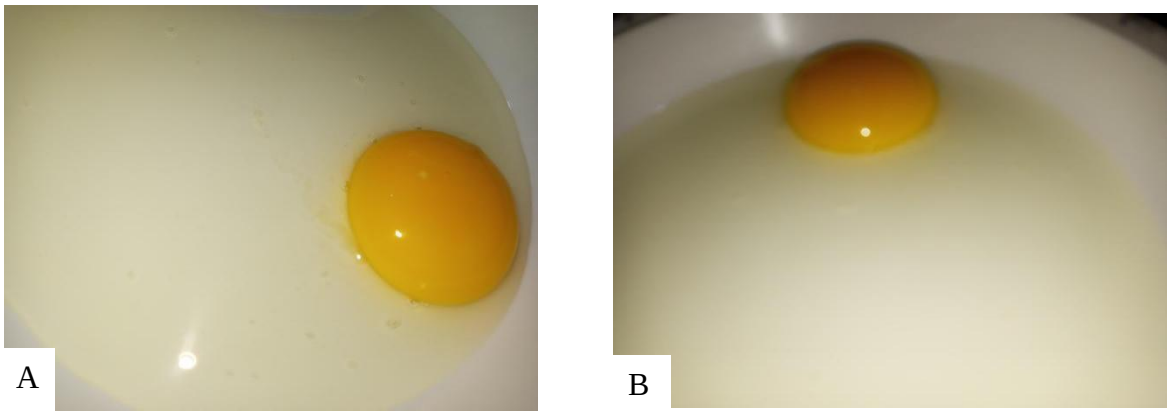


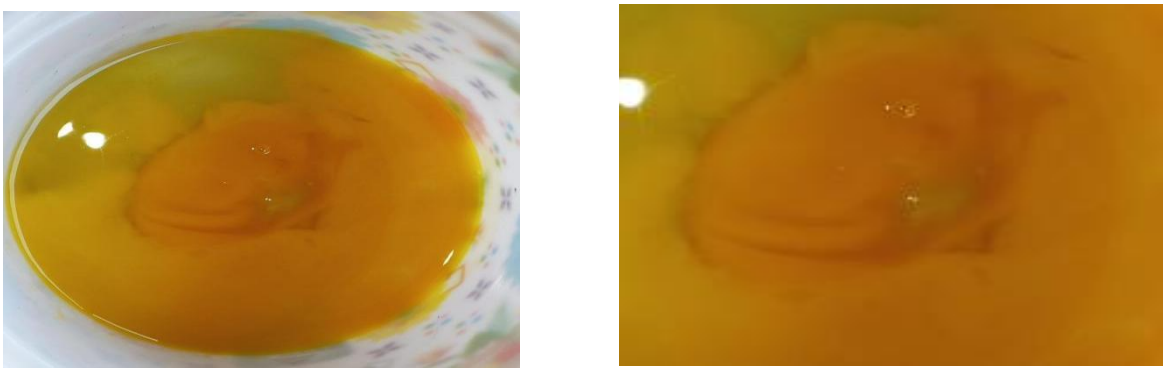
Figure 3.1: Shows that temperature fluctuate according to different environmental conditions .
The aim of this study was to study the effects of different temperatures on embryonic development in eggs. A total of 40 eggs were used, which were divided equally into four groups (eggs placed in the refrigerator, eggs placed at room temperature, eggs placed in flour, eggs placed in cotton).
Eggs from each group were observed daily for 15 days. Egg temperature, developmental changes, deterioration or survival status were noted during the observation.The temperature of each group was recorded daily.
The refrigerated eggs were kept at a constant low temperature (around 10°C). No developmental changes were observed at this temperature because this temperature was not suitable for embryonic development.



A B

Figure 3.2

Figure 3.2(A) and 3.2(B) shows that their were no development occur in refrigerated eggs.
In the room temperature group, the temperature ranged between 28°C and 36°C, but this fluctuation was insufficient for embryonic development and all the eggs were spoiled.

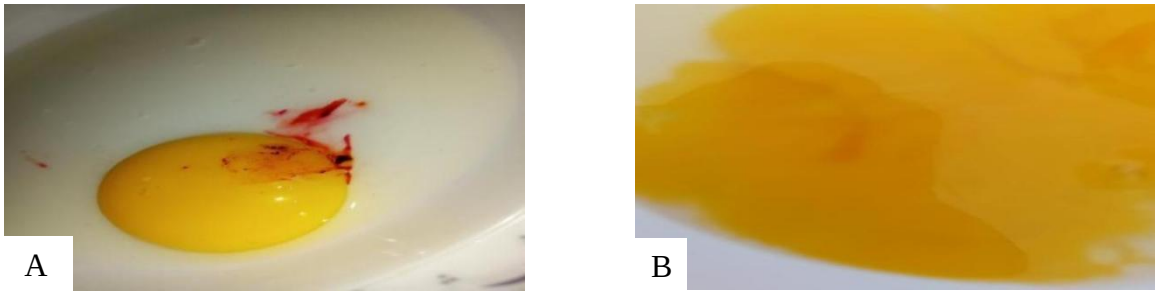


A B

Figure 3.3

Figure 3.3(A) and 3.3(B) shows that eggs were spoiled that is placed in room temperature.
Eggs laid in flour maintained a medium temperature range (28°C to 32°C), resulting in 4 eggs developing (40% survival rate).

Figure 3.4



A B

Figure 3.4(A) show that eggs was spoil and figure 3.4(B) show that eggs near to developed that were placed in flour.
Eggs laid in cotton had the highest temperature, increasing over time to 46°C. This group had the highest success, with 6 eggs developing successfully (60% survival rate).

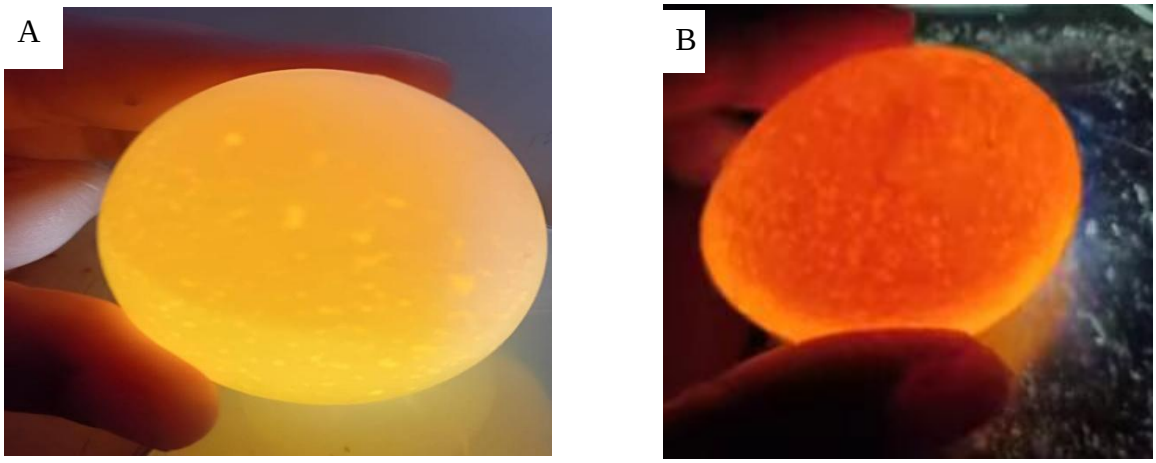


Figure 3.5

Figure 3.5(A) and figure 3.5(B) show that eggs were developed that were placed in cotton.

In our experiment, we observed a significant decrease in the growth rate of the eggs. One important reason for this may be that we used farm (commercially sold) eggs instead of indigenous (local and fertile) eggs. Farm eggs are usually infertile because they are obtained from hens that do not have access to a rooster. As a result, these eggs do not contain the zygote (zygote) that is necessary for embryonic development.On the other hand, indigenous eggs are generally fertile and are more suitable for developmental studies. Due to the lack of fertility in farm eggs, no embryonic development was observed in our experiment.

4. Discussion

Heat generation and distribution influence the EST (Meijerhof and van Beek, 1993), with MT being a variable that impacts heat distribution. The purpose of this experiment was to examine the effects of EST by using MT as a control method for EST. The results indicated that eggs subjected to lower EST during the initial week of incubation required more MT (less DT) in the subsequent two and three weeks. This outcome can be explained by a reduction in heat production during this period. In early incubation, low temperatures appear to affect the heat production in the embryo as well as having documented effects on post-hatch and embryonic development (Moreng and Bryant, 1954, 1956; Geers et al., 1983; Sarpong and Reinhart, 1985; Basharat et al., 2024).

So, a proper management plan throughout the incubation phase is crucial to ensure high-quality chicks and enhance post hatch health and productivity. This is critical time in the chick's existence, according to El-Hanoun et al. (2019), El-Sabrout et al. (2019), Rocha et al. (2022), and Fares et al. (2023).

Egg management techniques like storing eggs before incubation, environmental factors like temperature and relative humidity, and the hen's genotype (strain) and eggshell characteristics all influence the measurable trait of weight loss in eggs (Khalil et al., 2016; Grochowska et al., 2019; Okasha et al., 2023; Iftikhar et al., 2024).

However, a number of studies have demonstrated the importance of incubation temperature in promoting the cell multiplication of embryonic systems, which in turn enhances embryonic development (Morita et al., 2010; Badran et al., 2012; Piestun et al., 2013; Han et al., 2022). By altering respiration rate, tissue metabolism, and embryonic growth, they also showed that a temperature higher than normal can increase embryonic weight, leading to a shorter incubation period and easier eggshell breakage.

Incubation temperature is among the most crucial physical factors affecting embryo development, based on research that has shown the effect of incubation conditions on embryo development

(Freeman and Vince, 1974; Decuypere and Michels, 1992; Lourens et al., 2005, 2007; Molenaar et al., 2011).

Leksrisompong et al., 2007; Lourens, 2001; Meijerhof, 2000; Willemsen et al., 2010). Reduced incubation temperatures (35°C) after embryonic day 14 have been observed to hinder embryonic growth and prolong the incubation duration (Black and Burggren, 2004). Conversely, after embryonic day 14, elevated incubation temperatures (39. 5°C) enhanced the growth and development of the embryo (Leksrisompong et al., 2007).

Regulating embryo temperatures within suitable limits enhances hatchability and chick quality, based on scientific research and real-world experience (Meijerhof, 2009b). If the incubation temperature is excessively high or low during different incubation stages, embryonic mortality will increase (Decuypere et al., 1979; Suarez et al., 1996; Lourens, 2001; Joseph et al., 2006; Willemsen et al., 2010). As a result, hatchability and chick quality will decline.

In previous researches they give the optimal incubation temperature to eggs for hatching, and the results significantly leads to the embryo development and hatching the chick.

But in our experiment we give the different temperature conditions to eggs for embryonic development and chick hatching, and the eggs were also farm eggs not indigenous (local and fertile).

In this experiment, eggs were placed in a room, a refrigerator, flour, and cotton, and the temperature changes were monitored for 15 days. For 15 days, each group's eggs were examined every day. Observations were made about the temperature, survival status, deterioration, and developmental changes of the eggs.Every day, the temperature of every group was noted.

The eggs in the refrigerator were maintained at a consistent low temperature of approximately 10°C. Since this temperature was inappropriate for embryonic growth, no developmental alterations were seen. All of the eggs in the room temperature group were damaged because the temperature fluctuated between 28°C and 36°C, which was insufficient for embryonic development. A medium temperature range of 28°C to 32°C was maintained by eggs deposited in flour, resulting in the development of 4 eggs (40% survival rate) and 6 spoil eggs. In this condition survival rate is low as compared to mortality (Bilal, 2021; Sattar et al., 2024; Sajjad et al., 2024).

The highest temperature, reaching 46°C over time, was seen in eggs deposited on cotton. With six eggs, this group was the most successful and four eggs were near to spoiled. In this condition development rate is high as compared to mortality. We found that the eggs' development rate significantly decreased during our trial. The fact that we used farm (commercially sold) eggs rather than indigenous (local and fertile) eggs may be a major contributing factor. Because farm eggs are produced from chickens without access to a rooster, they are typically sterile.

Consequently, the zygote required for embryonic development is absent from these eggs. However, native eggs tend to be more prolific and are better suited for research on development. In our investigation, no embryonic development was seen since farm eggs are not fertile.

5. Conclusion

The aim of this study was to examine the effects of different temperatures on the embryonic development of chicken eggs. The results of the study show that temperature has a significant effect on embryonic development, egg survival, and chick birth.

The experiment involved keeping eggs in four different environmental conditions: refrigerator, room temperature, flour, and cotton. No embryo development occurred in the eggs kept in the refrigerator, indicating that the low temperature (about 9°C) is not suitable for embryonic development. Eggs kept at room temperature also deteriorated, indicating that uncontrolled temperatures are insufficient for embryonic development.

Eggs laid in cotton showed the highest success, with 60% of the eggs developing embryos. This indicates that the cotton provided a warm and stable environment suitable for embryo development. Eggs laid in flour showed 40% embryo development, indicating the effects of the intermediate temperature.

The research also found that even small changes in temperature can affect embryonic development. For example, a 1°C increase or decrease can have a significant impact on embryonic development, hatching rate, and chick quality.

Overall, this research confirms that temperature control is crucial for embryonic development. Proper temperature not only ensures egg survival but also helps in the birth of healthy chicks. Therefore, it is important to maintain the temperature at the appropriate level during egg incubation to achieve the best results.

6. References

Lourens, A., Van Den Brand, H., Meijerhof, R., & Kemp, B. (2005). Effect of eggshell temperature during incubation on embryo development, hatchability, and post hatch development. Poultry Science, 84, 914–920.

Yalcin, S., Özkan, S., & Shah, T. (2022). Incubation temperature and lighting: Effect on embryonic development, post-hatch growth, and adaptive response. Frontiers in Physiology, 1

Bilal, A. (2021). Clinical diagnosis and treatment of absence seizures: Case study. MAR Ophthalmology, 2(1).

Iftikhar, A., Bilal, A., Rakha, B. A., & Akhter, S. (2025). Evaluating the Cryoprotective Effects of Butylated Hydroxytoluene on Semen Quality Parameters of Phasianus colchicus. Journal of Agriculture and Biology, 3(1).

Sattar, R. Z., Bilal, A., Bashir, S., Iftikhar, A., & Yaqoob, I. (2024). Embryotoxicity of fluconazole on developing chick embryos. The Journal of Basic and Applied Zoology, 85(1), 8.

Ipek, A. Y., Sahan, U., Baycan, S. C., & Sozcu, A. R. (2014). The effects of different eggshell temperatures on embryonic development, hatchability, chick quality, and first-week broiler performance. Poultry Science, 93, 464–472.

Lopez, J. C., Kitto, L., & Hulet, R. M. (2018). Effect of eggshell temperature on survival rate, development at hatch, and 7-day growth. Journal of Applied Poultry Research, 27(2), 249–252.

Iraqi, E., Hady, A. A., Elsayed, N., Khalil, H., El-Saadany, A., & El-Sabrout, K. (2024). Effect of thermal manipulation on embryonic development, hatching process, and chick quality under heat-stress conditions. Poultry Science, 103(1).

Sajjad, M. K., Bilal, A., Iftikhar, A., Awais, M., Asif, I., Shaheen, F., & Zahoor, G. (2024). Examining the Association Between Pesticide Exposures and Chronic Diseases in Agricultural Workers. Remittances Review, 9(2), 2153-2176.

Bilal, A. (2021). Rabies is a zoonotic disease: a literature review. Occup. Med. Health Aff, 9(2).

French, N. A. (1997). Modeling incubation temperature: the effects of incubator design, embryonic development, and egg size. Poultry Science, 76, 124–133.

Jibrin, M. M., Idike, F. I., Ahmad, K., & Ibrahim, U. (2011). Modelling incubation temperature: the effects of incubator design, embryonic development and egg size. Journal of Agricultural Engineering and Technology, 19(1), 46–59.

Vilches-Moure, J. G. (2019). Embryonic chicken (Gallus gallus domesticus) as a model of cardiac biology and development. Comparative Medicine, 69, 184–203.

Basharat, M., Bilal, A., Rizwan, M., Asif, I., Shahin, F., & Hussain, M. (2024). Identification of fish diversity, distribution, and fauna at Head Qadirabad, Marala and Khankis, Chenab River, Punjab. Pakistan. Journal of Survey in Fisheries Sciences, 11(3), 75-81.

Macías Marín, O., Barrera, G., Flores, V., Quezada Tristan, A. G., Gonzalez, A., Perezchica, S., & Salazar De Santiago, M. M. (2023). Study of ex-ovo Embryonic Development of Gallus gallus domesticus. International Journal of Morphology, 41(2).

Fonseca, T., Silva, M. D. O., Alcântara, F., Cardoso, C., Franciolli, L., Sarmento, A. P., … Miglino, M. A. (2013). Embryonic development of chicken (Gallus Gallus Domesticus) From 1st to 19th Day-ectodermal structures. Microscopy research and technique. 76, 1217–1225.

Blumröder, V., & Tönhardt, D. (2002). Influence of long-term changes in incubation temperature on catecholamine levels in plasma of chicken embryos (Gallus gallus f. domestica). Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 131, 701–711.

Thompson-Davis, D. C. (1996). The effect of temperature on sex determination in the domestic chicken (Gallus domesticus). The University of Manchester. United Kingdom.

Feast, M. (1998). The effects of embryonic exposure to 22.0° C on the growth and sexual differentiation of the domestic chicken Gallus gallus domesticus. United Kingdom.

Bolin, G., Dubansky, B., & Burggren, W. W. (2017). Incubation relative humidity induces renal morphological and physiological remodeling in the embryo of the chicken (Gallus gallus domesticus). Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 204, 185–196.

Yoneta, H., Dzialowski, E. M., Burggren, W. W., & Tazawa, H. (2007). Endothermic heart rate response in broiler and White Leghorn chicks (Gallus gallus domesticus) during the first two days of post-hatch life. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 147(2), 529–535.

Tagirov, M., & Golovan, S. (2015). Sexual dimorphism in the early embryogenesis of the chicken (Gallus Gallus domesticus). Molecular Reproduction and Development, 82, 332–343.

Iqbal, A., Decuypere, E., Azim, A. E., & Kühn, A. (1990). Pre-and post-hatch high temperature exposure affects the thyroid hormones and corticosterone response to acute heat stress in growing chicken (Gallus domesticus). Journal of Thermal Biology, 15(2), 149–153.

Elf, P. K., & Fivizzani, A. J. (2002). Changes in sex steroid levels in yolks of the leghorn chicken, Gallus domesticus, during embryonic development. Journal of Experimental Zoology, 293(6), 594–600.

Branum, S. R., Tazawa, H., & Burggren, W. W. (2016). Phenotypic developmental plasticity induced by preincubation egg storage in chicken embryos (Gallus gallus domesticus). Physiological Reports, 4.

Bugden, S. C., & Evans, R. M. (1999). The development of a vocal thermoregulatory response to temperature in embryos of the domestic chicken. The Wilson Bulletin, 188–194.

Black, J. L., & Burggren, W. W. (2004). Acclimation to hypothermic incubation in developing chicken embryos (Gallus domesticus) II. Hematology and blood O2transport. Journal of Experimental Biology, 207(9), 1553–1561.

Eriksen, M. S., Haug, A., Torjesen, P. A., & Bakken, M. (2003). Prenatal exposure to corticosterone impairs embryonic development and increases fluctuating asymmetry in chickens (Gallus gallus domesticus). British Poultry Science, 44, 690–697.

Jessl, L., Lenz, R., Massing, F. G., Scheider, J., & Oehlmann, J. (2018). Effects of estrogens and antiestrogens on gonadal sex differentiation and embryonic development in the domestic fowl (Gallus gallus domesticus). PeerJ, 6.

Konarzewski, M., Gavin, A., Mcdevitt, R., & Wallis, I. R. (2000). Metabolic and organ mass responses to selection for high growth rates in the domestic chicken (Gallus domesticus). Physiological and Biochemical Zoology, 73(2), 237–248.