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Correlation between hatchability traits, moisture loss, and embryonic mortality in commercial Lohmann Brown Lite breeder birds in South Africa

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ABSTRACT

This study aimed to determine the relationship between hatchability traits, moisture loss and mortality in commercial Lohmann Brown Lite breeders in South Africa. A total of 5400 hatchable eggs were incubated. Descriptive analysis and the Pearson correlation coefficient were computed using MiniTab17. Fertility, embryo livability and mortality, total moisture loss, and hatchability were 95.06%, 86.56%, 6.37%, 13.27%, and 93.63%, respectively. There is a positive correlation between egg fertility and embryo livability ($p<0.001$; $r=0.86$) and between egg fertility and hatch of all set ($r=0.82$). There is a positive correlation between embryo livability and hatch of all sets ($p < 0.001$; $r = 0.81$). A negative correlation exists between moisture loss during days 0-10 and 11-18 of incubation ($p < 0.001$; $r = -0.64$). A positive correlation between total moisture loss and that during days 0-10 ($p<0.01$; $r=0.44$) and 11-18 ($p<0.05$; $r=0.41$) exists. A negative correlation was observed between hatch of fertile eggs and moisture loss ($p < 0.05$; $r = 0.32$). First-grade yield shows a positive correlation with total pullet yield ($p < 0.001$; $r = 0.95$). First-grade pullet yield has a negative correlation with male yield ($p < 0.001$; $r = -0.95$). Second-grade pullet yield has a positive correlation with overall pullet yield ($p<0.05$; $r=0.36$). Second-grade pullet yield has a negative correlation with male yield ($p<0.05$; $r=-0.36$. These results indicate that hatchability, embryonic mortality, and moisture loss are strongly influenced by fertility and incubation conditions. Optimizing these factors through proper management can improve chick quality, enhance hatchery efficiency, and increase productivity and profitability, contributing to sustainable poultry production and national food security.

Keywords: Hatchability, Embryo livability, fertility, moisture loss, commercial production

INTRODUCTION

The poultry industry is a vital component of animal agriculture, supporting the livelihoods of millions and providing a crucial source of high-quality protein (Mphepya *et al*., 2019; Franzo *et al*., 2023). In Southern Africa, poultry production, particularly of broilers, significantly contributes to several Sustainable Development Goals (SDGs), primarily SDG 2 (Zero Hunger), as well as SDG 1 (No Poverty) and SDG 5 (Gender Equality). Commercial poultry operations ensure a consistent and affordable supply of chicken eggs, which is essential for food security in the region. In South Africa, the poultry industry is a strategic national asset valued at R65 billion, making it the biggest employer and contributor within the farming industry (South African Poultry Association (SAPA), 2023). Of the total chicken population in the country, 24% is raised for egg production (Idowu *et al*., 2021). It is estimated that the egg industry will continue to expand in Africa, particularly in South Africa, due to a critical need to meet the increasing nutritional needs of the population (Tukur, 2011; Mokhaukhau *et al*., 2024). In the country, eggs are regarded as a highly nutritious staple food for people from every socio-economic status (Idowu et al., 2019; Mokhaukhau *et al*., 2024; Moswane & Oladele, 2024). Therefore, millions of eggs are incubated annually to produce layer chickens to meet this growing need. However, several studies have examined incubation parameters and hatchability traits (Fathi et al., 2022; Biesek, Wlaźlak, & Adamski, 2023). Nevertheless, there is a paucity of data on the correlation between hatchability traits, moisture loss, and embryonic mortality in commercial Lohmann Brown chickens in the South African context, which limits evidence-based optimisation of hatchery performance.

The most common breeds utilized for table eggs in the country are Hy-Line, Lohmann, and Amberlink strains (SAPA, 2023). For the supply of quality day-old chicks, successful incubation is essential (Ogbu & Oguike, 2019; SAPA, 2020). Incubation environmental conditions, such as temperatures (Avsar *et al*., 2022; Agyekum *et al*., 2022; Masia *et al*., 2024a,b), ventilation (Bilalissi *et al*., 2022), humidity (Noiva *et al*., 2014; Bassareh & Rezaeipour, 2021), hygienic conditions (Laban *et* *al*., 2024), and turning eggs (Willemsen et al., 2010; Martinez, 2018; Adame & Ameha, 2023), have been documented to be vital for incubation success. Moisture loss, hatchability traits, and embryo mortality determine the quality of day-old chicks. However, the specific quantitative relationships among these parameters in commercial Lohmann Brown Lite breeders remain unclear, and existing literature often reports inconsistent findings across breeds and production systems.

Inappropriate moisture loss compromises embryo development, leading to increased embryo mortality and reduced hatchability (Willemsen *et al*., 2010; Brusch & DeNardo, 2019; Gregorich *et al*., 2022; Nowaczewski *et al*., 2022). This highlights the need to investigate their interdependence under commercial conditions in South Africa. Understanding this relationship is crucial not only for enhancing hatchery efficiency but also for ensuring the production of robust chicks in commercial layer operations. Therefore, this study aims to evaluate the correlations between hatchability traits, egg moisture loss, and embryo mortality in commercial Lohmann Brown Lite breeders in South Africa, providing data that could inform management practices and optimize reproductive efficiency. This study hypothesized that increased extreme egg moisture loss during incubation is associated with reduced hatchability and elevated embryo mortality. Fertility is expected to correlate positively with embryo livability and overall hatchability. Additionally, moisture loss during early (days 0–10) versus late (days 11–18) incubation is expected to affect hatchability outcomes differentially. Testing these hypotheses will provide key insights into the interrelationships among moisture loss, embryo mortality, and hatchability, informing management strategies to enhance chick quality, hatchery efficiency, and production profitability.

MATERIALS AND METHODS

Study Area and Ethical Approval

The study received ethical clearance from the Animal Research Ethics Committee of Tshwane University of Technology, with approval number AREC202306003, before its commencement. The research was conducted at the Bergvlei Chicks Hatchery, a facility owned by Quantum Foods, located in Bronkhorstspruit, South Africa.

Flock Management

Lohmann Brown Lite laying birds were housed in open-sided facilities equipped with curtains to regulate airflow. The laying birds were kept up to 65 weeks of age (WOA). The concrete floor of the house was covered with a 3-5 cm layer of wood shavings. A stocking density of approximately 7.16 birds/m^2 was maintained, aligning with the Lohmann Parent Stock Management Guide. A total of 4500 females and 450 males were housed, maintaining a male-to-female ratio of 1:10, in accordance with the recommendations of Chen *et al*. (2025). This ratio strikes a balance that supports reproductive success and the welfare of both hens and roosters. All aspects of housing, animal rights, and welfare strictly adhere to the guidelines outlined in the Lohmann Parent Stock Management Guide. Feed and water are continuously available to the birds (*ad libitum*).

Incubation Process

At 40 weeks of Lohmann Brown Lite breeder age, a total of 5400 hatchable eggs were collected and fumigated, using paraformaldehyde overnight, in the central egg room. Eggs were stored for 2-3 days at 18-19°C at the hatchery for 2-3 days before incubation. The eggs underwent a pre-incubation heating phase for approximately 6 hours at a temperature of around 25°C before the primary incubation process commenced. The study utilized Petersime Airstreamers 4AS, which are single-stage setters and hatchers, for the incubation and hatching procedures. The incubation temperature and relative humidity in the setters and hatchers are presented in Table 1.

Table 1. Temperature and relative humidity during incubation

Days of incubation	Incubation temperature (°C)	Relative humidity (%)	Incubator
Day 0-4	37.8	55	Setter
Day 5-9	37.2	55	Setter
Day 10–11	37.0	55	Setter
Day 12-13	36.8	55	Setter
Day 14-15	36.5	55	Setter
Day 18	36.3	55	Hatcher
Day 19–21	36.3	56	Hatcher

The process of evaluating poultry eggs and chicks involved several stages, beginning with candling on day 10 to identify and remove infertile eggs. Eggs that failed to hatch were recorded as dead embryos as established by Reijrink *et al*. (2010). Hatched chicks underwent a grading process. First-grade chicks were characterised by being active, capable of walking straight on two legs, having two open eyes, a straight beak, full feathering, and completely healed navels. Conversely, chicks exhibiting unhealed navels, large belly buttons, crossed or twisted beaks, limb and body malformations, crooked toes, spraddled legs, incomplete feathering, closed eyes, stickiness, or albumen smearing were classified as culls or reject chicks. These culls were separated from the first-grade chicks and humanely euthanized using a high-speed macerator. After the standard incubation period of 518.4 hours (21.6 days), all hatched chicks were color-sexed to distinguish males (white) from females (brown).

The equations that follow were employed for calculating the following parameters:

$$\text{Hatchability rate} = \frac{\text{Total number of chicks hatched}}{\text{Total number of eggs set}} \times 100$$

$$\text{Mortality rate} = \frac{\text{Total number of dead embryos}}{\text{Total number of fertile eggs}} \times 100$$

$$\text{Infertile egg rate} = \frac{\text{Number of infertile eggs}}{\text{Total eggs per tray}} \text{ X } 100$$

$$\text{Day } 0 - 10 \text{ Incubation moisture loss} = \frac{\text{Egg weight at setting} - \text{Egg weight at candling}}{\text{Weight of eggs set}} \text{ X } 100$$

$$\text{Day } 11 - 18 \text{ incubation moisture loss} = \frac{\text{Egg weight after candling} - \text{Egg weight at transfer}}{\text{Total weight of eggs after candling}} \text{ X } 100$$

$$\text{Hatchability of fertile eggs} = \frac{\text{Total chicks hatched}}{\text{Total fertile eggs}} \text{ X } 100$$

$$\text{Pullets yield} = \frac{\text{Total pullets chicks hatched}}{\text{Total fertile eggs}} \text{ X } 100$$

Statistical Analysis

Descriptive data analysis (mean, standard deviation, coefficient of variation, minimum and maximum values) and the Pearson correlation coefficient were computed using MiniTab 17 (MiniTab 17 Statistical Software, 2017) to determine the strength and direction of the relationship between the variables.

RESULTS AND DISCUSSION

Summary statistics (means, standard deviations, minimum, and maximum) values for livability, hatchability, and chick quality across different temperature profiles are presented in Table 2. The embryo livability was 86.56% on average, with minimum and maximum values of 74.00% and 92%, respectively. The average fertility of the Lohmann Brown Lite chicken (95.06%) in this study was higher when compared to the fertility of the Lohmann Brown Lite chicken in the Republic of Congo (26.88%) observed by Missoko *et al*. (2024). This variation could be attributed to the different male-to-female mating ratio, breeding parents' condition, age, duration of egg storage and physical location and its conditions (Islam *et al*., 2002; Adu-Aboagye *et al*., 2020).

The average hatchability of fertile eggs (93.63%) and all set eggs (85.24%) in this study was higher when compared to the Lohmann Brown hatchability standard (80 – 82 %) (Lohmann Hatchery Management Guide, 04/13) and the Lohmann Brown Lite chicken in the Republic of Congo (17.18%) observed by Missoko *et al*. (2024), highlighting the impact of proper incubation and flock management practices on hatchability. The average total embryo mortality of the Lohmann Brown Lite chicken in the present study (6.37%) is lower than that observed in the same breed in the Republic of Congo (10.74%), as reported by Missoko *et al.*

(2024). The observed differences in hatchability and embryo mortality among studies on the same breed could be attributed to flock age (Iqbal *et al*., 2016; Masia *et al*., 2025), health (Fernandes *et al*., 2016; Okasha *et al*., 2023), environmental stress (Amjadian and Shahir, 2020), and egg quality (Wijnen *et al*., 2022; Okasha *et al*., 2023) and storage (Goliomytis *et al*., 2015; Yamak *et al*., 2016) and incubation practices (Adame and Ameha, 2023; Masia *et al*., 2024). Breed differences further underscore the genetic influence on hatchability traits. A study by Idowu et al. (2019) observed that Venda breeds have a hatchability of 86.03%, Potchefstroom Koekoek 81.83%, Ovambo 79.61%, and Naked Neck 80.26%. These values are generally lower than those observed in the present study for Lohmann Brown Lite breeders, suggesting that commercial lines selected for productivity under controlled incubation conditions can achieve superior hatchability compared to indigenous or dual-purpose breeds. Similarly, Fulani ecotypes reached 100% hatchability of set eggs and 85.59% for fertile eggs. In contrast, normal-feathered chickens had slightly lower values (86.67%), and Rhode Island Red chickens recorded 91.1% hatchability (Malago & Baitilwake, 2009), reinforcing the significance of breed on hatchability outcomes. The total moisture loss in the present study is 13.27%. Studies indicate that eggs need to lose between 10% and 13% of their moisture during incubation for optimal outcomes (Green, 2017; Lohmann Hatchery Management Guide, 04/13), as moisture loss below 9.1% may increase embryonic mortality. Fertile eggs absorb heat from the incubator during the first half of the incubation period; on the other hand, embryos also lose heat during the second half of the incubation (Tazawa & Whittow, 2000; Tona *et al*., 2022). All these mechanisms may have implications for the rate of moisture loss during incubation.

The correlation of moisture loss and hatchability traits in commercial Lohmann Brown Lite breeder birds in South Africa is presented in Table 3. There is a strong positive correlation between egg fertility and embryo livability ($p<0.001$; $r=0.86$) and between egg fertility and hatch of all set ($p<0.001$; $r=0.82$). This indicates that as egg fertility increases, both the survival rate of embryos and the overall hatch rate tend to increase significantly. There is a strong positive correlation between embryo livability and hatch of all sets ($p < 0.001$; $r = 0.81$). This implies that as embryo livability increases, the percentage of eggs that successfully hatch also tends to increase significantly. Furthermore, a significant correlation was found between hatch of all sets and embryo livability, and a non-significant correlation was found between hatch of fertile sets and fertility, as well as with embryo livability. This suggests that hatchability of all sets and embryo livability were primarily a function of fertility. A similar phenomenon was also observed by some authors (Wolc & Olori, 2009; Hossain et al., 2016) in chickens.

In the present study, a strong negative correlation was found between moisture loss during days 0-10 and days 11-18 of incubation ($p < 0.001$; $r = -0.64$). This suggests that lower moisture loss in the early incubation period is associated with higher moisture loss in the later period, allowing for a more balanced water loss to

Table 2. Summary statistics

Variable	Mean	SD	CV (%)	Min	Max
Fertility	95.06	3.08	3.24	84	99
Livability	86.56	4.87	5.62	74	92
Moisture loss					
Moisture loss: day 0-10	6.41	1.57	24.51	1.76	9.49
Moisture Loss: day 11-18	6.85	1.56	22.62	4.18	12.08
Total moisture loss	13.27	1.33	10.05	9.79	15.97
Hatchability traits					
Wet chicks (%)	2.24	2.29	101.98	0	10.85
Dry chicks (%)	97.76	2.29	2.34	89.15	100
1st grade female yield (%)	46.10	2.76	5.98	40.16	51.85
2nd grade female yield (%)	1.24	0.96	77.25	0	4.62
Total pullets (%)	47.34	2.95	6.24	40.16	53.33
Male (%)	52.66	2.95	5.61	46.67	59.84
Total hatch of fertile (%)	93.63	2.57	2.75	87.10	97.18
Total hatch of all sets (%)	85.24	3.95	4.63	72	92
Embryo Mortality	6.37	2.57	40.37	2.82	12.90

achieve optimal overall loss. Literature (Molenaar *et al*., 2010; Nowaczewski *et al*., 2022) indicates that the rate of moisture loss generally increases over incubation time, especially in the later stages, to facilitate proper embryonic development and air cell formation. In the present study, it was also noted that there's a moderate positive correlation between overall moisture loss and moisture loss during days 0-10 ($p < 0.01$; $r = 0.44$) and days 11-18 ($p < 0.05$; $r = 0.41$). This implies that higher overall moisture loss is moderately associated with higher moisture loss in both the early and late incubation phases. This phenomenon is attributed to the fact that the total moisture loss is simply the sum of the moisture lost during the early and late phases. Excessive total moisture loss can lead to embryo dehydration and reduced hatchability (Brusch 4th & DeNardo, 2019), highlighting the importance of monitoring moisture loss. On the other hand, too low moisture loss during the late stages of incubation can also lower hatchability (Molenaar *et al*., 2010; Willemsen *et al*., 2010; Gregorich *et al*., 2022; Nowaczewski *et al*., 2022) through impeding gas exchange and potentially leading to pasty chicks. To correct this, the incubation conditions — specifically, humidity and temperature — need to be adjusted accordingly.

A weak negative correlation was observed between hatch of fertile eggs and moisture loss ($p < 0.05$; $r = -0.32$). This suggests that higher moisture loss is associated with a slightly lower hatch rate of fertile eggs. Interestingly, literature indicates that fertile eggs may have a somewhat higher moisture loss than infertile eggs (Booth and Rahn 1990), attributed to the fact that the developing embryo produces metabolic water (Yalcon *et al*., 2022; Tona *et al*., 2022) and heat (Onagbesan *et al*., 2007; Mortola *et al*., 2015; Rosenberg *et al*., 2022), increasing the internal water vapour pressure during incubation. On the other hand, the finding that higher moisture loss is associated with a slightly lower hatch rate of fertile eggs contrasts with that reported by Hossain et al. (2016), who found a positive correlation between higher moisture loss percentages and egg hatchability.

In the present study, the first-grade yield shows a robust positive correlation with the total pullet yield ($p < 0.001$; $r = 0.95$). This is expected, as first-grade pullets are a component of the total pullet yield. On the other hand, first-grade pullet yield has a strong negative correlation with male yield ($p < 0.001$; $r = -0.95$). This indicates that as the yield of first-grade pullets increases, the yield of males tends to decrease significantly, suggesting a trade-off or inverse relationship in the production outcome. In the present study, second-grade pullet yield has a moderately positive correlation with overall pullet yield ($p < 0.05$; $r = 0.36$).

Table 3. Correlation of moisture loss and hatchability traits in commercial Lohmann Brown Lite breeder birds in South Africa

Variables (%)	Fertility	Livability	Moisture loss: day 0-10	Moisture Loss: day 11-18	Total moisture loss	Wet chicks	Dry chicks	1st-grade female yield	2nd-grade female yield	Total pullets	Male	Hatch of fertile
Livability	0.86***											
Moisture loss: day 0-10	-0.14^{NS}	-0.09^{NS}										
Moisture Loss: day 11-18	0.25^{NS}	0.24^{NS}	-0.64***									
Total moisture loss	0.12^{NS}	0.17^{NS}	0.44**	0.41*								
Wet chicks	0.31*	0.12^{NS}	-0.05^{NS}	-0.16^{NS}	-0.13^{NS}							
Dry chicks	-0.32*	-0.12^{NS}	-0.5^{NS}	0.16^{NS}	0.13^{NS}	-1.00						
1st-grade female yield	0.15^{NS}	0.14^{NS}	-0.20^{NS}	0.25^{NS}	0.09^{NS}	0.07^{NS}	-0.07^{NS}					
2nd-grade female yield	0.05^{NS}	0.07^{NS}	0.19^{NS}	-0.04^{NS}	0.18^{NS}	-0.14^{NS}	0.14^{NS}	0.04^{NS}				
Total pullets	0.15^{NS}	0.16^{NS}	-0.10^{NS}	0.22^{NS}	0.14^{NS}	0.02^{NS}	-0.02^{NS}	0.95***	0.36*			
Male	-0.15^{NS}	-0.16^{NS}	0.10^{NS}	-0.22^{NS}	-0.14^{NS}	-0.14^{NS}	0.02^{NS}	-0.95***	-0.36*	-1.00		
Hatch of fertile	0.27^{NS}	0.07^{NS}	-.012^{NS}	-0.15^{NS}	-0.32*	0.26^{NS}	-0.28^{NS}	0.17^{NS}	-0.21^{NS}	0.09^{NS}	-0.09^{NS}	
Hatch of all set	0.82***	0.81***	-0.14^{NS}	0.10^{NS}	-0.06^{NS}		-0.26^{NS}	0.21^{NS}	-0.07^{NS}	0.17^{NS}	-0.17^{NS}	0.64***

*p<0.05; **P<0.01; ***p<0.001; NS: p>0.05

On the other hand, second-grade pullet yield has a negative correlation with male yield ($p < 0.05$; $r = -0.36$). Similar to first-grade pullets, an increase in second-grade pullet yield is associated with a decrease in male yield, though the relationship is weaker than with first-grade pullets. The hatch of fertile and all set displayed a highly and moderately positive relationship ($p < 0.001$; $r = 0.64$), implying that optimising or ensuring the conditions for hatch of all set is a critical factor that directly and positively influences the hatch rate of fertile eggs. This relationship is not due to random chance.

CONCLUSION

This study demonstrates that hatchability, embryonic mortality, and egg moisture loss in commercial Lohmann Brown Lite breeders are strongly interrelated and influenced by factors such as fertility, incubation management, and breed characteristics. Higher fertility was positively associated with embryo livability and overall hatchability. At the same time, excessive moisture loss during early and late incubation correlated with increased embryonic mortality and reduced hatchability, confirming the study hypotheses. Maintaining optimal incubation conditions, including temperature and humidity, is therefore essential to enhance embryo survival and produce high-quality day-old chicks. Optimizing fertility, hatchability, and embryo survival improves hatchery efficiency, reduces losses, and supports cost-effective poultry production. Furthermore, maximizing hatchability contributes to national food security (SDG 2: Zero Hunger) and economic sustainability for poultry producers (SDG 1: No Poverty), advancing both sustainable and profitable layer production in South Africa. The findings provide actionable guidance for hatchery managers: careful monitoring of moisture loss and incubation parameters can directly improve chick quality, enhance survival rates, and maximize overall hatchery productivity.

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