Letters in Animal Biology

Journal homepage: www.liabjournal.com

Effect of flock age, egg size, and incubator type on embryo development and hatchability in the Indian River Broiler breeders in South Africa

Temosho R. Mabotha, Khathutshelo A. Nephawe, Takalani J. Mpofu*

Department of Animal Sciences, Tshwane University of Technology, Private bag X680, Pretoria 0001, South Africa

Article info

Received: 11 September 2025
Received in revised form: 18 November 2025
Accepted: 27 November 2025
Published online: 03 December 2025

Keywords
Broiler breeder
Egg size
Embryo mortality
Flock age
Hatchability
Incubation

* *Corresponding author:*
Takalani J. Mpofu
Email: MpofuTJ@tut.ac.za

Reviewed by:
Magda Ismail Abo-Samaha
Department of Animal Husbandry and Animal Wealth Development, Faculty of Veterinary Medicine, Alexandria University, Alexandria, Egypt
Consent to publish the name of second reviewer could not be obtained

Abstract

This study investigated the effects of flock age, egg size, and incubator type on embryo development and hatchability traits in the Indian River broiler breed in South Africa. A total of 4752 hatchable eggs from the breeder flocks at 25, 40, and 55 weeks of age were incubated in Linco and Buckeye incubators. Before incubation, eggs were graded into small (49 g), medium (50-59 g), and large (60-69 g) size groups. The general linear model procedure in Minitab 17 was used to analyse data and the means were separated using Fisher's LSD test ($p<0.05$). The breeder flocks at 40 weeks of age had higher ($p<0.05$) hatchability of total eggs set (91.06%), hatchability of fertile eggs set (92.52%), and first-grade chicks (90.93%) followed by 55 week flocks (72.69, 77.37, and 71.18%, respectively) and 25 week flocks (56.39, 64.07, and 55.61%, respectively). The higher proportion ($p<0.05$) of cull chicks was observed in flocks at 25 (0.78%) and 55 weeks of age (1.52%) compared to 40 weeks of age (0.13%). Flocks at 55 weeks yielded heavier ($p<0.05$) chicks (44.14g) at hatching. The highest ($p<0.05$) fertility (98.52%) and lowest total embryo mortality (7.41%) were observed in flocks with 40 weeks of age. Small-sized eggs had the highest ($p<0.05$) fertility (94.21%) compared to medium-sized eggs (92.80%). Large-sized eggs hatched heavier ($p<0.05$) chicks (44.21g) compared to medium (39.69g) and small-sized (33.86g) eggs, whereas the other hatchability traits were similar ($p>0.05$). Incubator type had no significant effect on the incubation and hatchability traits. In conclusion, flock age and egg size were the main determinants of Indian River broiler breed incubation and hatchability traits and should be considered when incubating eggs.

This is an open access article under the CC Attribution license (http://creativecommons.org/licenses/by/4.0/)

1. Introduction

The poultry industry is an important subsector of animal husbandry worldwide, sustaining the livelihoods of millions of people and supplying high-quality protein (Mphephya et al. 2019; Idowu et al. 2021; Attia et al. 2022; Franzo et al. 2023). Commercial poultry production, particularly broiler chicken, plays a significant role in contributing to food and nutritional security and meeting Sustainable Development Goals (SDGs) in Southern Africa, primarily focusing on SDG 2 (Zero Hunger), SDG 1 (No Poverty), and SDG 5 (Gender Equality). Beyond commercial production, most of the village poultry farming is managed by women, empowering them economically and enhancing their role in household decision-making (Galiè et al. 2019; Tenza et al. 2024). In South Africa, the poultry industry is a R65 billion strategic national asset and the largest employer and contributor to the agricultural sector and supporting emerging and commercial producers alike, in addition to the food security in the country (Ramaphala and Mbajiorgu 2013; SAPA 2020). Approximately 75% of the poultry production is associated with meat production and 25% with egg production (SAPA 2019). It is well noted that the consumption and demand of poultry meat have been growing exponentially over the years, attributed to population growth and greater per-capita consumption (Mottet and Tempio 2017; Connolly et al. 2022; Castro et al. 2023).

To cater the growing demand for broiler chicken meat, new broiler breeds, such as Ross, Cobb, Hubbard, and Arbor Acres, have been developed with the aim of improving crucial traits such as growth rate, feed efficiency, and disease resistance. However, all the operations of poultry industry depend on the supply of day-old chicks (Ogbu and Oguike 2019; SAPA 2020). Incubation techniques such as the use of different incubator types (Mesquita et al. 2021), modifying the incubation temperatures (Avsar et al. 2022; Agyekum et al. 2022; Masia et al. 2024), and ventilation techniques (Bilalissi et al. 2022) have been used to improve and maximize hatchery output, to support the growing demand for day-old chicks. The Indian River broiler breed, developed by Aviagen, has adapted to challenging climatic conditions (Indian River Broiler Management Handbook 2025) and has recently been introduced to South Africa (SAPA 2021). Despite its growing prominence in South Africa, there is a significant paucity of research done on this breed to date, specifically on reproductive performance, embryo development, hatchability, and chick quality. With the existing body of literature on other breeds, such as Ross 308, Cobb 500, and Arbor Acres, making direct extrapolation of the findings to the Indian River broiler breed can be potentially inaccurate or insufficient. Therefore, investigating the effect of the flock age, egg size, and incubator type on the embryo development, hatchability traits, and chick quality in the Indian River broiler breed in South Africa is essential for optimising production efficiency and economic sustainability. The findings of this study are expected to provide valuable, breed-specific data to broiler producers, hatcheries, and genetic companies, enabling them to optimise incubation management practices for Indian River broiler flocks.

2. Materials and Methods

2.1 Study Site and Experimental Design

The study was carried out at a hatchery farm in Mpumalanga province, South Africa. The study was used a 3 x 3 x 2 factorial design, with 3 flock ages (25, 40 and 55 weeks of age), 3 egg sizes (small 49 g, medium 50-59 g, and large 60-69 g), and 2 single-stage incubator types (Linco and Buckeye incubators). Eggs of these flock age groups were incubated separately, and the effects of flock age, egg size, and incubator type on incubation performance and hatchability were assessed.

2.2 Flock Management

The broiler chicken breeders were housed in an open-sided, curtain-ventilated house, covered with wood shavings to a depth of 3-5 cm. The stocking density was 4.97 birds/m^2 and the male-to-female mating ratio was 1:10, following the Indian River Broiler Management Handbook (2025) recommended standards. From placement at 21 weeks of age till disposal of birds, feeding was done once daily in the morning, following the guidelines provided in the Indian River Broiler Management Handbook (2025):

- **Pre-breeder meal (mash):** placement to 22 weeks of age
- **Phase 1 meal (mash):** 25–39 weeks of age
- **Phase 2 meal (mash):** 40–50 weeks of age
- **Phase 3 meal (mash):** 50 weeks of age to flock disposal

Water was provided ad libitum. Each house was provided with 32 nest boxes, each with 12 holes filled with wood shavings, two chain feeder lines, and one male feeder. The flocks were vaccinated against salmonella and treated for roundworms and mites. At 24, 48, and 56 weeks of age, Ostridose was used for control of roundworms (2.5 L in 10 L of water). At 26, 32, 38, 44, 50, 56, and 62 weeks of age, Servin (44 mL in 10 L of water) was sprayed next in the nest boxes to prevent mite infestation of birds. Furthermore, at 23, 28, 33, 38, 43, 48, 53, 58, and 63 weeks of age, Terminal Fogging Solution (TFS) 40 disinfectant (1.5 L of T.F.S 40 with 6 L of water mix) was sprayed on the wood shavings before transfer to poultry houses.

2.3 Incubation Performance Measurements

A total of 4752 hatchable eggs from Indian River broiler breeder flocks aged 25, 40, and 55 were used in this study. After collection from the breeder house, the eggs were graded into small (49 g), medium (50-59 g), and large (60-69 g) sizes. After grading, the eggs were placed on setter trays and fumigated at the central egg room of the farm with paraformaldehyde. Following fumigation, the eggs were kept at 18–19°C and 60-80% relative humidity (RH) overnight before being moved to the hatchery the next day. Within each egg size category, eggs were further randomly allocated to one of the incubators (Buckeye or Linco). The features of the incubators used are presented in Table 1. Eggs were weighed before incubation to determine the setting weight. Eggs were preheated at 19.5 °C and 17% RH for 9 hours and the incubation at 37.2 °C and 29.0% RH started automatically and immediately after preheating. On day 18, eggshell temperature (EST) was taken using Braun Thermoscan, eggs were re-weighed to determine the transfer weight, and candled. The eggs with evidence of living embryos were

Table 1. Features of the Linco and Buckeye incubators

Feature	Linco Incubator	Buckeye Incubator
Trolley structure	6 trolleys: 3 columns/trolley, 15 spaces/column, 45 trays max	6 trolleys: 2 columns/trolley, 18 spaces/column, 36 trays max
Total tray capacity	270	216
Eggs per tray	132	132
Total egg capacity	35 640	28 512
Operation	Automatic	Manual
Data recording	Yes (records incubation data)	No (does not record incubation data)
Temperature	Fahrenheit (°F)	Degrees Celsius (°C)
User interface	Screen display	No screen
Ventilation	Damper, automatic control	Damper, manual control
Humidity control	Defencer and electrolyte to heat water	Cold water with wet wick

transferred into hatchers fogged with a mixture of 125 mL of water and 125 mL of formalin at a temperature of 36.9 °C and 29.0% RH. The clear eggs were removed and kept for breakout. Chicks hatched on day 21 were weighed using a Snowrex scale, evaluated for physical quality by Pasgar©score system to categorise them as first-grade or culls, and their cloaca temperature was recorded as well. The unhatched eggs were kept for breakout. Chicks with good, dry and clean feathers, completely healed navel, smooth stomach, hocks without blemishes, flexibility (chick should flip over in less than 3 seconds), free from defects such as injuries, blindness, one eye, or crossed beak were considered as first-grade chicks and those without these characteristics were considered as culls. For the clear and unhatched eggs, the breakout procedure was conducted to determine the embryo mortality stage (early 1-9 days, mid 10-17 days, and late 18-21 days), and conditions (contaminated, eggs with early cracks, pips, exposed brain, crossed beak, and malposition). The embryo mortality stage determination was performed following the earlier protocol description by Reijrink et al. (2009) and Masia et al. (2024). Briefly, early-stage embryonic mortality occurs during the first 9 days of incubation and at this point, the embryo's eye pigment is visible, but it has not yet developed feathers. Middle-stage embryonic mortality takes place from day 10 to day 17 of incubation. During this period, the embryo is still small but has started to develop feathers. Lastly, late-stage embryonic mortality occurs from day 18 to day 21 of incubation and involves a fully developed embryo, where death may occur either with the yolk sac still external to the body, or with the yolk sac already absorbed, regardless of whether the embryo was alive or dead at the time of examination.

The following incubation and hatchability parameters were determined as described by Masia et al. (2024):

$$\text{Day 0 – 18 Incubation moisture loss (\%)} = \frac{\text{Egg weight at setting} - \text{Egg weight at candling}}{\text{Egg weight at setting}} \text{ X } 100$$

$$\text{Fertile eggs (\%)} = \frac{\text{Number of fertile eggs}}{\text{Total eggs per tray}} \text{ X } 100$$

$$\text{Infertile eggs (\%)} = \frac{\text{Number of infertile eggs}}{\text{Total eggs per tray}} \text{ X } 100$$

$$\text{Hatch of total egg set (\%)} = \frac{\text{Total number of chicks hatched}}{\text{Total number of eggs set}} \times 100$$

$$\text{Hatch of fertile egg set (\%)} = \frac{\text{Total number of chicks hatched}}{\text{Total fertile eggs}} \text{ X } 100$$

$$\text{Embryo mortality rate (\%)} = \frac{\text{Total number of the dead embryos}}{\text{Total number of fertile eggs}} \text{ X } 100$$

2.4 Statistical Analysis

The General Linear Model procedure of the MiniTab 17 (MiniTab 17 Statistical Software 2017) was used to analyse the data, whereas the mean differences were evaluated using Fisher's LSD test ($p < 0.05$).

The following statistical model was used:

$$Y_{ij} = \mu + T_i + B_j + S_k + TB_{ij} + TS_{ik} + BS_{jk} + TBS_{ijk} + \varepsilon_{ijk}$$

Where Y_{ij} = measurement of response (incubation, hatchability, and mortality), μ = overall mean, T_i = fixed effect of the flock age (25, 40, and 55 weeks), B_j = fixed effect of egg sizes (small, medium, and large), S_k = fixed effect of incubator types (Linco and Buckeye incubators), = interaction effects of the ith flock age and jth egg size, = interaction effects of the ith flock age and kth incubator type, = interaction effects of the jth egg size and kth incubator type, = interaction effects of the ith flock age, jth egg size, and kth incubator type, and ε_{ijk} = random error.

Noteworthy, the results showed that two-way and three-way interactions were insignificant ($p > 0.05$), therefore, the model was redefined to include only main effects as follows:

$$Y_{ij} = \mu + T_i + B_j + S_k + \varepsilon_{ijk}$$

3. Results

The least-squares means (LSM) for incubation and hatchability parameters, embryo mortality traits, and mortality breakdown across different age groups of Indian River broiler breeder flocks are presented in Table 2. Flock age groups significantly affected ($p < 0.05$) all the incubation, hatchability, and embryo mortality traits except the cloaca temperature ($p > 0.05$). For the incubation traits, flocks at 55 weeks of age had higher ($p < 0.05$) set weight (62.27 g), transfer weight (54.49 g), and day 0 -18 moisture loss (12.46%) followed by flocks at 40 weeks of age (set weight: 59.59 g, transfer weight: 52.66 g, day 0 -18 moisture loss: 11.62%) and flocks at 25 weeks of age (set weight: 50.47 g, transfer weight: 45.03 g, day 0 -18 moisture loss: 10.76%). Notably, day-18 eggshell temperature was statistically different ($p < 0.05$) across flock age groups, with older flocks having higher values (38.25 °C) compared to flocks at 25 weeks of age (37.82 °C).

For hatchability traits, the flocks with 40 weeks of age had higher ($p < 0.05$) hatch of total egg set (91.06%), hatch of fertile egg set (92.52%), and first grade chicks (90.93%) followed by flocks with 55 weeks of age (hatch of total egg set: 72.69%, hatch of fertile egg set: 77.37%, first grade chicks: 71.18%) and lower mean values were observed in flocks with 25 weeks of age (hatch of all egg set: 56.39%, hatch of fertile egg set: 64.07%, first grade chicks 55.61%). The higher proportion ($p<0.05$) of cull chicks was observed in flocks with 55 weeks of age (1.52%) compared to flocks with 40 weeks of age (0.13%) and intermediate values were observed in flocks with 40 weeks of age (0.78%). Flocks with 55 weeks of age yielded chicks with higher ($p < 0.05$) hatch weight (44.14 g), followed by flocks with 40 weeks of age (39.57 g) and low weight was observed in flocks with 25 weeks of age (33.93 g). However, cloaca temperature of hatched chicks was statistically similar ($p > 0.05$) across all flock ages.

All three age group breeder flocks exhibited significant differences from each other in terms of embryo mortality traits. A higher proportion ($p < 0.05$) of infertile eggs (12.05%), early dead (20.10%), mid-dead (3.58%), late dead (10.36%), and overall embryo mortality (34.03%) was observed in flocks with 25 weeks of age followed by the breeder flock group of 55 weeks of age and lower values were observed in breeder flocks of 40 weeks of age. Fertility ranged between 98.52 – 87.95%, with the highest value ($p < 0.05$) observed in flocks with 40 weeks of age (98.52%) followed by flocks with 55 weeks of age (94.08%) and 25 weeks of age (87.95%). Flock age affected ($p < 0.05$) all the embryo mortality parameters except malposition and abnormality. The pipped egg percentage was higher in flocks with 25 weeks of age (33.53%) followed by flocks with 55 weeks of age (20.91%) and 40 weeks of age (8.33%). Eggs with early cracks ranged between 0.75 – 3.35% with significantly lowers values observed in flocks with 40 weeks

Table 2. Least square means and their standard errors (SE) for incubation, hatchability, embryo mortality, and mortality breakdown across different flock ages

Traits	Flock age		
	25 weeks	40 weeks	55 weeks
Incubation traits			
Set weight (g)	50.47^{c}±0.16	59.59^{b}±0.12	62.27^{a}±0.15
Transfer weight (g)	45.03^{c}±0.10	52.66^{b}±0.12	54.49^{a}±0.15
day 0 -18 moisture loss (%)	10.76^{c}±0.05	11.62^{b}±0.06	12.46^{a}±0.08
Day-18 eggshell temperature (°C)	37.82^{b}±0.01	37.90^{ab}±0.01	38.25^{a}±0.01
Hatchability traits			
Hatch of total egg set (%)	56.39^{c}±0.79	91.06^{a}±0.57	72.69^{b}±0.73
Hatch of a fertile (%)	64.07^{c}±0.50	92.52^{a}±0.58	77.37^{b}±0.73
Culls (%)	0.78^{b}±0.15	0.13^{c}±0.17	1.52^{a}±0.23
First grade chicks (%)	55.61^{c}±0.50	90.93^{a}±0.58	71.18^{b}±0.75
Chick-hatch weight (g)	33.93^{c}±0.10	39.57^{b}±0.10	44.14^{a}±0.10
Cloaca temperature (°C)	39.58±0.08	39.69±0.08	39.83±0.08
Embryo mortality traits (%)			
Infertile	12.05^{a}±0.25	1.48^{c}±0.28	5.92^{b}±0.42
Fertile	87.95^{c}±0.25	98.52^{a}±0.29	94.08^{b}±0.37
Early dead	20.10^{a}±0.35	3.42^{c}±0.41	11.62^{b}±0.53
Mid dead	3.58^{a}±0.20	0.46^{c}±0.24	2.08^{b}±0.30
Late dead	10.36^{a}±0.31	3.52^{c}±0.35	8.46^{b}±0.53
Total embryo mortality	34.03^{a}±0.49	7.41^{c}±0.56	22.01^{b}±0.43
Embryo mortality breakdown (%)			
Pipped	33.53^{a}±3.29	8.33^{c}±3.58	20.91^{b}±3.82
Early crack	2.87^{a}±1.36	0.75^{b}±1.49	3.35^{a}±1.58
Contaminated	2.88^{c}±2.39	6.00^{b}±2.60	22.78^{a}±2.77
Chick upside-down	1.17^{b}±1.14	5.61^{a}±1.24	6.10^{a}±1.32
Malposition	46.16±4.25	56.68±4.63	42.07±4.93
Exposed brain	0.13^{b}±0.47	1.33^{a}±0.51	1.55^{a}±0.55
Crossed beak	6.17^{a}±1.01	0.91^{b}±1.10	2.21^{b}±1.17
Abnormality	1.86±0.78	1.85±0.85	3.29±0.90

$^{a, b, c}$ Row means with different superscripts differ significantly ($p< 0.05$); Row means without superscripts are not significantly different ($p>0.05$)

of age (0.75%) compared to 25 weeks of age (2.87%) and 55 weeks of age (3.35%) which did not differ statistically from each other. Flocks with 55 weeks of age had higher ($p < 0.05$) contaminated eggs (22.78%) followed by flocks with 40 weeks of age (6.00%) and lower values were observed in flocks with 25 weeks of age (2.88%). The chick upside-down and exposed brain conditions were significantly lower in flocks with 25 weeks of age (1.17%, 0.13%) compared to flocks with 40 weeks of age (6.61%, 1.33%) and 55 weeks of age (6.10%, 1.55%) which were statistically similar. The unhatched chicks with higher ($p < 0.05$) crossed beak were observed in flocks with 25 weeks of age (6.16%) compared to flocks with 40 weeks of age (0.91%) and 55 weeks of age (2.21%) which did not differ from each other. However, malposition and abnormality mortality conditions were statistically similar ($p > 0.05$) in all flock ages.

The least-squares means (LSM) for incubation and hatchability parameters, embryo mortality traits, and mortality breakdown across different egg sizes are presented in Table 3. All the incubation traits were significantly affected ($p < 0.05$) by the egg size. The large-sized eggs had higher ($p < 0.05$) set weight (58.59 g) and transfer weight (51.68 g) followed by medium-sized eggs (set weight: 57.38 g, transfer weight: 50.62 g) and small-sized eggs (set weight: 56.37 g, transfer weight: 49.87 g). The day 0 -18 moisture loss was lower ($p < 0.05$) in small-sized eggs (11.41%) compared to medium (11.72%) and large-sized eggs (11.73%) which did not differ significantly from each other. Day-18 eggshell temperature was statistically higher in large-sized eggs (38.29 °C) compared to the small sized eggs (37.74 °C), whereas day-18 eggshell temperature of the medium-sized eggs (37.82 °C) was statistically similar to both small and large-sized eggs.

Among the hatchability traits only chick-hatch weight was significantly ($p < 0.05$) affected by the chick weight. Large-sized eggs hatched into high weight chicks (44.21 g) followed by medium-sized eggs (39.69 g) and lower weights were observed in small-sized eggs (33.86 g). Among the embryo mortality traits the egg size significantly affected ($p < 0.05$) percentage infertile, fertile, and late dead chicks. Small-sized eggs revealed lower ($p < 0.05$) infertile eggs (5.79%) compared to medium-sized (7.20%) and large-sized (6.46%) eggs which were statistically similar to each other. The small-sized eggs revealed higher fertility (94.21%) and late dead (8.46%) compared to medium-sized eggs (92.80%, 6.76%), whereas large-sized eggs were not statistically different from either sizes. For embryo mortality breakdown, egg sizes significantly affected ($p < 0.05$) mortality due to contaminated eggs, chick upside-down, exposed brain, and crossed beak. The proportion of contaminated eggs was higher in medium-sized eggs (13.16%) compared to small-sized eggs (7.13%), whereas contaminated proportion of large-size eggs (11.37%) was statistically similar to other two egg sizes. The lower proportion of chick upside-down (0.93%) and crossed beak condition (1.28%) was observed in large-sized eggs compared to small-sized eggs (chick upside-down: 6.64%, crossed beak: 3.99%) and medium-sized eggs (chick upside-down: 5.31%, crossed beak: 4.02%) which did not differ significantly from each other. The higher proportion of unhatched chicks with exposed brains were observed in medium-sized eggs (2.33%) compared to large-sized eggs (0.06%) and proportion of small-sized eggs (0.51%) was statistically similar to other two sizes. Pipped eggs, eggs with early cracks, malposition, and abnormality were statistically similar ($p > 0.05$) in all egg sizes.

Table 3. Least square means and their standard errors (SE) for incubation, hatchability, embryo mortality, and mortality breakdown across different egg sizes

Traits	Egg size		
	Small	Medium	Large
Incubation traits			
Set weight (g)	56.37^{c}±0.26	57.38^{b}±0.18	58.59^{a}±0.14
Transfer weight (g)	49.87^{c}±0.17	50.62^{b}±0.11	51.68^{a}±0.09
day 0 -18 moisture loss (%)	11.41^{b}±0.09	11.72^{a}±0.06	11.73^{a}±0.05
Day-18 eggshell temperature (°C)	37.74^{b}±0.01	37.82^{ab}±0.02	38.29^{a}±0.01
Hatchability traits			
Hatch of total egg set (%)	73.26±0.84	73.31±0.55	73.58±0.44
Hatch of a fertile (%)	77.40±0.86	78.48±0.56	78.08±0.45
Culls (%)	0.62±0.26	0.98±0.17	0.83±0.14
First grade chicks (%)	72.64±0.86	72.32±0.56	72.76±0.45
Chick-hatch weight (g)	33.86^{c}±0.10	39.69^{b}±0.10	44.21^{a}±0.10
Cloaca temperature (°C)	39.56±0.08	39.58±0.08	39.75±0.08
Embryo mortality traits (%)			
Infertile	5.79^{b}±0.42	7.20^{a}±0.23	6.46^{ab}±0.22
Fertile	94.21^{a}±0.42	92.80^{b}±0.27	93.54^{ab}±0.22
Early dead	10.93±0.61	12.17±0.40	12.04±0.32
Mid dead	2.32±0.35	1.73±0.23	2.04±0.18
Late dead	8.46^{a}±0.53	6.76^{b}±0.34	6.97^{ab}±0.28
Total embryo mortality	22.73±0.83	20.66±0.55	21.06±0.44
Embryo mortality breakdown (%)			
Pipped	26.78±5.13	13.89±3.68	22.10±2.54
Early crack	0.81±2.13	3.94±1.53	2.22±1.06
Contaminated	7.13^{b}±3.73	13.16^{a}±2.67	11.37^{ab}±1.85
Chick upside-down	6.64^{a}±1.78	5.31^{a}±1.28	0.93^{b}±0.88
Malposition	50.14±6.63	47.84±4.76	46.93±3.29
Exposed brain	0.51^{ab}±0.74	2.33^{a}±0.53	0.06^{b}±0.37
Crossed beak	3.99^{a}±1.57	4.02^{a}±1.13	1.28^{b}±0.78
Abnormality	4.73±1.21	1.22±0.87	1.05±0.60

[a, b, c] Row means with different superscripts differ significantly ($p < 0.05$); Row means without superscripts are not significantly different ($p > 0.05$)

The least-squares means (LSM) for incubation and hatchability parameters, embryo mortality traits and mortality breakdown in two different incubators are presented in Table 4. All the incubation, hatchability, and embryo mortality traits were statistically similar ($p > 0.05$) across the two incubators except for the day-18 eggshell temperature which was higher ($p < 0.05$) in the Linco incubator (38.19°C) than the Buckeye incubator (37.78 °C). However, among the embryo mortality breakdown incubator type significantly affected ($p < 0.05$) percentage of pipped, eggs with early cracks, contaminated eggs, chick upside-down, malposition, and crossed beak conditions. Buckeye incubator yielded higher ($p < 0.05$) proportion of pipped (22.97%) and contaminated (11.83%) eggs compared to Linco incubator (18.87%,

Table 3. Least square means and their standard errors (SE) for incubation, hatchability, embryo mortality, and mortality breakdown in different incubators

Traits	Incubator	
	Buckeye	Linco
Incubation traits		
Set weight (g)	57.33±0.08	57.56±0.08
Transfer weight (g)	50.60±0.08	50.85±0.08
day 0 -18 moisture loss (%)	11.66±0.04	11.57±0.04
Day-18 eggshell temperature (°C)	37.78[b]±0.01	38.19[a]±0.01
Hatchability traits		
Hatch of total egg set (%)	73.65±0.40	73.16±0.40
Hatch of a fertile (%)	78.32±0.41	77.63±0.41
Culls (%)	0.69±0.12	0.92±0.12
First grade chicks (%)	72.96±0.40	72.19±0.41
Chick-hatch weight (g)	39.25±0.09	39.18±0.09
Cloaca temperature (°C)	39.68±0.06	39.73±0.06
Embryo mortality traits (%)		
Infertile	6. 58±0.20	6.35±0.20
Fertile	93.42±0.20	93.65±0.20
Early dead	11.56±0.29	11.86±0.29
Mid dead	2.02±0.16	2.06±0.16
Late dead	7.16±0.25	7.63±0.25
Total embryo mortality	20.72±0.39	21.55±0.39
Embryo mortality breakdown (%)		
Pipped	22.97[a]±3.00	18.87[b]±2.84
Early crack	0.83[b]±1.25	3.82[a]±1.18
Contaminated	11.83[a]±2.18	9.28[b]±2.06
Chick upside-down	3.35[b]±1.04	5.24[a]±0.99
Malposition	44.02[b]±3.88	52.59[a]±3.67
Exposed brain	1.03±0.43	0.90±0.41
Crossed beak	1.86[b]±0.92	4.33[a]±0.87
Abnormality	2.70±0.71	1.87±0.67

[a, b, c] Row means with different superscripts differ significantly ($p < 0.05$); Row means without superscripts are not significantly different ($p > 0.05$)

9.28%), whereas Linco incubator yielded higher early crack eggs (3.82%), unhatched eggs with chick upside-down (5.24%), malposition (52.59%), and crossed beak (4.33%) compared to the Buckeye incubator (0.83%, 3.35%, 44.02%, 1.86%, respectively). The percentage of exposed brain and abnormality were statistically similar ($p > 0.05$) between Buckeye and Linco incubators.

4. Discussion

The effects of flock age, egg size, and incubator type are well documented in most of the broiler chicken breeds; however, to the knowledge of the authors, no such research is available for the Indian River broiler breeder. Most of the previous studies focussed on the effect of age in Ross 308 (Damaziak et al. 2021; Darmus et al. 2021), Hubbard Flex (Damaziak et al. 2021), egg weight/size in Cobb 500 (Ramaphala and Mbajiorgu 2013), Potchefstroom Koekoek chickens (Molapo and Motselisi 2020), Indigenous Venda chickens (Alabi et al. 2012; Ng'ambi et al. 2013) and Indonesial local chickens (Rahardja et al. 2020), and incubator type in Emu (*Dromaius novaehollandiae*) (Adewumi et al. 2008), Cobb and Avian breeders (El-Shhat et al. 2017), Ross 308 (Yousaf et al. 2021), and Cobb 500 (Araujo et al. 2016; Mesquita et al. 2021; Kalaba et al. 2023). However, no such focused studies on the Indian River broiler breeders have been carried out. It is well established in the literature that flock age significantly influences the incubation traits and fertility (Koppenol et al. 2015; Abudabos et al. 2017), hatchability, and embryo mortality (Ipek and Soczu 2015; Nangsuay et al. 2016; Mitrovic et al. 2017; Nowak et al. 2019). The association between flock age and chick quality is also well established in the literature (Nowak et al. 2019; Durmus et al. 2021; Dassi et al. 2022; Wlazlak et al. 2023; Agbehadzi et al. 2024; Cam et al. 2024).

The present study revealed that eggs produced by older flocks (55 weeks of age) exhibited higher moisture loss by day 18 of incubation compared to medium-age (40 weeks) and young flocks (25 weeks of age). An increasing trend of moisture loss was observed with increasing age of breeder flocks. This could be attributed to the fact that thinner eggshell in older flocks facilitates more evaporative loss compared to younger flocks (Molapo and Motselisi 2020). A similar moisture loss trend across flock ages was observed in Cobb 500 and Ross 308 breeds (Jabba and Ditta 2017; Yousaf et al. 2024). On the contrary, Jabba and Yousaf (2017) reported the higher moisture loss in the prime flock (medium-aged flocks) compared to young and old flocks in the Ross 308 breed. This proves that flocks of different ages do not lose the same amount of moisture during incubation, irrespective of the breed. The normal moisture loss of the eggs at day 18 of the incubation ranges between 9.5-12.5% (Cormic 2019). The moisture loss in all flock ages for the present study ranged from 10.76 to 12.46% which is within an acceptable range. Eggs that lose insufficient water during incubation will increase the costs of maintaining chicks at farms due to poor post-hatch performance (Maatjens et al. 2016; Abera et al. 2017; Souza da Silva et al. 2021). The explained phenomenon of poor post-hatch performance in this study would not be expected because the moisture loss was within the acceptable range.

The intrinsic characteristics of a newly hatched chick are critical determinants of its ability to survive, grow efficiently, and obtain optimal health throughout its productive life. The finding that medium-aged Indian River broiler breeder had a higher hatchability of eggs set than young (25 weeks of age) and older flocks (55 weeks of age) could be attributed to the fact that older flocks lay eggs with poor firmness, low albumin and yolk quality (Mendes et al. 2012; Feddern et al. 2017), and poor shell thickness, which have adverse impact on the survival of embryo (Sujata et al. 2019). More importantly, young flock fails to transmit enough antibodies to the egg and there is a decline in absorption of macronutrients in older flock (Wlazlak et al. 2023) which affect the life of the developing embryo and consequently affect the hatchability of eggs. The hatchability trend with respect to the age of breeder flock in the present study is supported by earlier researchers as well in Ross 308 and Cobb 500 (Jabbar and Ditta 2017; Jabbar and Yousaf, 2017; Mitrovic et al. 2017). Older flocks (55 weeks of age) in the present study produced chicks with higher hatch weight compared to young (25 weeks of age) and medium-age (40 weeks) flocks, which could be attributed to the fact that the egg weight increases with the advancing age of the hens due to physiological ageing, providing more yolk and albumen crucial for embryonic development (El Sabry et al. 2013; Araujo et al. 2016; Iqbal et al. 2016; Rahardja et al. 2020). Consequently, chicks hatching from these heavier eggs tend to have a higher initial body weight at hatch, as their initial size directly correlates with the nutrients available in the egg. In addition, the yolk sac is absorbed into the stomach of the chick at the last stage of embryo development or the incubation process. This observation is supported by the previous studies, which reported the higher Cobb 500 and Ross 308 chick-hatch weight in older flocks compared to young flocks and medium-aged flocks (Ipek and Sozcu 2015; Jabbar and Ditta 2017; Yousaf et al. 2024).

The present study revealed a greater proportion of cull chicks in older flocks, which is consistent with the previous reports in Cobb 500 breed (Ipek and Sozcu 2015; Nowak et al. 2019) and Hubbard classic (Iqbal et al. 2016), whereas it is contrary to previous reports in Ross 308 (Nowak et al. 2019). It is well documented that older flocks produce thin shell eggs (Molapo and Motselisi 2020) and subsequently result in more culls (Onasanya and Ikeobi 2013). Higher culling rates could be caused by a longer hatch window (Ipek and Soczu 2013), where the thin shell eggs tend to hatch early and consequently spend a longer time under high temperature in the hatchers, which can lead to poor chick quality. Ideally, chicks should be removed from the hatcher within 24 hours to the chick holding room, since the temperature in the hatcher is higher than that in the chick processing area. Moreover, thin eggshells in older laying flocks increase the risk of egg fracture, moisture loss, and bacterial penetration (Cheng and Ning 2023), which can severely impact the developing embryo, leading to poor chick quality and higher culling rates. This decline in shell quality is primarily due to age-related physiological changes in hens, affecting calcium utilisation and deposition, and is a major concern for poultry producers due to its substantial economic implications for hatchability and overall productivity.

Though higher fertility was observed in 40 week old flocks, followed by 55 week old flocks compared to young 25 week old flocks, the fertility range was within an acceptable range across all flock ages in the present study. Earlier studies have reported normal fertility across all ages in Ross, Hubbard Classic, Arbor Acre, and Cobb breeds (Jabbar and Ditta 2017; Nowak et al. 2019). This could be attributed to enough male-to-female mating ratio in the poultry house. The present study observed higher embryo mortality in the young flocks (25 weeks of age) compared to old flocks (55 weeks of age) and lowest mortality at medium age (40 weeks of age). This could be attributed to the fact that eggs from older flocks contain a large yolk (Nangsuay et al. 2016; Araujo et al. 2017; Molapo and Motselisi 2020), which provides sufficient nutrients for the growth and survival of the developing embryo compared to the eggs from young flocks (Araujo et al. 2017; Van der Wagt et al. 2020; Yang et al. 2020; Alkubaisy et al. 2021). In addition, better shell quality at 40 weeks of age further enhance the egg fertility. Another reason of low fertility might be the immature gametes and inexperienced mating in the young flocks compared to mature and older flocks. Conversely, several studies suggest a consistent pattern where advanced maternal age in broiler breeders correlates with a greater incidence of embryonic death during the incubation period (Salahi et al. 2012; Fikremariam and Tilahun 2016; Yousaf et al. 2024). However, several other researchers have reported that flock age does not affect embryo mortality during incubation (Alsobayel and Albadry 2012; Sujata et al. 2019). Hence, there is no consensus amongst researchers on the effect of flock age on embryo mortality during incubation.

The present study shows that large and medium-sized eggs lost greater moisture during incubation compared to small-sized eggs. This could be due to the large number of egg pores on large and medium-sized eggs compared to small-sized eggs. The results are in line with those reported by Kumar et al. (2024) in the Himachal Pradesh native breed. Contrary to the present findings, in Cobb strain (Ulmer-Franco et al. 2010), CARI-BRO broiler breed (Sudhir et al. 2016), and Ross 308 strain (Duman and Sekereglu 2017), higher moisture loss in small eggs compared to medium and large eggs was observed. The higher amount of water lost might be due to the higher surface-to-volume ratio of small-sized eggs (Sudhir et al. 2016). In the present study, it was observed that the eggshell temperature varies with the breeder age and egg size. There is consensus among researchers that older flocks produce larger eggs compared to younger flocks. This can be attributed to the fact that embryos from larger eggs have higher metabolic heat production, and these eggs have a lower surface-area-to-volume ratio for heat exchange (Lourens et al. 2006; Hamidu et al. 2007; Gualhanone et al. 2012; Boonkum et al. 2025). Consequently, heat exchange may be reduced among eggs in the incubator.

In the present study, the hatchability traits except chick-hatch weight remained similar across egg sizes. This means that egg sizes have no impact on hatchability, and this could be attributed to the non-significant total embryo mortality across egg sizes observed in the current study. These results are similar to those reported in Cobb 500 chickens (Ramaphala and Mbajiorgu 2013). However, significant differences in hatchability traits were observed in Indigenous Venda chickens (Ng'ambi et al. 2013), Hubbard classic broiler (Iqbal et al. 2016), Fayoumi chickens (Senbeta 2017), CARI-BRO Vishal (Sudhir 2016), Potchefstroom Koekoek chickens (Molapo and Motselisi 2020), Indonesian local chickens (Rahardja 2020), Rhodes Island Red X Fayoumi chickens (Bassareh and Razaeipour 2021), and Himachal Predesh Native chickens (Kumar et al. 2024). There is a consensus among researchers that medium-size eggs result in the production of good-quality day-old chicks (Ulmer-Franco et al. 2010; Alabi et al. 2012; Rahardja et al. 2020; Kruent et al. 2022). Similar to the results of the present study, increase in egg size increases the chick-hatch weight (Ipek and Sozcu 2015; Bassareh and Razaeipour 2021; Muhammed et al. 2023). This could be due to the higher set and transfer weight of large-sized eggs compared to small and medium-sized eggs, as observed during the incubation in the present study. Contrary to the observation of present study, higher proportion of cull chicks were observed in large-sized eggs compared to small and medium-sized eggs in Foyoumi x Dominant breed (Fikremariam and Tilahun 2016) and Hubbard classic broiler breeders (Iqbal et al. 2016).

The present study observed that small-sized eggs had higher fertility compared to medium-sized eggs which was reflected in an earlier study on Cobb 500 broiler chicken as well (Ramaphala and Mbajiorgu 2013). The observed higher fertility in small-sized eggs could be attributed to the fact that small-sized eggs have a thick eggshell, which protects and shields the internal egg quality from easily deteriorating. In contrast, Bassareh and Razaeipour (2021) observed that medium-sized eggs had higher fertility, followed by large-sized eggs and lastly by small-sized eggs in Ross 308 broiler breed. Furthermore, the variation in fertility in the present study and those in the literature could be attributed to the breed difference, male and female factors, and nutritional and environmental factors. Though, no differences in early and mid-embryonic deaths was observed, the results of the present study revealed higher late dead embryonic mortality in small-sized eggs. This could be attributed to the fact that embryos have increased metabolic demands during late stages of embryonic development and need to remove increasing levels of carbon dioxide (Givisiez et al. 2020; Wang et al. 2025). However, small-sized eggs have a less number of egg pores, which can lead to insufficient gaseous exchange and could consequently increase embryonic mortality (Muhammedhujar and Negassi 2023). On the contrary, several researchers reported higher total embryo mortality in large-sized eggs in Indigenous Venda chickens, Fayoumi, Desi, Crossbred, and Ross 308 breeders (Ng'ambi et al. 2013; Rashid et al. 2013; Iqbal et al. 2016; Duman and Sekeroglu 2017). This could be attributed to the fact that pH is higher in large-sized eggs (Nasri et al. 2020), which is conducive to bacterial contamination and can terminate fertility on the yolk or end the life of the developing embryo during incubation. Furthermore, Sudhir et al. (2016) and Molapo and Motselisi (2020) reported higher embryonic mortality in small-sized eggs on CARI-BRO Vishal and Potchefstroom Koekoek broiler chickens.

The mortality breakdown in the present study revealed a lower mortality due to contaminated eggs in young flocks and small-sized eggs. This could be attributed to thin eggshells in older laying flocks, which could increase the risk of egg cracks and bacterial penetration (Cheng and Ning 2023). Furthermore, higher proportion of large-size contaminated eggs could be attributed to their high pH that promotes bacterial infection or penetration and old flocks lay eggs with high pH (Nasri et al. 2020). In line with the results of present study high egg contamination was observed in Isa Label Naked Neck older flocks (Machado et al. 2020; Araujo et al. 2016). However, contrasting reports have revealed higher contamination of eggs in young flocks (Jabbar and Yousaf 2017; Yousaf et al. 2024). Higher proportion of cracked eggs in older flocks was observed in the present study and similar observations have been reported in earlier studies as well (Jabbar and Yousaf 2017; Yousaf et al. 2024). This could be due to thin eggshells (Molapo and Motselisi 2020) or poor eggshell quality (Mendes et al. 2012; Feddern et al. 2017; Wlazlak et al. 2023) in older flocks. Similarly, higher proportion of unhatched pipped eggs was observed in young flocks compared to medium and older flocks. This could be attributed to the fact that young flocks produce eggs with a thick eggshell (Molapo and Motselisi, 2020). However, egg size did not affect the pipped unhatched eggs, early crack, malposition, and abnormality across eggs in the present study. Most of these embryo mortality conditions are caused by poor nutrition or human error at setting and transfer, such as mistakes during egg grading, rough placing of eggs on the trollies, and rough transfer. Contrary to the present study, large-sized eggs were reported to have higher unhatched pipped eggs compared to small and medium-sized eggs (Iqbal et al. 2016).

Incubator type did not affect the incubation, embryo mortality traits, and hatchability, with the exception of a higher day-18 eggshell temperature observed in the Linco single-stage incubator. This could be attributed to the structural and operational design of the incubator. Previous studies reported that design and operational profiles, such as multi-stage or single stage, can affect the incubation process (Jabbar and Ditta 2017). The present study used only single-stage incubators. High incubation temperatures are generally associated with early hatching and deformities, while lower temperatures lead to poor embryo development (Hamidu et al. 2018; Agyekum et al. 2022). However, this was not the case in this study, as Linco single-stage incubator yielded chicks with lower deformities compared to the Buckeye single-stage incubator. An optimum day 18 eggshell temperature is 37.0°C, which supports ideal embryo metabolism, mitigating possible heat stress, and consequently results to an appropriate hatch window, which increases chick quality (Hamidu et al. 2018; Agyekum et al. 2022).

5. Conclusions

Flock age and egg size are the main determinants of Indian River broiler breed incubation, hatchability traits, and embryonic mortality, whereas the type of single-stage incubator had an insignificant effect. Better results were observed in flocks at 40 weeks of age and in medium-sized eggs. Future studies on this breed can be designed towards dynamic incubation profiles, adjusting incubation environment based on the egg characteristics, such as flock laying age and egg sizes, rather than a one-size-fits-all approach.

Declarations

Funding: This work was partially funded by the Tshwane University of Technology Postgraduate Scholarship

Conflict of interest: Authors declare no conflicts of interest

Acknowledgements: Researchers are grateful to the concerned hatchery for providing resources (facilities and partial funding) to conduct this research and to the staff who assisted in data collection and recording

Ethics approval: The study was approved by the Tshwane University of Technology Animal Research Ethics Committee (AREC202504006)

References

Abera D, Abebe A, Begna F, Tarekegen A, Alwei M. (2017). Growth performance, feasibility and carcass characteristics of Cobb 500 commercial broiler under small-scale production in Western Ethiopia. Asian Journal of Poultry Science 11(1): 49-56. https://doi.org/10.3923/ajpsaj.2017.49.56

Abudabos AM, Aljumaah RS, Algawaan AS, Al-Sornokh H, Ai-Atiyat RM. (2017). Effects of hen age and egg weigh class on hatchability of free range chicken eggs. Brazilian Journal of Poultry Science 19(1): 33-40. https://doi.org/10.1590/1806-9061-2016-0264

Adewumu AA, Ayodele IA, Lameed GA. (2008). The effect of incubator type on hatchability and chick survival of Emu *Dromaius Novae Hollandiae* (Le Souef 1907). Journal of Applied Science and Environmental Management 12(2): 13-15. https://doi.org/10.4314/jasem.v12i2.55515

Agbehadzi RK, Meteyake HT, Adjei-Mensah B, Sasu P, Koranteng AA, Dassidi N, Hamidu JA, Tona K. (2024). Effect of layer breeder age and reduced incubator oxygen concentrations on embryo development, hatching events, chick quality, embryonic mortality and hatchability of fertile eggs. Heliyon 10(22): e40468. https://doi.org/10.1016/j.heliyon.2024.e40468

Agyekum G, Okai MA, Tona JK, Donkoh A, Hamidu JA. (2022). Impact of incubation temperature profile on chick quality, bone, and immune system during the late period of incubation of Cobb 500 broiler strain. Poultry Science 101(9): 101999. https://doi.org/10.1016/j.psj.2022.101999

Alabi OJ, Ng'ambi JW, Norris D. (2012). Effect of egg weight on physical egg parameters and hatchability of indigenous Venda chickens. Asian Journal of Animal and Veterinary Advances 7(2): 166-172. https://doi.org/10.3923/ajava.2012.166.172

Alkubaisy SA, Majid AA, Abdulateef SM, Al-Bazy FA, Attallah AK, Abdualmajeed OM, Mohammed TT, Abdulatee FM, Mahmud KI. (2021).

Effect of *in-ovo* injection of biotin on chick's embryonic development and physiological traits. IOP Conference Series: Earth and Environmental Science 761: 012111. https://doi.org/10.1088/1755-1315/761/1/012111

Alsobayel AA, Albadry MA. (2012). Effect of age and sex ratio on fertility and hatchability of Baladi and Leghorn laying hens. Journal of Animal and Plant Science 22(1): 15-19.

Araujo ICS, Leandro NSM, Mesquita MA, Cafe MB, Mello HHC, Gonzales E. (2016). Effect of incubator type and broiler breeder age on hatchability and chick quality. Brazil Journal of Poultry Science 18(2): 17-25. https://doi.org/10.1590/1806-9061-2015-0146

Araujo ICS, Leandro NSM, Mesquita MA, Cafe MB, Mello HHC, Gonzales E. (2017). Water vapor conductance: a technique using eggshell fragments and relations with other parameters of eggshell. Revista Brasileira de Zootecnia 46(12): 896-902. https://doi.org/10.1590/S1806-92902017001200004

Attia YA, Rahman MT, Hossain MJ, Basiouni S, Khafaga AF, Shehata AA, Hafez HM. (2022). Poultry production and sustainability in developing countries under the COVID-19 crisis: lessons learned. Animals 12(5): 644. https://doi.org/10.3390/ani12050644

Avşar KO, Uçar A, Özlü S, Elibol O. (2022). Effect of high eggshell temperature during the early period of incubation on hatchability, hatch time, residual yolk, and first-week broiler performance. Journal of Applied Poultry Research 31(1): 100197. https://doi.org/10.1016/j.japr.2021.100197

Bassareh M, Razaeipour V. (2021). Effect of egg size and different levels of humidity during incubation period on the embryonic development, hatching percentage and chicks yield of broiler breeder. Austin Journal of Veterinary Science and Animal Husbandry 8(1): 1074.

Wlazlak S, Pietrzak E, Biesek J, Dunislawska A. (2023). Modulation of the immune system of chickens a key factor in maintaining poultry production-a review. Poultry Science 102(8): 102785. https://doi.org/10.1016/j.psj.2023.102785

Bilalissi A, Meteyake H. T, Kouame Y. A. E, Oke O. E, Lin H, Onagbesan O, Decuypere E, Tona K. (2022). Effects of pre-incubation storage duration and nonventilation incubation procedure on embryonic physiology and post-hatch chick performance. Poultry Science 101(5): 101810. https://doi.org/10.1016/j.psj.2022.101810

Boonkum W, Chankitisakul V, Kananit S, Kenchaiwong W. (2024). Heat stress effects on the genetics of growth traits in Thai native chickens (*Pradu Hang dum*). Animal Bioscience 37(1): 16–27. https://doi.org/10.5713/ab.23.0165

Cam M, Samli MS, Kaya ZK, Harman H, Bilir A, Kirikci K. (2024). Effect of hen age on egg quality, hatching performance and chick quality in chukar partridge (*Alectoris chuckar*). Eurasian Journal of Veterinary Sciences 40(1): 34-40. https://doi.org/10.15312/EurasianJVetSci.2024.423

Castro FLS, Chai L, Arango J, Owens CM, Smith PA, Reichelt S, Dubois C, Menconi A. (2023). Poultry industry paradigms: Connecting the dots. Journal of Applied Poultry Research 32(1): 100310. https://doi.org/10.1016/j.japr.2022.100310

Cheng X, Ning Z. (2023). Research progress on bird eggshell quality defects: a review. Poultry Science 102(1): 102283. https://doi.org/https://doi.org/10.1016/j.psj.2022.102283

Connolly G, Clark CM, Campbell RE, Byers AW, Reed JB, Campbell WW. (2022). Poultry Consumption and Human Health: How Much Is Really Known? A Systematically Searched Scoping Review and Research Perspective. Advances in Nutrition 13(6): 2115–2124. https://doi.org/10.1093/advances/nmac074

Cormic J. (2019). Factors affecting weight loss of eggs during incubation. International Hatchery Practice 35(6): 16-17. https://www.positiveaction.info/files/pdfs/articles/hp35_6p16.pdf

Damaziak K, Koznaka-Lipka M, Gozdowski D, Gołębiowska A, Kędziorek E. (2021). Effects of broiler breeder strain, age, and eggs preheating profile in single-stage systems on the hatchability of eggs and quality of chicks. Animal 15(1): 100057. https://doi.org/10.1016/j.animal.2020.100057

Dassi N, Kowonou KAR, Dzibodi MA, Onabesan O, Kokou T, Lin H. (2022). Effects of egg weight and breeder age on egg quality, hatching parameters, and post-hatch performance of Cherry Valley broiler ducks. European Poultry Science 86: 1-18. https://doi.org/10.1399/eps.2022.365

Duman M, Sekeroglu A. (2017). Effect of egg weights on hatching results, broiler performance and some stress parameters. Brazilian Journal of Poultry Science 19(2): 255-262. https://doi.org/10.1590/1806-9061-2016-0372

Durmuş M, Kurşun K, Baylan M, Kutlu HR. (2021). The effect of flock age on hatching results and chick quality in ross 308 broiler. Turkish Journal of Agriculture-Food Science and Technology 9(2): 362-367. https://doi.org/10.24925/turjaf.v9i2.362-367.4005

El-Sabry MI, Yalcin S, Turgay-Izzetoglu G. (2013). Interaction between breeder age and hatching time effects intestine development and broiler performance. Livestock Science 157: 12-617. https://doi.org/10.1016/j.livsci.2013.07.012

El-Shhat A, Tag El-Din T, Elmetwally S. (2017). Effect of Incubator System and Strain on Productive Performance of Broilers. Journal of Animal and Poultry Production 8(8): 277-283. https://doi.org/10.21608/jappmu.2017.45982

Feddern V, De Prá MC, Mores R, Nicoloso, RS, Coldebella A, Abreu PG. (2017). Egg quality assessment at different storage conditions, seasons and laying hen strains. Ciência e Agrotecnologia 41: 322-333. https://doi.org/10.1590/1413-70542017413002317

Fikremariam F, Tilahun A. (2016). Fertility and hatchability in Fayoumi and Dominant breeds of chicken in Debere Zeit Agricultural Research Centre, Ethiopia. Academia Journal of Agricultural Research 4(5): 241-246.

Franzo G, Legnardi M, Faustini G, Tucciarone CM, Cecchinato M. (2023). When Everything Becomes Bigger: Big Data for Big Poultry Production. Animals 13(11): 1804. https://doi.org/10.3390/ani13111804

Galiè A, Teufel N, Girard AW, Baltenweck I, Domínguez-Salas P, Price MJ, Jones R, Lukuyu B, Korir L, Raskind IG, Smith K, Yount KM. (2019). Women's empowerment, food security and nutrition of pastoral communities in Tanzania. Global Food Security 23: 125-134. https://doi.org/10.1016/j.gfs.2019.04.005

Givisiel PEN, Moreira Filho ALB, Santos MRB, Oliveira HB, Ferket PR, Oliveira CJB, Malheiros RD. (2020). Chicken embryo development: metabolic and morphological basis for *in ovo* feeding technology. Poultry Science 99(1): 6774-6782. https://doi.org/10.1016/j.psj.2020.09.074

Gualhanone A, Furlan RL, Fernandez-Alarcon MF, Macari M. (2012). Effect of breeder age on eggshell thickness, surface temperature, hatchability and chick weigh. Brazilian Journal of Poultry Science 14(1): 09-14. https://doi.org/10.1590/S1516-635X2012000100002

Hamidu JA, Fasenko GM, Feddes JJR, O'Dea EE, Ouellette CA, Wineland MJ, Christensen VL. (2007). The effect of broiler breeder genetic strain and parent flock age on eggshell conductance and embryonic metabolism. Poultry Science 86(11): 2420-2432. https://doi.org/10.3382/ps.2007-00265

Hamidu JA, Torres CA, Johnson-Dahl ML, Korver DR. (2018). Physiological response of broiler embryos to different incubator temperature profiles and maternal flock age during incubation. 1. Embryonic metabolism and day-old chick quality. Poultry Science 97(8): 2934–2946. https://doi.org/10.3382/ps/pey089

Idowu PA, Zishiri O, Nephawe KA, Mtileni B. (2021). Current status and intervention of South Africa chicken production – A review. World's Poultry Science Journal 77(1): 115–133. https://doi.org/10.1080/00439339.2020.1866965

Indian River Broiler Management Handbook. (2025). An Aviagen brand. https://aviagen.com/assets/Tech_Center/LIR_Broiler/Aviagen-IR-Broiler-Handbook-EN.pdf

Ipek A, Sozcu A. (2013). Broiler chick quality and scoring methods. Journal of Agricultural Faculty of Uludag University 2: 131-137. https://dergipark.org.tr/tr/download/article-file/154201

Ipek A, Sozcu A. (2015). The effect of broiler breeder age on intestinal development during hatch window, chick quality and first week broiler performance. Journal of Applied Animal Research 43(4): 402-408. https://doi.org/10.1080/09712119.2014.978784

Iqbal J, Khan SH, Mukhtar N, Ahmed T, Pasha RA. (2016). Effects of egg size and age on hatching performance and chick quality of broiler breeder. Journal of Applied Animal Research 44(1): 54-64. https://doi.org/10.1080/09712119.2014.987294

Jabbar A, Ditta YA. (2017). Effect of broiler breeders age on hatchability, water loss, chick yield and dead in shell. World's Veterinary Journal 7(2): 40-46. http://dx.doi.org/10.5455/wvj.20170493

Jabbar A, and Yousaf A (2017). Effect of age wise incubation programme on broiler breeder hatchability and post hatch performance. Online Journal of Animal and Feed Research 7(1): 13-17.

Kalaba ZM, Ismail FSA, Kassem MF. (2023). Physiological differences, physical characteristics, and some plasma parameters on chicks hatched from multi stage incubator system versus single stage incubator system. Journal of Animal and Poultry Production 14(10): 119-124. https://doi.org/10.21608/jappmu.2023.236889.1093

Koppenol A, Delezie E, Wang Y, Franssens L, Willwms E, Ampe B, Buyse J, Everasert N. (2015). Effect of maternal dietary EPA and DHA supplementation and breeder age on embryonic and post-hatch performance of broiler offspring: Age and n-3 pufa affect embryonic and post-hatch performance. Journal of Animal Physiology and Animal Nutrition 99: 36-47. https://doi.org/10.1111/jpn.12308

Kumar J, Jamwal K, Bhardwaj N, Sankhyan V, Dinesh K, Katoch S. (2024). Effects of egg size on hatchability parameters and chick quality in native chicken. Indian Journal of Poultry Science 59(2): 206-216. https://doi.org/10.56093/ijps.v59i2.165173

Kruenti F, Lamptey VK, Okai MA, Adu-Aboagye G, Oduro-Owuso AD, Bebanaayele F, Suurbessig B. (2022). The influence of flock age and egg size on egg shape index, hatchability and growth of Japanese quail chicks. Journal of Innovative Agriculture 9(1): 8-16. https://doi.org/10.37446/jinagri/rsa/9.1.2022.8-16

Lourens A, Molenaar R, van den Brand H, Heetkamp M J, Meijerhof R, Kemp B. (2006). Effect of egg size on heat production and the transition of energy from egg to hatchling. Poultry Science 85(4): 770–776. https://doi.org/10.1093/ps/85.4.770

Maatjens CM, Van Roovdert-Rrijrink IA, Van Der Anker I, Engel B, Van Der Pol CW, Kemp B, Van Den Brand H. (2016). Temperature during the last week of incubation ||. Effects on first week broiler development and performance. Poultry Science 95(9): 2136-2144. https://doi.org/10.3382/ps/pew145

Machado JP, Mesquita MA, Cafe MB, Assis SD, Verissimio S, Santos RR, Leandro NSM, Araujo ICS. (2020). Effects of breeder age on embryonic development, hatching results, chick quality, and growing performance of the slow-growing genotype. Poultry Science 99: 6697-6704. https://doi.org/10.1016/j.psj.2020.09.008

Masia KS, Nephawe KA, Mtileni B, Modiba MC, Ncube KT, Ngcobo JN, Janse Van Rensburg W, Mpofu TJ. (2024). Effect of high incubation temperature on embryo livability, mortality, hatchability, and chick quality in commercial layers. American Journal of Animal and Veterinary Science 19(24): 393-403. https://doi.org/10.3844/ajavsp.2024.393.403

Mesquita MA, Araújo ICS, Café MB, Arnhold E, Mascarenhas AG, Carvalho FB, Stringhini JH, Leandro NSM, Gonzales E. (2021). Results of hatching and rearing broiler chickens in different incubation systems. Poultry Science 100(1): 94–102. https://doi.org/10.1016/j.psj.2020.09.028

Mendes AS, Paixão SJ, Restelatto R, Marostega J, Morello GM. (2012). Performance and preference of broiler chickens under different light sources. 2012 IX International Livestock Environment Symposium (ILES IX), 08-12 July, Valencia, Spain. American Society of Agricultural and Biological Engineers, St. Joseph, Michigan. https://doi.org/10.13031/2013.41591

MiniTab 17 Statistical Software (2017). State College, PA: Minitab, Inc. www.minitab.com

Mitrovic S, Dimitrijevic MR, Peric L, Stanisic G, Pandurevic T. (2017). Influence of the Cobb 500 hybrid parent age and egg storage period on incubation parameters. Biotechnology in Animal Husbandry 33(4): 409-423. https://doi.org/10.2298/BAH1704409M

Molapo S, Motselisi M. (2020). The effect of egg size (weight) on the egg shell thickness, egg yolk and hatchability in Koekoe chickens. Online Journal of Animal and Feed Research 10(6): 278-281. https://dx.doi.org/10.51227/ojafr.2020.37

Mottet A, Tempio G. (2017). Global poultry production: current state and future outlook and challenges. World's Poultry Science Journal 73(2): 245–256. https://doi.org/10.1017/S0043933917000071

Mphepya LC, van Rensburg WJ, Mpofu TJ, Mtileni BJ, Nephawe KA. (2019). Influence of male-male competition on reproductive performance and mortality of broiler breeders following intra-spiking. Poultry Science 98(10): 4549–4554. https://doi.org/10.3382/ps/pez273

Muhammed SM, Yakubu A, Dogara MU, Abdullahi HR, Ubangari MA. (2023). Effect of egg weight and storage time on hatch weight of Fulani ecotype chicken eggs under artificial incubation. Nigerian Journal of Animal Science 25(3): 83-89.

Muhammedjuhar AA, Negassi A. (2023). Review on egg handling and management of incubation and hatchery environment. Asian Journal of Biological Sciences 16(4): 474-484. https://doi.org/10.3923/ajbs.2023.474.484

Nasri H, van den Brand H, Najjar T, Bouzouaia M. (2020). Egg storage and breeder age impact on egg quality and embryo development. Journal of Animal Physiology and Animal Nutrition 104: 257–268. https://doi.org/10.1111/jpn.13240

Nangsuay A, Meijerhof R, Van Der Anker I, Peetkam MJW, Morita, VDS, Kemp B. (2016). Effect of breeder age, broiler strain, and eggshell on development and physiological status of embryos and hatchlings. Poultry Science 95: 1666-1679. https://doi.org/10.3382/ps/pew080

Ng'ambi JW, Thamaga MW, Norris D, Mabelebele M, Alabi OJ. (2013). Effects of egg weight on hatchability, chick-hatch weight and subsequent productivity of indigenous Venda chickens in Polokwane, South Africa. South African Journal of Animal Science 43(5): 69. https://doi.org/10.4314/sajas.v43i5.13

Nowak B, Pawlina E, Ilska K, Mucha A, Kruszynski W. (2019). Breeder line and age affects the occurrence of developmental defects, the number of culled one-day old broiler chick and their body mass. Veterinarni Medicina 64(07): 323-333. https://doi.org/10.17221/137/2018-VETMED

Ogbu OC, Oguike MA. (2019). Hatchability of fertile eggs in poultry industry. Journal of Agriculture and Sustainability 12(1): 107-123.

Onasanya G, Ikeobi C. (2013). Egg physical traits, performance, fertility and hatchability in exotic and Nigerian indigenous chickens. Standard Research Journal of Agricultural Sciences 1(1): 1-8.

Rahardja DP, Hakim MR, Empra T, Savitri RD. (2020). Effects of weight and storage duration of hatching eggs of Indonesial Local Chicken on several measures of internal quality and hatchability. Earth and Environmental Science 492: 012034. https://doi.org/10.1088/1755-1315/492/1/012034

Ramaphala NO, Mbajiorgu C. (2013). Effect of egg weight on hatchability and chick hatch-weight of Cobb 500 broiler chickens. Asian Journal of Animal and Veterinary Advances 8: 885-892. https://doi.org/10.3923/ajava.2013.885.892

Rashid A, Khan SH, Abbas G, Amer MY, Khan MJ, Iftikhar N. (2013). Effect of egg weight on hatchability and hatchling weight in Fayoumi, desi and crossbred (Rhodes Island Red X Fayoumi). Chickens. Veterinary World 6(9): 592-595. https://doi.org/10.5455/vetworld.2013.592-595

Reijrink IAM, Meijerhof R, Kemp B, Graat EAM, van den Brand HD. (2009). Influence of Pre-storage Incubation on Embryonic Development, Hatchability and Chick Quality. Poultry Science 88(12): 2649–2660. https://doi.org/10.3382/ps.2008-00523

Salah A, Khabishi MM, Esmailizadeh AK. (2012). Effect of pre incubation upside-down positioning of eggs from breeder flocks with different ages on hatchability and chick quality. Animal Production Science 52: 269-275. https://doi.org/10.1071/AN11127

Senbeta EK. (2017). Effect of egg size on hatchability and subsequent growth performance of Fayoumi chickens. Journal of Agricultural Science 9(7): 1916-9760. https://doi.org/10.5539/jas.v9n7p116

South African Poultry Association (SAPA). (2019). Industry Profile. https://www.sapoultry.co.za/pdf-docs/sapa-industry-profile.pdf

South African Poultry Association (SAPA). (2020). 2020 Industry Profile. https://www.sapoultry.co.za/wp-content/uploads/2022/03/SAPA-INDUSTRY-PROFILE-2020.pdf

South African Poultry Association (SAPA). (2023). State of the SA poultry industry. https://www.sapoultry.co.za/wp-content/uploads/2025/01/SAPA-INDUSTRY-PROFILE-2023.pdf

Souza Da Silva C, Molenaar R, Giersberg, MF, Rodenburg TB, Van Riel JW, De Baere K, Van Dosselaer I, Kemp B, Van Den Brand H, De Jong IC. (2021). Day-old chicken quality and performance of broiler chickens from 3 different hatching systems. Poultry Science 100(3): 100953. https://doi.org/10.1016/j.psj.2020.12.050

Sudhir KJ, Meesam R, Leena D, Chaturvedani A. (2016). Effect of egg weight on pre-hatch performance in broiler chickens. International Journal of Science, Environment and Technology 5(6): 4422-4426.

Sujata D, Rajarshi S, Subhransu P, Bikas D, Asish D. (2019). Factors associated with embryonic mortality of eggs of vanaraja breeder chicken reared on litter system. International Journal of Current Microbiology and Applied Science 8(4): 525-532. https://doi.org/10.20546/ijcmas.2019.804.057

Tenza T, Mhlongo LC, Ncobela CN, Rani Z. (2024). Village Chickens for Achieving Sustainable Development Goals 1 and 2 in Resource-Poor Communities: A Literature Review. Agriculture 14(8): 264. https://doi.org/10.3390/agriculture14081264

Ulmer-Franco AM, Fasenko GM, Christopher EE. (2010). Hatching egg characteristics chick quality and broiler performance at 2 breeder flock ages and from 3 egg weights. Poultry Science 89: 2735-2742. https://doi.org/10.3382/ps.2009-00403

Van Der Wagt I, De Joung IC, Mitchell MA, Molenaar R, Van Den Brand H. (2020). A review on yolk sac utilization in poultry. Poultry Science 99(4): 2162-2175. https://doi.org/10.1016/j.psj.2019.11.041

Wang H, Wang Y, Liu J, Hou Q, Ren Z, Liu Y, Yang X. (2025). Lioidomics reveals lipids changes in the hepatic during the late chick embryonic development. Poultry Science 104 (7): 105218. https://doi.org/10.1016/j.psj.2025.105218

Yang J, Ding X, Bai S, Wang B, Zeng Q, Peng H, Su Z, Xuan Y, Fraley GS, Zhang K. (2020). Effect of maternal dietary vitamin E on the egg characteristics, hatchability and offspring quality of prolonged storage eggs of broiler breeder hens. Journal of Animal Physiology and Animal Nutrition 104(5): 1384-1391. https://doi.org/10.1111/jpn.13371

Yousaf A, Shahnawaz R, Khan S, Khan MR, Said A, Rahman M-U, Hassan J, Ishaq, Said MF, Subhani A. (2021). Comparative evaluation of single stage vs multistage incubations systems on the performance of hatching eggs from Ross-308 broiler breeders and post hatched performance. International Journal of Biotechnology and Bioengineering 7(9): 190-199.

Yousaf A, Yasoob TB, Anwar DM, Ahmad B, Tareen F, Nasrullah S. (2024). Effect of egg weight on water loss and chick yield of broiler breeders. Matthew Journal of Veterinary Science 8(2): 43. https://doi.org/10.30654/MJVS.10043

Citation

Mabotha TR, Nephawe KA, Mpofu TJ. (2025). Effect of flock age, egg size, and incubator type on embryo development and hatchability in the Indian River Broiler breeders in South Africa. Letters in Animal Biology 05(2): 136 – 145. *https://doi.org/10.62310/liab.v5i2.263*