

The Android-Controlled Automatic Incubator: Design and Effect on Hatching Performance of Cihateup Duck Eggs

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Abstract: Traditional hatching of duck eggs without temperature and humidity control and with manual egg turning often results in low hatchability. This study aimed to design an Android-controlled automatic incubator and to evaluate its technical performance and its effect on the hatching performance of Cihateup duck eggs. The study was conducted from September to December 2024 in Rajamandala Village, Tasikmalaya Regency, Indonesia. The incubator used a microcontroller, temperature and humidity sensors, a heater, a fan and an automatic egg-turning mechanism, and it was monitored and controlled through an Android application. Technical performance was evaluated through sensor accuracy and the stability of temperature and relative humidity during incubation. The hatching trial used a completely randomized design with two treatments, namely conventional incubation with manual turning and incubation in the automatic incubator. The variables observed were fertility, embryonic mortality, hatchability and day-old duckling weight, and the data were analyzed using an independent samples t-test. The sensors showed a temperature error of 1.2% and a humidity error of 3.8%. The automatic incubator significantly increased the hatchability of fertile eggs from 64.5% to 81.3% and reduced embryonic mortality from 35.5% to 18.7%. The Android-controlled automatic incubator is technically reliable and can be recommended as an appropriate hatching technology for smallholder Cihateup duck farmers.

Keywords: Automatic Incubator; Cihateup Duck; Embryonic Mortality; Hatchability; Internet of Things.

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A. INTRODUCTION

Local ducks are an important source of eggs, meat and household income for smallholder farmers in Indonesia. The Cihateup duck is a local genetic resource from West Java that is widely raised in Tasikmalaya and its surrounding areas as both a layer and a meat-type duck, and it offers business opportunities for rural communities (Matitaputty & Suryana, 2014). The sustainability of such enterprises depends on a continuous supply of good-quality day-old ducklings (DOD), which in turn depends on the successful hatching of fertile eggs. Ducks generally do not incubate their own eggs, so duck farmers rely on other brooding birds or on incubators (Yanti et al., 2022). Natural incubation using a broody hen or a Muscovy duck is limited to approximately 10–15 eggs per bird (Sugara et al., 2023), whereas an incubator allows eggs to be hatched on a much larger scale (Prabowo et al., 2024).

Hatching success is determined by the interaction among temperature, relative humidity, ventilation and egg turning during incubation (Boleli et al., 2016), as well as by egg quality and pre-incubation factors such as egg weight, egg storage and breeder age (Abd El-Hack et al., 2019, 2022). Egg turning is particularly critical: reducing the turning frequency from 24 to 3 times per day progressively increased early and late embryonic mortality and reduced the hatchability of fertile eggs by up to 19.70% (Oliveira et al., 2020). In waterfowl eggs, a wider turning angle reduced late embryonic mortality and improved hatchability and hatchling quality (Guo et al., 2021). Consequently, traditional hatching in which eggs are turned by hand and the temperature and humidity are neither measured nor regulated tends to result in low hatchability (Saputera et al., 2020).

The Internet of Things (IoT) enables devices to collect and exchange data through a network with minimal human intervention, and IoT-based technologies aim to simplify processes and improve the efficiency of systems in various fields, including agriculture (Nizetić et al., 2020). In IoT-based incubators, a microcontroller reads temperature and humidity sensors, regulates the heater and fan, and transmits the data to a smartphone application so that the incubation conditions can be monitored remotely in real time (Purwanti et al., 2021; Abdullah & Hamdan, 2023; Prabowo et al., 2024). This approach has been applied to duck egg incubators (Yanti et al., 2022) and combined with solar panels as an alternative energy source (Peprah et al., 2022; Mutaqim et al., 2024).

However, most of these studies evaluated the engineering performance of the incubator, such as sensor accuracy, temperature stability and data transmission, rather than the biological hatching performance of the eggs (Abdullah & Hamdan, 2023; Prabowo et al., 2024; Mutaqim et al., 2024). Studies that evaluate an Android-controlled incubator in terms of both its technical performance and the hatching performance of local Indonesian duck eggs, particularly Cihateup duck eggs, remain limited. Therefore, this study aimed to (1) design an Android-controlled automatic incubator for duck eggs, (2) evaluate its technical performance in terms of sensor accuracy and the stability of temperature and relative humidity, and (3) compare the fertility, embryonic mortality, hatchability and DOD weight of Cihateup duck eggs incubated in the automatic incubator with those incubated conventionally.

B. METHOD

1. Time and Location

The study was conducted from September to December 2024 in Rajamandala Village, Rajapolah District, Tasikmalaya Regency, West Java, Indonesia, at the hatching facility of the Kelompok Megar Bebek Mukti. The incubator was designed and assembled by the research team of Universitas Perjuangan Tasikmalaya in collaboration with Universitas Siliwangi.

2. Materials and Equipment

The material used was 500 fertile Cihateup duck eggs obtained from the breeding flocks of the Kelompok Ternak Bebek Mukti. The breeders were 52 weeks old with a male-to-female ratio of 1:7, and the eggs were stored for no more than 7 days at 16–18 °C before incubation. The eggs were selected based on a clean and intact shell, a normal shape (neither too round nor too elongated), uniform size and colour, and a smooth shell surface. Only eggs

weighing 60–70 g were used to obtain uniform egg weight. The equipment consisted of the automatic incubator, a conventional incubator, a calibrated digital thermohygrometer as the reference instrument, a digital scale with a precision of 0.01 g, and a candling lamp.

3. Design of the Automatic Incubator

The automatic incubator consisted of a microcontroller connected to a Wi-Fi network, a temperature and humidity sensor, a heater, a fan, a humidifier, an automatic egg-turning motor and a built-in candling lamp. The microcontroller read the sensor at fixed intervals, switched the heater, fan and humidifier on or off to maintain the set points, and sent the data to an Android application, which displayed the temperature and humidity in real time and allowed the user to change the set points remotely. The specifications of systems are presented in Table 1.

Table 1. Specifications of the Automatic Incubator

Component	Specification
Egg capacity	500 eggs
Dimensions and housing material	80 × 60 × 70 cm; plywood with 2 cm styrofoam insulation and an acrylic observation window
Microcontroller	ESP32
Temperature and humidity sensor	DHT22
Heater and fan	4 × 25 W incandescent bulbs; 12 V DC fan (0.3 A)
Humidifier	Ultrasonic mist maker (24 V) with water reservoir
Egg turning	Automatic, 6 times per day, angle $\pm 45^\circ$
Monitoring and control	Android application through a Wi-Fi network
Candling	Built-in candling lamp
Power supply	Grid electricity with 12 V battery backup And solar panel

4. Experimental Design

The technical performance of the incubator was tested by comparing the sensor readings with those of the reference thermohygrometer placed at the same position in the incubation chamber. Readings were taken 30 times at three set points (37.0, 37.5, and 38.0 °C). The temperature and relative humidity in the incubation chamber were recorded every 10 minutes throughout the incubation period. The hatching trial used a completely randomized design with two treatments: T0, conventional incubation in which the eggs were turned manually three times per day and the temperature and humidity were not automatically controlled, representing the hatching practice of the farmers; and T1, incubation in the Android-controlled automatic incubator. Each treatment consisted of five replicates, and each replicate consisted of 50 eggs, so that a total of 500 eggs were used. The eggs were randomly allocated to the treatments and replicates.

5. Incubation Procedure

In T1, the eggs were incubated at 37.5 °C and 62% relative humidity from day 1 to day 24 and at 37.0 °C and 72% relative humidity from day 25 until hatching, following the

incubation conditions commonly applied to duck eggs (Boğa Kuru et al., 2023). Egg turning was carried out automatically and stopped on day 25. The eggs were candled on days 7 and 25 to identify infertile eggs and dead embryos, which were then removed and opened to determine the stage of embryonic death. The ducklings were counted and weighed after their down had dried on day 28.

6. Observed Variables

The variables observed were fertility, early and late embryonic mortality, hatchability of fertile eggs, hatchability of total eggs, DOD weight and relative hatch weight. Fertility, mortality and hatchability were calculated based on the number of eggs in each replicate (Boğa Kuru et al., 2023), using Equations (1) to (5).

$$\text{Fertility (\%)} = (\text{fertile eggs} / \text{eggs set}) \times 100 \quad (1)$$

$$\text{Embryonic mortality (\%)} = (\text{dead embryos} / \text{fertile eggs}) \times 100 \quad (2)$$

$$\text{Hatchability of fertile eggs (\%)} = (\text{hatched ducklings} / \text{fertile eggs}) \times 100 \quad (3)$$

$$\text{Hatchability of total eggs (\%)} = (\text{hatched ducklings} / \text{eggs set}) \times 100 \quad (4)$$

$$\text{Relative hatch weight (\%)} = (\text{DOD weight} / \text{egg weight}) \times 100 \quad (5)$$

Early embryonic mortality was defined as embryonic death detected up to the first candling, and late embryonic mortality as embryonic death detected after the first candling, including embryos that died in the shell. The sensor error was calculated using Equation (6).

$$\text{Error (\%)} = (|\text{sensor reading} - \text{reference reading}| / \text{reference reading}) \times 100 \quad (6)$$

7. Data Analysis

The data on sensor accuracy and on the temperature and relative humidity of the incubation chamber were analyzed descriptively and presented as means $\pm$ standard deviations. The hatching performance data of the two treatments were compared using an independent samples t-test at a 5% significance level. Percentage data were arcsine square-root transformed before analysis, and the analysis was performed using IBM SPSS Statistics version 22 (IBM Corp., Armonk, NY, USA).

C. RESULTS AND DISCUSSION

1. Technical Performance of the Automatic Incubator

All functions of the automatic incubator, including temperature and humidity monitoring, set-point adjustment and egg turning, could be operated through the Android application, so that the condition of the incubator could be checked without being at the hatchery. The accuracy of the sensors is presented in Table 2. The mean error was 1.2% for temperature and 3.8% for relative humidity, corresponding to an accuracy of 98.8% and 96.2%, respectively. For comparison, Mutaqim et al. (2024) reported a temperature monitoring accuracy of 99.07% in an IoT-based solar-powered incubator.

Table 2. Accuracy of the Temperature and Humidity Sensors

Parameter	Sensor	Reference	Error (%)
Temperature (°C)	37.95 ± 0.31	37.50 ± 0.25	1.20
Relative humidity (%)	65.6 ± 2.1	63.2 ± 1.8	3.80

The temperature and relative humidity during incubation are presented in Table 3. In T1, the temperature in the setter phase averaged 37.48 ± 0.12 °C and the relative humidity $61.8 \pm 1.9\%$, whereas in T0 the temperature fluctuated between 35.6 and 39.1 °C. Stable conditions are expected because the microcontroller continuously adjusted the heater and fan according to the set points, as also reported for IoT-based incubators by Prabowo et al. (2024) and Abdullah and Hamdan (2023). Stability is essential because temperature and relative humidity determine embryonic development and, ultimately, hatchability (Boleli et al., 2016; Abd El-Hack et al., 2022).

Table 3. Temperature and Relative Humidity during Incubation (mean ± SD)

Phase and parameter	T0 (conventional)	T1 (automatic)
Setter – temperature (°C)	37.6 ± 0.9	37.48 ± 0.12
Setter – relative humidity (%)	58.4 ± 7.6	61.8 ± 1.9
Hatcher – temperature (°C)	37.3 ± 1.0	37.02 ± 0.15
Hatcher – relative humidity (%)	63.5 ± 8.2	71.6 ± 2.3

2. Hatching Performance of Cihateup Duck Eggs

The hatching performance of the Cihateup duck eggs is presented in Table 4. Fertility did not differ significantly between treatments ($P > 0.05$), which was expected because fertility is determined by the breeders and egg handling before incubation. The automatic incubator increased the hatchability of fertile eggs from 64.5% to 81.3% ($P < 0.05$) and reduced total embryonic mortality from 35.5% to 18.7% ($P < 0.05$).

Table 4. Hatching Performance of Cihateup Duck Eggs in Conventional and Automatic Incubation

Parameter	T0 (conventional)	T1 (automatic)	P-value
Fertility (%)	86.8	87.6	0.78
Early embryonic mortality (%)	12.4	10.5	0.42
Late embryonic mortality (%)	23.0	8.2	0.003
Hatchability of fertile eggs (%)	64.5	81.3	0.004
Hatchability of total eggs (%)	56.0	71.2	0.006
DOD weight (g)	42.6	43.4	0.12
Relative hatch weight (%)	65.7	66.7	0.09

The difference in hatchability can be attributed mainly to the stability of the incubation environment and the regularity of egg turning. Oliveira et al. (2020) found that reducing the turning frequency increased early embryonic mortality from 2.84% to 14.31% and late embryonic mortality from 3.57% to 8.05%. In duck eggs, different turning techniques did not affect hatchability as long as the eggs were turned regularly (Subagja et al., 2024), whereas in waterfowl eggs a wider turning angle reduced late embryonic mortality (Guo et al., 2021). Embryonic mortality differed between treatments mainly in the late phase of incubation (23.0% vs 8.2%), whereas early embryonic mortality was similar (12.4% vs 10.5%; $P > 0.05$). Early embryonic death is largely associated with factors acting before or at the start of incubation, such as breeder age and egg storage (Christensen, 2001; Elibol et al., 2002), and in duck eggs prolonged pre-incubation storage has been shown to increase early embryonic death (Sankaralingam et al., 2023). Because all eggs came from the same flock and were stored under the same conditions, a similar early mortality between treatments was expected. In contrast, late embryonic death is more sensitive to the incubation environment. From mid-incubation onwards, embryonic heat production raises embryo temperature above the incubator air temperature, and large eggs dissipate this heat less efficiently (French, 1997; Molenaar et al., 2010).

An incubator without automatic control is therefore prone to overheating in the second half of incubation, consistent with the temperature in T0 reaching 39.1 °C (Table 3). Furthermore, the relative humidity in the T0 hatcher (63.5%) was below the target of approximately 72%. In Pekin duck eggs, relative humidity during the second half of incubation affects egg weight loss, embryonic mortality and hatchability of fertile eggs (El-Hanoun et al., 2012). Turning may also have contributed: eggs in T0 were turned only three times per day manually, compared with six times per day automatically in T1. Turning during incubation affects albumen utilisation and embryo growth (Tona et al., 2005), and insufficient turning increases the incidence of malpositioned embryos (Elibol & Brake, 2006). Taken together, these results suggest that the main advantage of the automatic incubator lies in its ability to maintain stable temperature and humidity and regular turning during the critical late phase of incubation. The hatchability of fertile eggs in T1 can also be compared with that of Pekin duck eggs incubated under controlled conditions, which ranged from 79.5% to 89.5% depending on egg weight (Boğa Kuru et al., 2023).

Egg quality and pre-incubation factors also influence the results (Abd El-Hack et al., 2019). In Pekin ducks, heavy eggs showed lower hatchability of fertile eggs and higher early embryonic mortality than light and medium eggs (Ipek & Sozcu, 2017; Boğa Kuru et al., 2023), and egg weight itself is affected by breeder age (Onbaşilar et al., 2014). In this study, egg weight was kept within a narrow range for both treatments, so that differences in hatching performance could be attributed to the incubation method. Egg weight was positively correlated with hatching weight ($r = 0.586$), whereas the shape index was not significantly correlated with hatching weight (Boğa Kuru et al., 2023). In the present study, DOD weight did not differ significantly between treatments (42.6 vs 43.4 g; $P > 0.05$), nor did relative hatch weight (65.7 vs 66.7%; $P > 0.05$). Because hatching weight is largely determined by egg weight, and only eggs weighing 60–70 g were set, the similar egg weight in both

treatments (64.8 vs 65.1 g) would be expected to result in a similar DOD weight. The numerically higher DOD weight and relative hatch weight in T1 may reflect the more stable humidity in the automatic incubator, as appropriate incubation humidity has been associated with a greater duckling weight at hatching in Pekin ducks (El-Hanoun et al., 2012). However, this difference was not statistically significant, indicating that the main benefit of the automatic incubator was an increase in the number of ducklings hatched rather than in their individual weight. Furthermore, candling with the built-in lamp allowed infertile eggs to be removed early, which is important because infertile eggs may deteriorate during incubation and release harmful gases that contaminate fertile eggs (Zhou et al., 2023).

For smallholder farmers, the main practical benefits of the incubator are remote monitoring through a smartphone, automatic egg turning that reduces labour, and a larger egg capacity than natural incubation (Sugara et al., 2023; Prabowo et al., 2024). Its adoption, however, requires training, because skill-based training has been shown to increase farmers' knowledge and the adoption of recommended poultry practices (Sharma et al., 2024). The incubator depends on a stable electricity supply and a Wi-Fi network; a battery backup or solar panel can be added to reduce the risk of hatching failure during power outages (Peprah et al., 2022; Mutaqim et al., 2024).

D. CONCLUSIONS

The Android-controlled automatic incubator designed in this study was technically reliable, with a sensor error of 1.2% for temperature and 3.8% for relative humidity, and it maintained stable incubation conditions that could be monitored and controlled remotely. Compared with conventional incubation, the automatic incubator significantly increased the hatchability of fertile Cihateup duck eggs from 64.5% to 81.3% and reduced embryonic mortality from 35.5% to 18.7%. The improvement was mainly due to a reduction in late embryonic mortality, whereas DOD weight was not affected. The incubator can therefore be recommended as an appropriate hatching technology for smallholder Cihateup duck farmers, although further testing under field conditions with several hatching batches and an evaluation of its operating cost is suggested.

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