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Precision Livestock Farming (PLF) in Laying Quail Farming: Monitoring Environmental Conditions

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Abstract.
In poultry farming, Precision Livestock Farming (PLF) has presented a strong positive impact, helping producers manage, monitor and control both poultry and egg production operations. Furthermore, PLF can solve problems that affect the welfare of birds and/or provide early warning of such problems, allowing producers to take action in the early stages. In this context, sensors can be used to monitor and control environmental parameters that directly affect the welfare of birds and, consequently, their productive capacity. The objective of this study was to develop and implement a prototype embedded system for monitoring temperature, relative humidity (RH), light intensity and feed consumption in a Japanese quail (Coturnix japonica) breeding nursery. A brooder house made of wood and hexagonal wire mesh measuring 1.0 m x 0.6 m x 0.6 m (length x depth x height) was used. The floor was raised off the ground and presented a slope to facilitate the collection of eggs in a tray. Nine Japanese quails, aged 30 days, were housed. Commercial feed and fresh water were provided daily and placed in a trough-type feeder and drinker. The environmental parameters of the aviary were monitored using embedded systems composed of ESP32 microcontrollers and sensors (a) DHT11, for monitoring temperature and relative humidity (RH); (b) BH1750, for monitoring light intensity; and (c) a 1 kg load cell in conjunction with an HX711 amplifier converter for monitoring daily feed consumption. The Arduino Integrated Development Environment (IDE) and available library codes (DHT11, BH1750, HX711, Wifi.h, SPIFFS and Wire) were used with the necessary adjustments. The DHT11 and BH1750 sensors were calibrated using linear regression, obtaining R^2 = 0.9619; 0.9617 and 0.9939 for temperature, RH, and light intensity, respectively. The load cell and HX711 amplifier set was calibrated using the tool available in the code itself. The circuits were powered by 1400 mAh batteries. The data were collected by the sensors every 15 minutes and then sent via Wi-Fi to the Google Sheets, which served as the database. The DHT11 and BH1750 sensor circuits were housed in 3D-printed cases specially designed for this purpose. The trough-type feeder was installed above the load cell on a fixed wooden surface structure adjacent to the poultry house's wire mesh. The poultry house was monitored over a period of 21 days. The algorithms implemented not only maintained network connectivity but also optimized battery power consumption, allowing the prototypes to operate independently from the electrical grid and

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enabling remote monitoring, consultation, and analysis of the collected data in real time. The prototypes demonstrated technical and economic feasibility for the implementation of a PLF system in quail farming. For future work, we intend to automate the control of the monitored variables and evaluate the impacts of automation on the management of laying quails in comparison to traditional management.

Keywords.
Intelligent farm, quail welfare, ESP32, remote monitoring.

Introduction

The application of process engineering principles and techniques to livestock farming to automatically monitor, model and manage animal production is called precision livestock farming (PLF). In poultry farming, PLF has emerged as a promising approach to improve efficiency, sustainability and animal welfare, especially due to the difficulty of individually controlling animals, since birds are, usually, raised in large numbers. In addition, PLF can provide early warning of issues occurring within the poultry house, allowing producers to act in the initial stages (Tullo et al. 2017; Li et al. 2020). By integrating sensors, one can continuously monitor and control environmental parameters and feeding, that directly affect the welfare of birds and, consequently, their productive capacity (Choukidar and Dawande 2017).

In Brazil, quail farming has gained ground in the national poultry industry owing to: (1) the high productivity of laying quails; (2) the growing demand for quail eggs and (3) lower investment in the production system when compared to other birds (Macêdo 2019). According to Grieser et al. (2024), Brazil ranks fifth in the world as a producer of quail meat and second in terms of egg production. In 2023, the quail population in Brazil exceeded 15 million birds, according to data from the Brazilian Institute of Geography and Statistics (IBGE). During the same period, egg production reached 250.3 million dozen, generating approximately R$ 577.5 million (IBGE 2023).

As with other animal production systems, in in quail farming, environmental variables (such as temperature, humidity, and light intensity) can act as limiting factor for animal performance, behavior and overall productivity. Moreover, feed intake is a key indicator of animal health and production efficiency, being directly influenced by environmental conditions (Castro et al. 2017; Muniz et al. 2015).

A significant portion of the studies available in the literature on automation in the poultry sector focuses primarily on the egg production chain, particularly incubators and hatchery systems (Perlin et al. 2019; Ashish 2017; Symon et al. 2017; Sanjaya et al. 2018; Tchimmoue et al. 2016). Despite the growing adoption of automation technologies in poultry farming, there is still a lack of studies specifically addressing quail production. Moreover, limited attention has been given to monitoring systems aimed at assessing animal welfare and environmental conditions in real time.

Therefore, this study proposes the development and evaluation of embedded systems for environmental (temperature, RH and light intensity) and feeding monitoring, aiming to provide real-time and remote access to those relevant data on the management of Japanese quail (Coturnix japonica) and intends to contribute to the modernization of quail farming by providing data on the technical feasibility of implementing a precision livestock farming system in this sector.

Development of the monitoring system for quail farming

The development of the monitoring system followed the steps: a) design of the circuits on a laboratory bench; b) adjustments of the libraries available in the IDE for each circuit; c) sensors calibration; d) adaptation of the codes for publication of the calibrated measurement; e) installation and testing of the circuits in the poultry house; f) directing the quails to the poultry house; g) parameter’s monitoring (21 days).

Three embedded systems (called Circuit 1, Circuit 2 and Circuit 3), composed of ESP32 microcontrollers and specifics sensors were assembled for the measurement and monitoring of distinct parameters each. The calibration process for the sensors used in the circuits will be described below. The Arduino Integrated Development Environment (IDE) and available library codes (DHT11; BH1750; HX711; Wifi.h; SPIFFS; Wire) were used with the necessary adjustments.

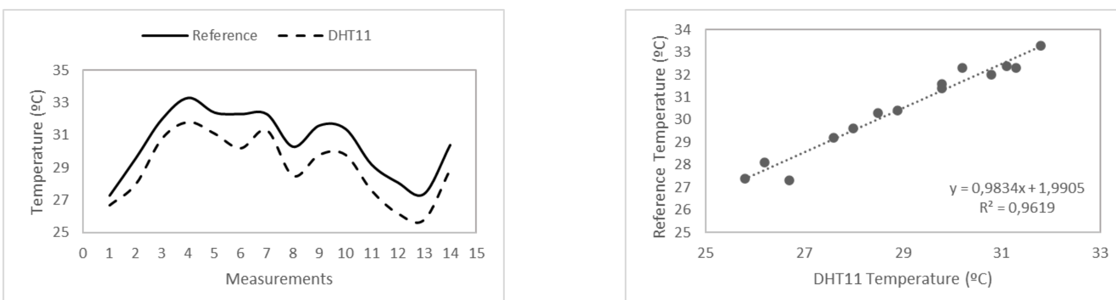
Sensor's calibration

Circuit 1: Temperature and relative humidity (RH) monitoring system

For the temperature and RH monitoring, the circuit was assembled on a breadboard using a DHT11 whit integrated module. The sensor was connected to the microcontroller such that the VCC pin was connected to the 3.3 V output, the DATA pin to GPIO 4, and the GND pin to the ground of the circuit.

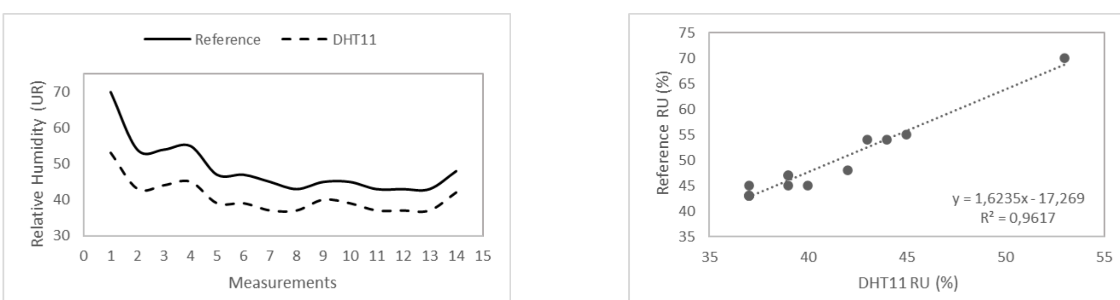
Prior to the final circuit assembly, the sensor calibration was performed against a digital incubator thermo-hygrometer. Fourteen measurements were carried out, with a one-hour interval between each reading (Wardani et al. 2023), ensuring different times of the day and varying climatic conditions. The data measured by the DHT11 sensor were sent to the Blynk IoT platform while YawCam software was used for monitoring and recording the thermo-hygrometer measured values. The calibration was performed (a) analyzing the data that were measured by the sensor with the thermos-hygrometer comparison using linear regression method, using the coefficient of determination (R^2) and the root mean square error (RMSE) and (b) implementing the obtained regression equation (calibration curve) in the microcontroller code to correct the measurements.

The DHT11 temperature calibration data are presented in Figure 1 a and b. While the DHT11 RH are presented in Figure 2 a and b.



(a) (b)

Fig. 1 DHT11 sensor calibration for temperature using linear regression: (a) comparison between reference data and sensor measurements; (b) equation of the fitted linear model and coefficient of determination (R^2)



(a) (b)

Fig. 2 DHT11 sensor calibration for RH using linear regression: (a) comparison between reference data and sensor measurements; (b) equation of the fitted linear model and coefficient of determination (R^2)

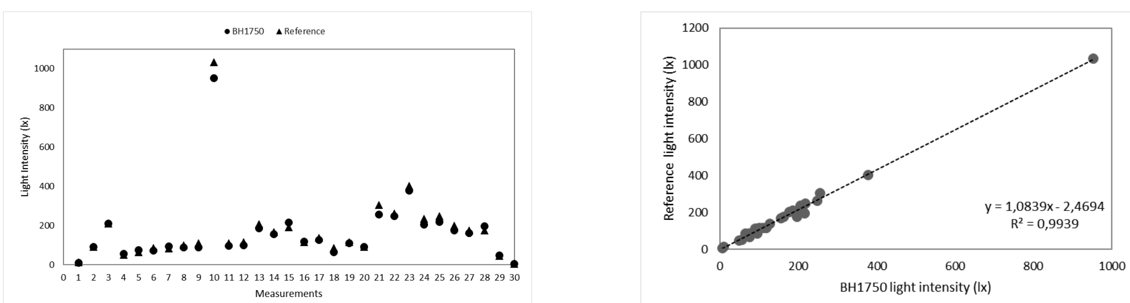
For temperature analysis, the coefficient of determination (R^2) obtained from the linear regression was 0.9619, indicating a strong linear relationship between the sensor measurements and the reference values. This result, combined with the RMSE of 1.6 °C, demonstrates that the sensor is capable of accurately tracking temperature variations for the intended application. Variations of this magnitude are consistent with those reported in the literature for similar sensors under real operating conditions (Yuliana 2023) and do not compromise the system's performance for the intended application.

A similar behavior was observed for relative humidity: coefficient of determination (R^2) of 0.9617, with a strong correlation between the sensor and reference measurements. Nevertheless, a higher RMSE value was obtained (8.6%), indicating larger deviations compared to temperature measurements. The typical accuracy of ±5% is reported in the manufacturer's datasheet for the DHT11 sensor (Aosong Electronics 2026). Again, this deviation is expected under field conditions (Yuliana 2023) and remains acceptable for the intended application.

Circuit 2: Light intensity monitoring system

For light intensity measurement and monitoring, the circuit was assembled on a breadboard using a BH1750 light sensor. The sensor was connected to the microcontroller in such a way that the VCC pin was connected to the 3.3 V output, the SCL pin to GPIO 22, the SDA pin to GPIO 21, and the GND pin to the ground wire of the circuit.

The BH1750 light sensor was calibrated using a digital lux meter (ICEL, model LD-545) as a reference. The calibration was performed by directly comparing the values measured by the sensor and the reference instrument. Both BH1750 and lux meter were set up outdoors, in an open area, and positioned side by side with parallel height. Measurements were taken every 15 minutes across different periods of the day, including early morning (05:45 a.m. to 08:00 a.m.) intermediate period (10:00 a.m. to 12:15 p.m.) and late afternoon (04:00 p.m to 06:15 p.m.), allowing analysis of the variation in light intensity under different conditions throughout the day (Shiddiqy and Sunardi 2024). Data measured by the BH1750 sensor were automatically sent to the Blynk IoT platform while the lux meter readings were recorded manually. The BH1750 sensor calibration was carried out the same way as it was for DHT11 sensor. The BH1750 sensor calibration data are presented in Figure 3 a and b.



(a) (b)

Fig. 3 BH1750 sensor calibration for temperature using linear regression: (a) comparison between reference data and sensor measurements; (b) equation of the fitted linear model and coefficient of determination (R^2)

The BH1750 sensor exhibited a coefficient of determination (R^2) of 0.9939, indicating an excellent linear relationship with the reference measurements. The RMSE value obtained of 22.9 lux is considered low relative to typical environmental external illumination levels, demonstrating the sensor's, and therefore, Circuit's 2 suitability for accurate light intensity monitoring.

Circuit 3: Feed consumption

For feed consumption measurement and monitoring, a one-kilogram (1 kg) single point load cell and an HX711 amplifier were used. This particular circuit was not implemented on a breadboard due to reliability considerations. Instead, all electrical connections were made through soldering to ensure greater mechanical stability and signal integrity.

The load cell was mounted using a fixed–free configuration using a wooden support structure that was fixed to the external side of the poultry house, in close proximity to the wire mesh. This arrangement would prevent the quails from climbing onto the trough-type feeder while still allowing their access to the feed.

The lower end of the load cell was rigidly attached to a wooden base, using screws, ensuring mechanical stability. The upper end (the sensing platform) was connected to the trough-type feeder, also fixed with screws, where the load (feed) was applied. This arrangement allows the load cell to deform properly under applied weight, ensuring accurate measurement of mass. The ESP32 board and the HX711 amplifier module were installed beneath the wooden base and housed within a plastic electrical enclosure, ensuring proper organization and protection against environmental factors.

After the full assembly of the system and the soldering of all electrical connections, ensuring mechanical and electrical stability, its calibration was performed.

For the system calibration, an adapted version of the calibration code from the HX711 library by Rob Tillaart, available in the Arduino IDE, was used. Initially, the scale.read() function was employed to obtain the raw electrical signal generated by the force applied to the load cell, aiming to measure exclusively the signal corresponding to the feeder positioned on it. Subsequently, the resulting code, adapted to the system requirements, was uploaded to the ESP32 microcontroller to perform signal sampling and to display the values through the Serial Monitor. The value corresponding to the feeder signal was then recorded.

After that, a known mass of 10 grams was added to the feeder in order to obtain the signal corresponding to the feeder plus the known mass, and this value was also recorded. Then, the difference between the signal obtained from the feeder with the known mass and the signal from the feeder alone was calculated. The resulting value corresponds to the calibration factor. Finally, using the scale.get_units() function from the library, together with the applied calibration factor, tests were performed with other known masses to verify the effectiveness of the calibration. The values displayed on the IDE Serial Monitor were consistent with the actual masses, indicating that the calibration was successful and the system was thus ready for operation.

Monitoring system Integration and Physical Implementation

After the calibration of the sensors, batteries (1400 mAh each) were added to the circuits so that they would be independent of electrical power via wire.

Data publication was achieved by creating a script in Google Sheets, where a URL was created to receive the sensor values. In the Arduino IDE, the HTTPClient.h library was used to make HTTP requests and send data to the URL created in the App Script. To ensure the reliability of the published data, the SPIFFS.h library was used to locally store data not published due to potential internet network instabilities. As a final implementation to the codes, fifteen-minute intervals were defined between readings, thus the deep sleep feature was employed, using the esp_sleep.h library.

A 3D printer (Sermoon D1, Creality 3D) equipped with 1.75 mm white PETG filament was used to obtain the protective housing for Circuit 1 and Circuit 2. An open-source project available on GitHub (Crocker-White, 2020) was used for 3D printing the Circuit’s 1 case while for Circuit 2 the case was created using a 3D computer-aided design (CAD) platform. The case was equipped with a light diffuser with the aim of reducing variations caused by direct light incidence and promoting a more uniform distribution of illumination over the sensor.

Following the installation of the Circuit 1 and Circuit 2 within their enclosures, the devices were coupled to the poultry house, both at upper central region, in order to better represent the average environmental conditions, the installation of Circuit 3 has been presented before since it was needed to be performed for calibration stage.

For quail's housing, a poultry house built of wood and hexagonal wire mesh measuring 1.0 m x 0.6 m x 0.6 m (length x depth x height) was used. The floor was raised off the ground and presented a slope to facilitate the collection of eggs in a tray.

Nine Japanese quails (Coturnix japonica), after 30 days of age, were housed. Commercial feed and fresh water were provided daily and placed in a trough-type feeder and drinker.

Figure 4 illustrates the arrangement of the poultry house as well as the placement of the electronic circuits in the experimental setup.

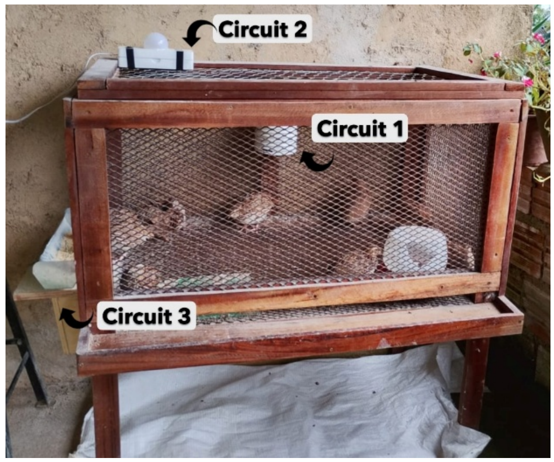


Fig. 4 Experimental setup showing the cage structure and the positioning of the electronic circuits

The experiment (monitoring) ran for 21 consecutive days. During this period, the values measured by the sensors could be remotely accessed and verified at any time using the spreadsheets hosted on Google Sheets.

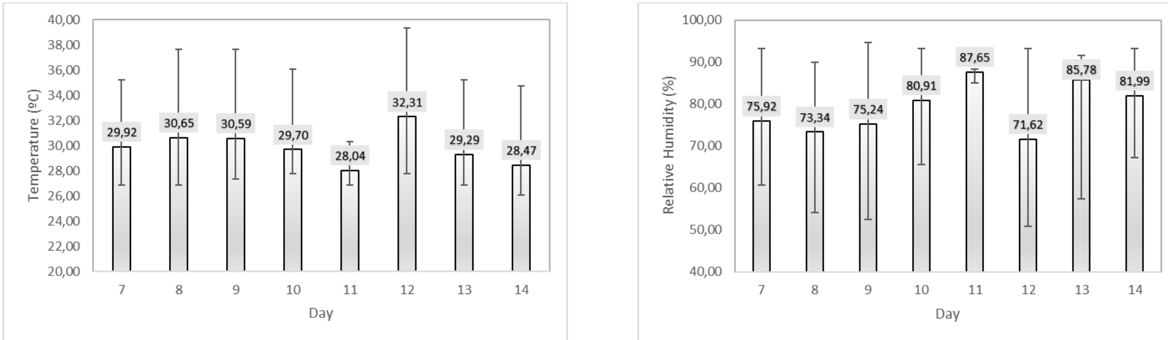
Proposed monitoring system: results and evaluation

After the monitoring period, the data published in Google Sheets were analyzed. Although data were collected continuously over the 21 days at 15-minute intervals, only a representative period is shown for clarity. Thereby the data from days 7 to 14 are shown for visualization purposes, as they represent a central and stable period of the experiment. It is important to highlight that similar patterns were observed throughout the entire monitoring period and the full dataset was used for analysis, including mean, minimum and maximum values.

Circuit 1: Temperature and relative humidity (RH) collected data

Figure 5 presents the bar chart of average (a) temperatures and (b) relative humidity (RH), with error bars indicating the minimum and maximum values. This variation between minimum and maximum values can be attributed to the larger fluctuations occurring during the day and may be influenced by external factors such as solar radiation and ambient temperature changes.

According to Castro et al. (2017) and Muniz et al. (2015), the ideal ambient air temperature (thermal comfort zone - TCZ) for laying quail ranges between 18 and 22 ºC and the RH between 60 and 70%. Thus, both the average temperature and RH observed during the experiment were higher than that indicated in the literature. Although the poultry house was maintained under shaded conditions in a covered area, the noticed values indicate that additional measures are needed to improve thermal conditions inside it for the quails, which is relevant information for the farmer.

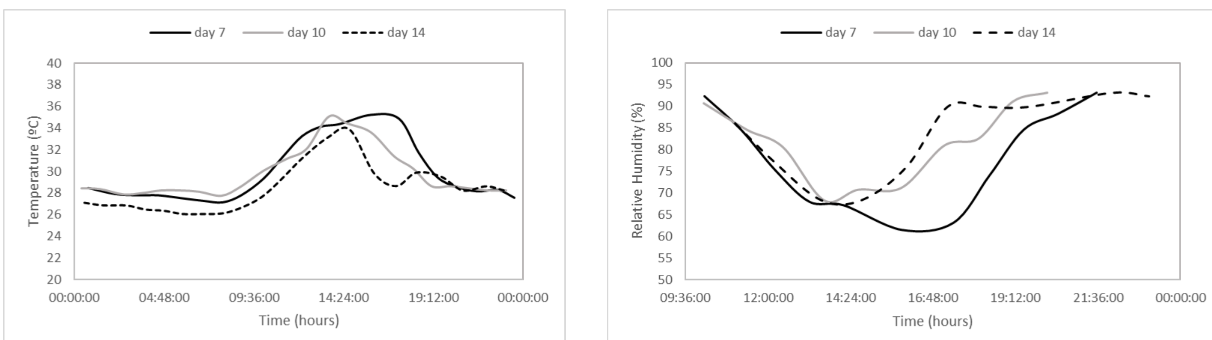


(a) (b)

Fig. 5 Average (a) temperature and (b) RH values over days 7 to 14

A similar trend can be observed for both temperature and relative humidity variation between minimum and maximum values, i. e., larger temperature variations corresponding to larger variations in relative humidity. Indeed, it can be well noted that, on day 11, there was little variation in both temperature and, therefore, relative humidity, indicating consistent measurements and suggesting reliable sensor performance during the experiment period.

Figure 6 shows the (a) temperatures and (b) relative humidity (RH), variation (time series) over days 7, 10 and 14. The data are plotted as separate lines to enhance clarity, making it easier to observe the consistent daily parameters behavior.



(a) (b)

Fig. 6 Time series of (a) temperature and (b) RH over days 7, 10 and 14

The results presented in Figure 6 show a clear daily profile in temperature and RH variation. While temperature increases during the daytime (reaching its maximum value around midday), and decreases at night, the opposite is observed for relative humidity, following expected environmental conditions. Moreover, the similar behavior for the 3 curves from the same parameter, indicates good repeatability, suggesting that the Circuit 1 performed consistently and reliably, for temperature and RH monitoring throughout the experiment period.

It must be highlighted however, that although the Circuit 1 performed adequately during daytime conditions, the relative humidity data recorded at night (when humidity levels are higher) showed lower reliability, possibly due to reduced sensor accuracy under high humidity conditions. Therefore, the time series analysis was restricted to the period between 09:00 a.m. and 10:00 p.m.

The DHT11 sensor presents manufacturer-specified accuracy of approximately ±2 ºC for temperature and ±5% for RH, which introduces uncertainty in the recorded measurements (Amadi and Jaja, 2026). In this study, the temperature data showed consistent and repeatable patterns over the monitored days, indicating a stable performance of Circuit 1 throughout the entire period of a day (24 hours). However, for relative humidity, a reduction in data reliability was observed especially during nighttime periods, when humidity levels were higher.

Amadi and Jaja (2026) demonstrated that the DHT11 sensor presents acceptable performance for RH measurements but the authors worked under controlled conditions with humidity levels between 50% and 70%. In the present study, the environmental conditions of the Amazon region, where the experiment data took place and where humidity levels are typically elevated, should be taken into consideration, principally during the rainy season in January. Under these conditions, RH frequently approaches the upper operating limits of the DHT11 sensor, which may compromise its accuracy.

Despite this limitation, DHT11 sensor proved to be adequate for monitoring general environmental trends inside the poultry house, especially for identifying daily patterns of temperature and humidity variation. Therefore, the Circuit 1 can be considered suitable for practical monitoring applications, although it is not intended for high-precision measurements.

Circuit 2: Light intensity collected data

Due to the high variability of light intensity throughout the day, with values ranging from near zero at night to peak values during daylight, the analysis approach using bar charts with minimum and maximum error bars was not adopted and instead, only time series plots (Figure 7) were presented to better illustrate the temporal evolution of light intensity.

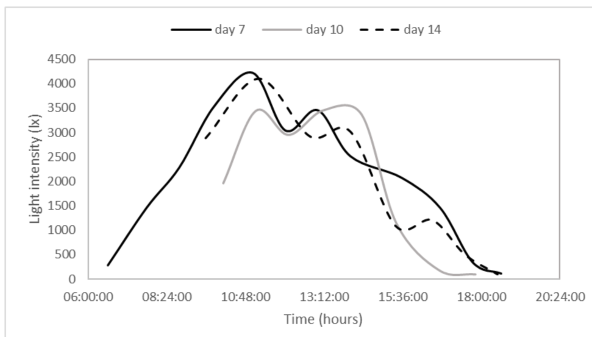


Fig. 7 Time series of light intensity over days 7, 10 and 14

According to Molino (2013), light represents one of the most relevant factors for birds (both wild and domestic) as it directly affects hormonal production and, consequently, egg production. Recommendations for light regimes for laying hens are based on international studies. For quails in the laying phase, exposure of 18 to 24 hours of light is recommended to improve productivity (Muniz et al. 2015). From Figure 7 it can be observed that the quails were exposed, during the experiment period, to an average time of 12 hours of luminosity per day. Such luminosity was due to sunlight and so, in this case, to maximize egg laying, artificial lighting must be introduced. Therefore, monitoring light intensity plays an important role in elucidating its effects on both egg productivity and quality in poultry production systems.

Regarding to BH1750 sensor, the data collected are consistent with the natural daily solar cycle, suggesting that the sensor adequately captured the temporal variation of ambient light conditions. Additionally, the similarity between the curves, even for non-consecutive days, reinforces the stability of the monitored environment and the reliability of the Circuit 2.

It can be noted from Figure 7 that, for all days, the data are available until around 7:00 p.m. and while data for day 7 are available from approximately 6:00 a.m., measurements for days 10 and 14 begin only around 9:00 a.m. During periods of low light intensity, the sensor exhibited inconsistent or unreliable readings, indicating reduced reliability under near-dark conditions. As a result, these data were excluded from the analysis to ensure the quality and consistency of the results.

This behavior can be associated with inherent limitations of the BH1750 sensor under low illuminance conditions. Although the sensor is designed for measuring ambient light in lux, its performance tends to degrade near its lower detection limit, where signal levels are very low and more susceptible to noise. Similar limitations have been reported for low-cost light sensors, which generally present reduced accuracy and higher variability under low light intensity conditions (Hidayat and Broto 2025; Beyaz and Gül 2022).

Even with the limitations presented by the BH1750 sensor, Circuit 2 proved to be a suitable and reliable low-cost alternative for monitoring light intensity as it is a useful tool for estimating the duration of light exposure into the quail's poultry house, supporting decisions regarding the need for artificial lighting.

Circuit 3: Feed consumption collected data

Figure 8 presents the temporal variation of feed mass over the three chosen representative days. It could be observed a general decreasing trend throughout the day, corresponding to the feed consumption by the quails. In specific times, it can be noticed a sudden increases in mass value, which is associated with feed replenishment events, and after it a gradual decrease. Additionally, small fluctuations in the values were detected, that can be associated to quail interaction with the feeder, noises or system sensitivity. Besides these variations, the overall behavior remained consistent, allowing the identification of feeding patterns over time.

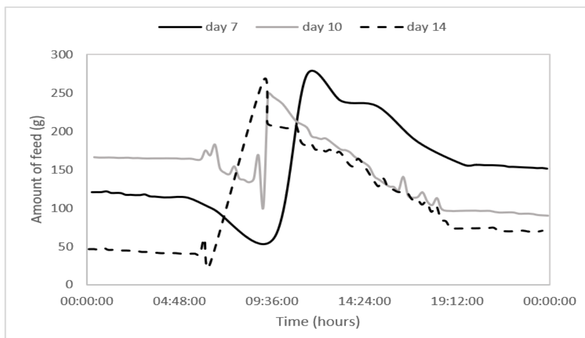


Fig. 8 Time series of feed consumption over days 7, 10 and 14

From Figure 8 it can be observed that at the end of the day, a residual mass of approximately 50 grams remained in the feeder. This may indicate that the amount of feed supplied slightly exceeds the quail's daily consumption. However, it is important to highlight that, this residual mass may also be associated with feed fragments, accessibility limitations and/or measurement uncertainties at low mass values. Thus, although the observed values suggest a potential for optimizing feed supply, further evaluation is required to ensure that any reduction does not negatively impact animal welfare or productivity.

From the analysis of the temporal variation of feed mass, it is possible to identify periods of higher consumption based on the slope of the curves. A more pronounced decrease in mass was observed between approximately 10:00 a.m. and 2:00 p.m., indicating higher feeding activity during this interval. In contrast, minimal variations were observed during early morning and late afternoon periods, suggesting reduced feed intake. This pattern is consistent with the natural behavior of quails, potentially influenced by environmental factors such as light intensity and temperature, which tend to be more active during daylight hours.

The present study is in agreement with the literature which states that the use of a load cell coupled with the HX711 amplifier enables accurate and continuous mass monitoring, as the module amplifies low-level signals and provides high-resolution digital conversion, making it suitable for real-time applications in monitoring systems (Ayoola et al. 2018).

Conclusion

The Circuit 1 (ESP32 + DHT11 sensor) was found to be a viable low-cost solution for environmental monitoring, despite its reduced stability under high relative humidity conditions, which should be considered in its application. Future improvements may consider the use of higher-accuracy sensors, such as the DHT22, considering the sensor’s application in the Amazon region (right relative humidity).

The Circuit 2 (ESP32 + BH1750 sensor) was verified to be effective in capturing the daily variation of light intensity, particularly under moderate to high illumination conditions. Although limitations were observed under low-light environments, the sensor remains a useful tool for estimating the duration of light exposure and may support decision-making related to the implementation of artificial lighting.

The Circuit 3 (Load Cell + HX711 amplifier) was capable of capturing both consumption dynamics and management events, providing valuable insights into feeding behavior.

The developed systems were shown to be a viable alternative for fast and remote access to information related to both environmental conditions and animals’ feed intake. Based on these data, it is possible to establish relationships between monitored variables and support decision-making, in line with the principles of Precision Livestock Farming (PLF). Furthermore, this initial study is of great importance for guiding the development of improved and more refined versions of these systems.

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