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APPLICATIONS OF FUZZY LOGIC, SENSING, AND IOT TECHNOLOGIES IN THE MONITORING OF ENVIRONMENTAL CONDITIONS IN LAYER POULTRY HOUSES: A SCOPING REVIEW

APLICAÇÕES DA LÓGICA FUZZY, SENSORIAMENTO E TECNOLOGIAS IOT NO MONITORAMENTO DA AMBIÊNCIA EM AVIÁRIOS DE POSTURA: UMA REVISÃO DE ESCOPO

APLICACIONES DE LA LÓGICA DIFUSA, EL SENSADO Y LAS TECNOLOGÍAS IOT EN EL MONITOREO DEL AMBIENTE EN GALLINEROS DE POSTURA: UNA REVISIÓN DE ALCANCE

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ABSTRACT

Given the relevance of layer poultry farming to Brazilian agribusiness and the need to ensure adequate environmental conditions for bird welfare and productive performance, it is pertinent to investigate how technologies and intelligent models have been applied to the housing environment of poultry facilities. This study aims to identify, map, and characterize research that integrates, individually or in combination, fuzzy logic, environmental sensing, and IoT technologies in the monitoring of the environment in layer poultry houses. A scoping review was conducted according to JBI methodology and PRISMA-ScR guidelines, including database searches, rigorous study selection, and data extraction. A total of 52 studies published between 2020 and 2025 were included. Most research was carried out in Indonesia and China, with a predominance of field studies. Temperature and humidity were the most frequently monitored variables, whereas gas measurements appeared less frequently. Low-cost sensors from the DHT and MQ families and hardware platforms such as ESP and Arduino were predominantly employed. Fuzzy logic was the main artificial intelligence technique identified, although many systems operated without intelligent models. Most proposals were integrated with cloud-based solutions, but few employed long-range wireless networks. The review also identified many studies focused on broiler chickens, limited adoption of environmental classification, and an almost complete absence of validation using recognized environmental indices. It is concluded that, despite the technological advances observed, important gaps remain regarding environmental classification and validation, the use of artificial intelligence, gas monitoring, long-range communication, and the development of solutions specifically tailored to layer poultry houses.

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Keywords: Fuzzy Logic. Animal Environment. Internet of Things (IoT). Layer Poultry Farming. Environmental Sensing.

RESUMO
Considerando a relevância da avicultura de postura para o agronegócio brasileiro e a necessidade de assegurar condições ambientais adequadas ao bem-estar e ao desempenho produtivo das aves, torna-se pertinente investigar como tecnologias e modelos inteligentes têm sido aplicados na ambiência de aviários. O objetivo deste estudo é identificar, mapear e caracterizar pesquisas que integrem, de forma isolada ou combinada, lógica fuzzy, sensoriamento ambiental e tecnologias IoT no monitoramento da ambiência em aviários de postura. Para tanto, realizou-se uma revisão de escopo conforme metodologias do JBI e PRISMA-ScR, com buscas em bases científicas, seleção criteriosa e extração de dados. Foram incluídos 52 estudos publicados entre 2020 e 2025. Observou-se predominância de pesquisas conduzidas na Indonésia e na China, com maior ocorrência de estudos de campo. Temperatura e umidade foram as variáveis mais monitoradas, enquanto a medição de gases apareceu em menor escala. Sensores de baixo custo das séries DHT e MQ e plataformas como ESP e Arduino foram majoritariamente empregados. A lógica fuzzy foi a técnica de inteligência artificial predominante, embora muitos sistemas tenham operado sem modelos inteligentes. A maioria das propostas integrou-se à nuvem, mas poucas utilizaram redes sem fio de longa distância. Identificaram-se ainda muitos estudos para frangos de corte, baixa adoção de classificação ambiental e quase inexistência de validação por índices reconhecidos. Conclui-se que, apesar dos avanços tecnológicos observados, persistem lacunas relacionadas à classificação e validação ambiental, uso de inteligência artificial, monitoramento de gases, comunicação de longo alcance e desenvolvimento de soluções específicas para aviários de postura.

Palavras-chave: Lógica Fuzzy. Ambiência Animal. Internet das Coisas (IoT). Avicultura de Postura. Sensoriamento Ambiental.

RESUMEN
Considerando la relevancia de la avicultura de postura para el agronegocio brasileño y la necesidad de asegurar condiciones ambientales adecuadas para el bienestar y el desempeño productivo de las aves, resulta pertinente investigar cómo las tecnologías y los modelos inteligentes se han aplicado a la ambiencia de los aviarios. El objetivo de este estudio es identificar, mapear y caracterizar investigaciones que integren, de forma aislada o combinada, lógica difusa, sensoriamento ambiental y tecnologías IoT en el monitoreo de la ambiencia en aviarios de postura. Para ello, se llevó a cabo una revisión de alcance conforme a las metodologías del JBI y PRISMA-ScR, con búsquedas en bases científicas, selección rigurosa y extracción de datos. Se incluyeron 52 estudios publicados entre 2020 y 2025. Se observó predominio de investigaciones realizadas en Indonesia y China, con mayor ocurrencia de estudios de campo. La temperatura y la humedad fueron las variables más monitoreadas, mientras que la medición de gases apareció en menor escala. Sensores de bajo costo de las series DHT y MQ y plataformas como ESP y Arduino fueron empleados de forma predominante. La lógica difusa fue la principal técnica de inteligencia artificial identificada, aunque muchos sistemas funcionaron sin modelos inteligentes. La mayoría de las propuestas se integró a la nube, pero pocas utilizaron redes inalámbricas de largo alcance. Asimismo, se identificó un número elevado de estudios con pollos de engorde, baja adopción de clasificación ambiental y casi inexistente validación mediante

índices reconocidos. Se concluye que, a pesar de los avances tecnológicos observados, persisten brechas relacionadas con la clasificación y la validación ambiental, el uso de inteligencia artificial, el monitoreo de gases, la comunicación de largo alcance y el desarrollo de soluciones específicas para aviarios de postura.

Palabras clave: Lógica Difusa. Ambiencia Animal. Internet de las Cosas (IoT). Avicultura de Postura. Sensado Ambiental.

1 INTRODUCTION

Laying poultry stands out as one of the most important activities in the Brazilian livestock sector, contributing significantly to food security and the national economy. In 2024, Brazil produced 57.6 billion eggs, reaching a per capita consumption of 269 units per inhabitant, positioning itself as the fifth largest producer in the world, with a gross production value of R$ 26.1 billion (Brazilian Association of Animal Protein - ABPA, 2025). These data show the relevance of the activity and, consequently, the need to improve processes involving animal welfare and productivity.

The productive performance of the birds is strongly conditioned by the environmental variables present inside the poultry houses. According to Baêta and Souza (2010), variables such as temperature, humidity, radiation and ventilation make up the thermal environment and influence the comfort and health of birds. Situations of heat stress or poor air quality can compromise important physiological functions, affecting the growth, immune resistance and feed efficiency of laying hens. The maintenance of homeothermy, especially within the thermoneutral zone, the ideal range of ambient temperature for maximum production efficiency, is crucial to avoid production losses and ensure animal welfare (Silva, 2001).

The breeding of laying hens is divided into three distinct phases, breeding, rearing and production, each with specific requirements regarding animal welfare and the ideal environment. The recommended ranges of temperature, humidity and gas concentration vary according to the age of the birds, however the technical literature presents divergences in these values, which reinforces the need for a careful and standardized approach to environmental control (Silva; Abreu; Mazzuco, 2020).

Faced with these challenges, the use of digital and intelligent technologies in poultry farming has gained prominence. Sensors, actuators, microcontrollers, wireless networks and software have been integrated into poultry production for continuous monitoring of the environment and health of birds. In the field of artificial intelligence, fuzzy inference models have been successfully applied to deal with uncertainties and assist in data-driven decision-making, with the potential to simulate human reasoning and generate adaptive responses in real time (Simões; Shaw, 2007; Abreu, 2022).

Despite the advances achieved by these solutions, the technical-scientific literature still shows considerable heterogeneity regarding the fuzzy models employed, the monitoring technologies adopted, the environmental variables analyzed, and the ideal ranges recommended for these variables. In particular, it is verified that the use of fuzzy logic integrated with environmental sensors, data transmission by technologies such as LoRa network and cloud storage, has not yet been comprehensively mapped in poultry production, especially in laying hen aviaries. In view of this, a scoping review is necessary and appropriate to identify, map and characterize existing studies, allowing us to understand the extent and nature of scientific production on the subject, in addition to revealing opportunities for advancement in areas still under consolidation.

A preliminary search was carried out to identify existing scoping reviews and systematic reviews on the use of fuzzy logic, sensing and IoT technologies applied to the monitoring of the environment in laying hen aviaries. This search took place on August 29, 2025, using the following scientific platforms and databases: IEEE Xplore, Scopus, Science Direct, Scielo, Web of Science, CAPES Journals, and Google Scholar. No reviews were identified that addressed these elements in an integrated manner, which highlights the originality and relevance of the present proposal.

Therefore, the objective of this scoping review is to identify, map and characterize studies that integrate fuzzy logic, environmental sensors and data transmission and analysis technologies, in the monitoring of the environment in laying hen aviaries, seeking to understand how these elements have been combined in the scientific literature and what gaps still persist to support future innovations and research in the area.

2 METHODOLOGY

This scoping review was conducted according to the methodology proposed by the Joanna Briggs Institute (JBI) (Peters *et al.*, 2020), following the guidelines of the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) (Tricco *et al.*, 2018). The complete protocol of this review was previously registered in the Open Science Framework (OSF) platform, under DOI: 10.17605/OSF.IO/YQ6BG.

According to Arksey and O'Malley (2005), scoping reviews aim to comprehensively map the literature, characterizing trends and identifying gaps in broad or underexplored fields, thus offering a comprehensive view of the state of the art and guiding future research, however, they generally do not evaluate the methodological quality of the studies. Its conduction follows five stages: (1) formulation of the research question; (2) identification of relevant studies; (3) selection of studies; (4) mapping and data extraction; and (5) synthesis and presentation of the results.

As advised by the Joanna Briggs Institute, the acronym PCC (Population, Concept and Context) was used to prepare the research question. In this model, Population refers to laying hens; the Concept covers the monitoring of the environment associated with the use of fuzzy logic, environmental sensing, low-cost IoT technologies, data transmission and cloud storage; and the Context corresponds to commercial aviaries intended for laying production. Thus, the following research question was defined: What are the approaches, technologies and parameters used in studies that apply fuzzy logic and IoT technologies in monitoring the environment of laying aviaries? Additional questions were also formulated, namely: Which environmental variables (temperature, humidity, gases) are most frequently monitored? How is environmental data collected, transmitted, and processed in these studies?

The stage of identifying relevant studies was conducted comprehensively, through searches in scientific databases recognized for their academic rigor, including IEEE Xplore, Scopus, Science Direct, SciELO, Web of Science and the CAPES Journals portal, as well as gray literature, such as Google Scholar, in order to capture studies not indexed in traditional databases. The consultations were carried out on August 29, 2025, using the publication filters between 2020 and 2025 and inclusion of texts in Portuguese, English or Spanish. The search strategy was elaborated based on the elements of the acronym PCC, using descriptors combined by Boolean operators, such as: (fuzzy) AND (chickens OR laying OR hens OR broilers OR poultry house OR layer house OR poultry shed) AND (temperature OR humidity OR environmental OR conditions OR monitoring OR thermal OR comfort) AND (iot OR sensing OR sensor OR smart OR wireless OR lora OR network OR communication OR cloud OR computing OR processing). According to the specificities of each database, some terms and operators needed to be adapted, as described in the protocol of this review.

Eligibility criteria were defined to ensure the selection of studies aligned with the proposed objective. As an inclusion criterion, studies that address the monitoring of the environment in poultry houses through the use of fuzzy logic, sensing or data transmission, in isolation or in combination, were considered. In turn, the exclusion criterion included studies that do not deal with the monitoring of the environment of poultry houses with the application of fuzzy logic or sensing or data transmission technologies, as well as review articles, texts without access to full content, and duplicate publications.

Although the focus of this scoping review is the monitoring of the environment in laying aviaries, it was decided to include studies conducted in broiler systems whenever they addressed technologies, sensing methods, IoT architectures or computational models applicable to environmental control in poultry facilities. This methodological decision was adopted due to the recognized similarity of environmental requirements (temperature, humidity, gases and ventilation) between the production systems, as well as the scarcity of specific studies directed to the laying poultry industry identified during the search phase.

In the study selection stage, all records obtained in the searches carried out in the databases were imported into the free software StArt (State of the Art through Systematic Review), developed by the Software Engineering Research Laboratory at UFSCAR (LAPES, 2025), which assisted in the organization and management of the screening process. The selection took place in two phases: in the first, titles, abstracts and keywords were evaluated to verify adherence to the inclusion criteria; in the second, potentially relevant studies were analyzed in full to confirm eligibility. The entire procedure was performed by two independent researchers, and any disagreements were resolved by consensus or with the help of a third researcher.

The mapping and data extraction stage was carried out based on the included studies, using structured extraction tables prepared by the authors themselves. These tables included the following fields: author, year of publication, country of origin, study objective, methodological design (experimental, field, or case study), technologies employed (such as microcontrollers, sensors, communication networks, and cloud storage systems), monitored environmental variables (temperature, humidity, and gases), artificial intelligence techniques used (fuzzy logic, neural networks, or decision tree), actuator control, environmental classification, evaluated species (laying or beef hens) and main results observed. Data extraction was conducted independently by two researchers, and any divergences were resolved by consensus or, when necessary, with the mediation of a third evaluator.

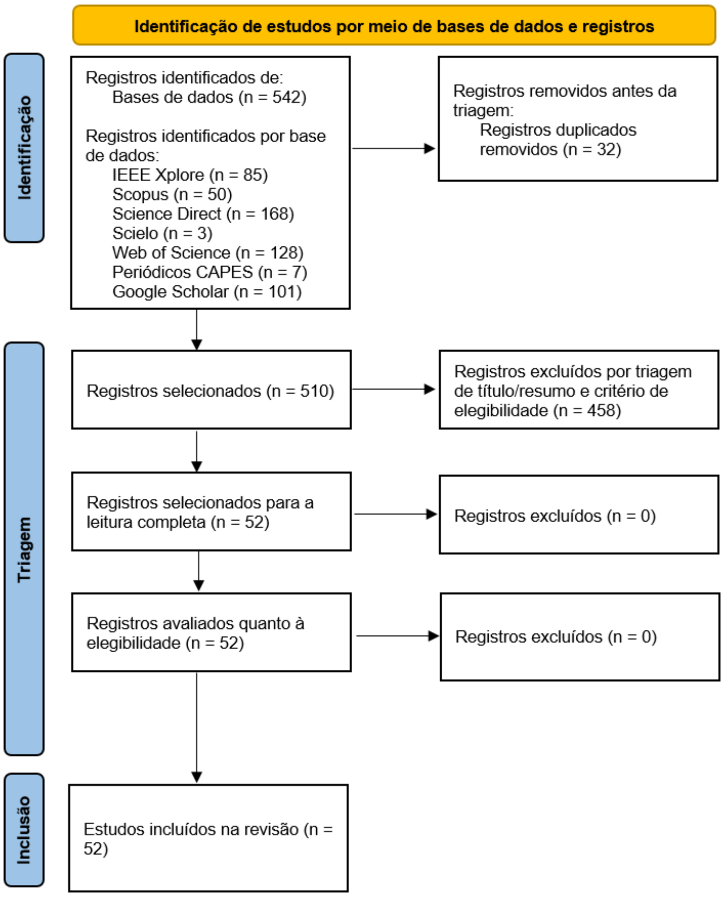
In the synthesis and presentation of the results stage, the extracted data were organized and presented in tables and Figures, in line with the objective of the review and with the established guiding questions. The descriptive analysis included the interpretation of the results, the methodological characterization of the included studies, and the identification of gaps in the scientific literature. This process involved the identification of the most monitored environmental variables, the types of sensors and IoT technologies used, the artificial intelligence techniques used, and the strategies for collecting, transmitting, and processing environmental information.

3 RESULTS

The search carried out in databases and sources of gray literature identified a total of 542 records. After the removal of 32 duplicate records, 510 studies were retained for the initial screening by title and abstract, of which 458 were excluded because they did not meet the eligibility criteria. Subsequently, 52 articles were evaluated in full, resulting in the final inclusion of 52 studies that made up the set of studies included in this review. Figure 1 presents the PRISMA-ScR flowchart, which describes in detail the process of identification, screening, eligibility and inclusion of evidence sources.

Figure 1

PRISMA-ScR flowchart of the study selection process



Source: Prepared by the authors.

Among the selected studies, it was observed that part of the research was focused on broiler chickens. Although they did not directly represent the target population of this review, these studies were maintained because they met the eligibility criteria, especially with regard to the use of fuzzy logic, sensing, and IoT technologies applied to environmental monitoring. These works contributed to broadening the understanding of the technological solutions available in the poultry sector.

Table 1 presents the general characterization of the 52 studies included, with regard to the distribution by country, most of the studies were carried out in Indonesia, with 23 studies (44.2%), followed by China, with 8 (15.4%). Brazil, India, and Morocco presented 4 studies each (7.7%). Malaysia contributed 3 studies (5.7%), while Pakistan and Bangladesh recorded 2 each (3.9%). Colombia and Cyprus appeared with only 1 study each (1.9%).

Regarding the methodological design, it was observed that most of the studies included corresponded to field studies, totaling 27 studies (51.9%). Next, experimental studies were identified, represented by 23 studies (44.3%). Only one study was classified as a case study (1.9%) and another as a modeling and simulation study (1.9%).

Regarding the databases consulted, it was found that most of the studies included were identified in Google Scholar, which gathered 36 studies (69.2%). IEEE Xplore contributed with 10 studies (19.2%), while Scopus presented 4 (7.8%) and CAPES Journals recorded 2 studies (3.8%). Studies from the Science Direct, SciELO or Web of Science databases were not selected.

Table 1

General characterization of the included articles

Author / Year / Country	Objective of the Study	Main results
Liani *et al.*, 2021 Indonesia	Monitor temperature and humidity in poultry houses using LoRaWAN and fuzzy logic to assess the thermal comfort of broiler chickens.	The system transmitted temperature and humidity data via LoRaWAN, and the fuzzy model identified optimal thermal conditions for the broiler birds.
Lashari *et al.*, 2023Pakistan	Implement an IoT system to monitor temperature, humidity, O_2, CO_2, CO and NH_3 in broiler houses.	The IoT system monitored six environmental parameters in a real-world scenario, detecting acceptable levels of O_2, CO_2, NH_3 and CO.
Silva *et al.*, 2025 Brazil	Develop an embedded fuzzy system with web application for thermal control of broiler aviaries.	The IoT system with fuzzy logic achieved 98% accuracy and performed automatic thermal control via the web
Ali *et al.*, 2024 Pakistan	Develop an intelligent environmental control system for poultry houses, based on IoT and machine learning.	The Decision Tree model achieved 99.97% accuracy and allowed the automation of temperature, humidity, water, light and gases control in the aviary.

Malika *et al.*, 2021 Malaysia	Develop an IoT system to monitor temperature and humidity in aviaries with automatic activation.	The system monitored temperature, humidity and activated heating and ventilation automatically, sending alerts to the user.
Lehaa T. *et al.*, 2025 India	Develop an IoT system to monitor and control temperature, humidity, ammonia gas, and water in poultry houses.	The system maintained temperature and humidity within the ideal range; Reduced ammonia and accurately automated actuators.
Adha *et al.*, 2022 Malaysia	Propose and test an IoT framework to monitor temperature, humidity and ammonia in poultry houses.	The prototype validated the sensor readings, with data displayed on the website in a stable and reliable way.
Reddy *et al.*, 2024 India	Develop an IoT - CNN system to optimize temperature, humidity and air quality in poultry houses.	CNN reduced environmental deviations, increased stability, and outperformed PID, Fuzzy, and MPC methods.
Liu *et al.*, 2022 China	Evaluate the environmental quality of poultry houses using fuzzy logic and correlate with laying rate.	The fuzzy logic revealed environmental variations and a strong correlation with the laying rate.
Pranta; Islam; Khan, 2025 Bangladesh	Create and test an online decision-tree-based AI model integrated with sensors to control heat stress in layers.	The system reduced temperature and UTI, increased egg production (14.5%) and acted with 100% accuracy and low cost.
Santos; Borges, 2022 Brazil	Develop a low-cost IoT system to monitor temperature and humidity in small poultry houses.	The system monitored temperature and humidity, sent data for local and remote viewing, demonstrating practical feasibility.
Rubio; Ortiz, 2021 Colombia	Implement an IoT system to monitor and control environmental variables in poultry houses.	The system monitored temperature, humidity, ventilation, NH_3 gas, and automated fogging and drinking fountains, sending data to the cloud.
Husein; Kharisma, 2020 Indonesia	Develop a fuzzy–IoT system to control temperature and humidity in broiler houses.	The system kept the temperature and humidity close to ideal, displayed real-time data, and improved the weight uniformity of the chickens.
Prasetia; Dahlan; Lifwarda, 2024 Indonesia	Develop an IoT system to monitor temperature and humidity in broiler chicken coops.	The system with microcontroller and sensor, monitored temperature, humidity, activated ventilation, light and buzzer according to variations, maintaining conditions close to ideal.
Sanjaya; Fadlil, 2023 Indonesia	Develop an IoT system to monitor and control temperature and humidity in broiler houses.	The system activated ventilation, fogging and heating according to temperature and humidity, presented low reading error and sent data to the cloud.
Perdanasari; Etikasari; Rukmi, 2023 Indonesia	Develop an IoT system to monitor and control temperature, humidity and ammonia in real time in laying aviaries.	The system monitored temperature, humidity, and NH_3 gas stably for 16 days, with automatic actuator triggering and consistent sensor readings.
Suprianto; Pristiyaningrum; Prasetyo, 2022 Indonesia	Develop an IoT system with fuzzy logic (Sugeno) to control temperature and humidity in a prototype broiler aviary.	The system kept the temperature around 30.3 °C and the humidity around 70.5 percent, controlling the actuators by fuzzy logic and displaying the environmental data in real time.
Fahrurrozi *et al.*, 2024 Indonesia	Develop an IoT system integrated with the Random Forest model to predict environmental conditions of the aviary.	The Random Forest AI model with temporal variables achieved 96.66% accuracy and worked integrated with the web system.
Ishak *et al.*, 2024 Indonesia	Develop an IoT system to monitor temperature, humidity and ammonia at different points on the farm, evaluating accuracy and usability.	The system measured temperature, humidity, and ammonia with low error (0.5–3.1%), detected NH_3 concentration peaks, and recorded everything in real time on the dashboard and LCD.

Shanmugapriya; Sangeethadevi; Kalaivani, 2022 India	Develop an IoT system with a wireless sensor network to monitor temperature, humidity, air quality and safety in poultry houses.	The system maintained a temperature close to 32 °C and stable humidity around 60%; The exhaust fan reduced pollutants and the alerts and dashboard worked in real time.
Susanto *et al.*, 2023 Indonesia	Design IoT system to monitor temperature and trigger lamp automatically in pre-defined ranges.	The system measured the temperature accurately; the lamp turned on below 28°C and turned off above 31°C; and the control operated stably by ThingSpeak.
Syafar; Anwar; Ridwansyah, 2021 Indonesia	Develop an IoT system to monitor temperature, humidity, and ammonia, sending data to the smartphone.	The system monitored temperature, humidity and ammonia with the DHT22 and MQ-135 sensors; sent the data via GSM to the smartphone; and activated exhaust fan, heating and cooling.
Nalendra *et al.*, 2021 Indonesia	Evaluate the effectiveness of an IoT system to monitor temperature, humidity, and gas by observing the reaction of birds.	The system measured temperature, humidity and gas with sensors; showed small differences for the thermohygrometer; and maintained adequate conditions, with normal reaction of the birds.
Budiarto *et al.*, 2020 Indonesia	Implement an IoT system to monitor temperature, ammonia and food, with automatic alerts.	The system controlled the temperature by fuzzy logic, monitored ammonia and food accurately, and sent data to the server, with SMS alerts.
Setiadi; Arifiandi, 2024 Indonesia	Develop automatic feeder and IoT system to monitor temperature in aviary.	The system released feed at the defined times, displayed temperature and humidity on the LCD, activated a fan above 30 °C and a lamp below 25 °C, and maintained a Wi-Fi connection up to 10 m.
Saputra *et al.*, 2020 Indonesia	Implement fuzzy control in IoT module to regulate temperature and humidity in simulated heating environment for chicks.	The system sent data to the cloud; the actuators were controlled by fuzzy logic; and the PWM of the fan and heater showed a low error (0.11% and 0.22%) in relation to the MATLAB.
Adek *et al.*, 2024 Indonesia	Develop and evaluate an IoT system with fuzzy controller to regulate temperature, humidity and ammonia in chick rearing box.	Fuzzy control maintained low temperature and humidity, stabilized ammonia between 8–12 ppm, and reduced energy consumption, improving chick performance.
Arief; Damayanti, 2022 Indonesia	Develop a fuzzy system to optimize temperature in the early stage of chick rearing	The fuzzy control maintained the reference temperature for 14 days, showed responses close to the MATLAB, and regulated the temperature effectively with heating and cooling.
Fadhliana; Suryawan; Ariyadi, 2021 Indonesia	Develop a fuzzy microcontroller system to control temperature and humidity in quail cages.	The system showed a minimal difference between MATLAB and Arduino, adjusted temperature and humidity according to the fuzzy rules and obtained a very low average deviation (0.0438).
Mulya *et al.*, 2024 Indonesia	Evaluate the performance of an IoT system on a real farm to monitor temperature, humidity, electrical voltage and CCTV images.	The system collected real-time data, displayed measurements and videos on the web, and recorded a temperature of 27–35 °C, humidity of 60–90%, and voltage of 143–218V.
Rosikin *et al.*, 2023 Indonesia	Develop a fuzzy system to automate temperature, humidity and ammonia control with spray drive.	The system controlled the variables by fuzzy logic, sent data to the cloud and showed 100% accuracy, but low sensitivity and accuracy, indicating the need for improvements.
Manju *et al.*, 2024 India	Develop an IoT system to monitor and control temperature, humidity, water level, ammonia and waste on the farm.	The system monitored variables in real time, triggered ventilation, exhaust and water replenishment, sent data to the web

		and operated stably, reducing manual intervention.
Praing *et al.*, 2025 Indonesia	Develop an IoT system with fuzzy to automatically control the temperature in broiler sheds.	The system adjusted fan and lamp as per the fuzzy rules, displayed the data in the cloud, the DHT22 sensor showed high accuracy, and the control maintained the proper temperature.
Lahlouh *et al.*, 2020 Morocco	Implement and evaluate a fuzzy controller to regulate temperature, humidity and gases in a chicken rearing system.	The fuzzy controller reduced errors and flicker, decreased CO_2 and NH_3 gases, increased bird weight gain and reduced energy consumption by up to 43%.
Liu *et al.*, 2024 China	Develop and test an intelligent IoT platform for environmental monitoring and management in poultry houses.	The platform operated for more than 500 days with high data integrity and validity (>94%), monitored environment, consumption, and production, sent alerts, and maintained stable web integration.
De-Sousa *et al.*, 2023 Brazil	Develop and validate a fuzzy model to classify the vulnerability of broiler systems to heat stress.	The fuzzy model showed high accuracy and sensitivity (>0.9) in comfort and high stress, moderate performance in thermal discomfort and predictions consistent with the literature and weather forecasts.
Panagi *et al.*, 2025 Cyprus	Develop and validate an integrated platform with AI and multiple sensors for environmental and behavioral monitoring, productivity prediction and decision support in laying farms.	The system monitored temperature, humidity, audio and video; generated environmental alerts and forecasts; and AI modules showed high accuracy, including egg counting with 100% accuracy in the field.
Zheng *et al.*, 2021 China	Develop a sensor-based and cloud-based poultry management system for environmental and operational monitoring.	The system integrated environmental sensors, transmitted data via WSN to the cloud, and enabled real-time monitoring and disease diagnosis.
Kaimujjaman; Hossain; Khatun, 2023 Bangladesh	Develop and test an automatic system to monitor and control temperature and humidity in broiler aviaries.	The system controlled temperature and humidity, reduced mortality and improved feed conversion, production efficiency and economic performance compared to the conventional system.
Aulia; Kurniawan, 2024 Indonesia	Develop an automatic system with fuzzy logic to control the temperature in a mini house for newborn chicks.	The system stabilized the temperature using automatic heating and ventilation and showed high sensor accuracy (99.62%).
Kandarsamy; Mashori, 2024 Malaysia	Develop a smart chicken coop with automation to monitor and control temperature, humidity, light, food, water, and cleanliness.	The system maintained adequate environmental conditions, automated feeding, water and cleaning, improved safety and sustained good growth of the birds.
Wijaya; Hartati, 2024 Indonesia	Implement automatic temperature and humidity control using fuzzy logic to improve the thermal comfort of broilers.	The system reduced temperature and humidity, improved the ITU from 27.6% to 50.56%, increased the productive performance of the birds and stored the data in the cloud.
Lorencena *et al.*, 2020 Brazil	Propose a system for automatic control and environmental supervision of poultry houses.	The system controlled temperature and humidity, improved thermal distribution in simulations, and allowed remote supervision.
Yu *et al.*, 2025 China	Build an environmental monitoring system and propose a fuzzy model to evaluate the comfort of laying sheds.	The system monitored six environmental variables and generated fuzzy evaluations in real time; Adequate conditions increased posture.

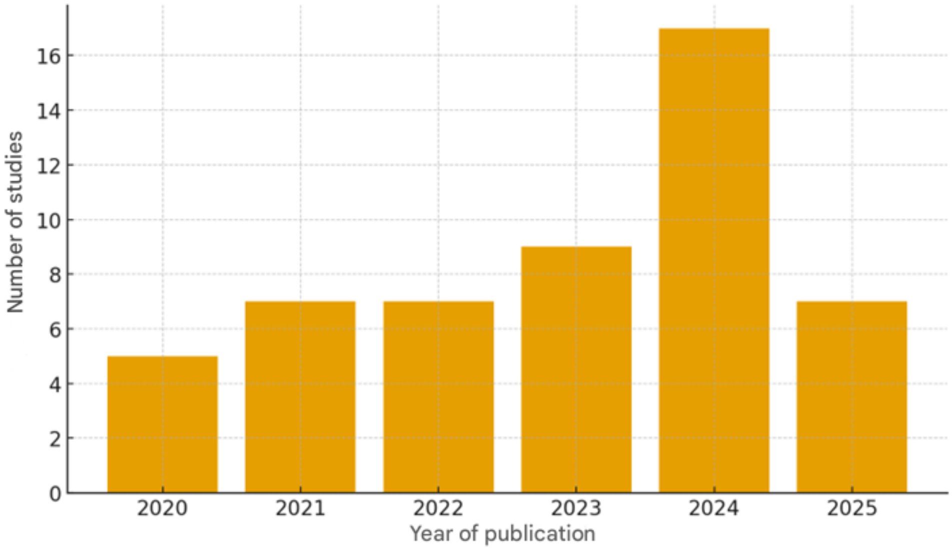
Gao *et al.*, 2022 China	Build a microclimatic model of rearing aviary and develop a decoupled fuzzy control strategy.	The model reproduced temperature and humidity with good accuracy, and the fuzzy control reduced environmental deviations compared to manual control.
Zhang; Ma; Khadka, 2024 China	To develop an adaptive system to predict multiple environmental factors in poultry houses using Multif-LSTM.	The Multif-LSTM predicted temperature, humidity and NH_3 with greater accuracy, reducing errors and increasing the R^2 in relation to the RNN and LSTM models.
Lahlouh *et al.*, 2024 Morocco	Develop and validate a state-space model to predict temperature and humidity in mechanically ventilated poultry houses.	The model predicted temperature and humidity with high accuracy (R^2 0.93–0.95) and low errors, reproducing well the environmental variations at different ages and ventilation modes.
Li *et al.*, 2023 China	Apply adaptive fusion and the Dempster–Shafer Theory of Evidence to integrate multiple sensors and improve environmental assessment in laying aviary.	The multisensory fusion system monitored temperature, humidity, light, and NH_3, and the adaptive and evidence algorithms increased the accuracy of the environmental assessment.
Elghardouf *et al.*, 2023 Morocco	Develop and validate mathematical models for air velocity and differential pressure in an air-conditioned aviary.	The model predicted air velocity and pressure with high accuracy (error < 1.1%), and measurements in real aviary showed good fit in natural, mixed and tunnel modes.
Elghardouf *et al.*, 2024 Morocco	Develop and compare environmental control strategies optimized by evolutionary algorithms to regulate temperature, humidity, NH_3 and CO_2 in poultry houses.	The control by active rejection of disturbances, optimized by particle swarm, showed better performance than the integral proportional derivative control. Genetic and gray wolf algorithms have brought smaller gains.
Rachmanita *et al.*, 2025 Indonesia	Implement a solar-powered, IoT-integrated environmental control system in broiler poultry house.	The system monitored temperature, humidity and NH_3 in real time, triggered exhaust fans, reduced energy costs by around 10% and improved productivity and mortality.
Li *et al.*, 2024 China	Apply multivariate analysis to characterize the microclimate of poultry houses in winter using data from multiple sensors.	It identified key variables and, with principal component analysis and fuzzy grouping, characterized indoor areas by air quality with greater accuracy.

Source: Prepared by the authors.

In 2020, 5 studies (9.5%) were identified, a number that increased to 7 studies in 2021 (13.5%) and remained the same in 2022, also with 7 studies (13.5%). In 2023, 9 studies were published (17.3%), while 2024 had the highest volume, with 17 studies (32.7%). Finally, 2025 recorded 7 studies (13.5%). Figure 2 shows the distribution of the 52 studies included by year of publication.

Figure 2

Distribution of studies by year of publication



Source: Prepared by the authors.

Table 2 presents a general summary of the 52 selected studies, covering the following indicators: poultry species evaluated, environmental variables monitored, type of environmental sensor used, type of hardware platform used, type of wireless data transmission network, type of artificial intelligence technique applied, use of storage systems and/or cloud data consultation, automatic control of actuators, environmental classification and validation of results with recognized environmental indexes. It should be noted that the same study may employ more than one indicator within each category, for example, combining different hardware platforms or multiple types of network. Thus, the frequencies and percentages presented reflect the number of occurrences and do not necessarily total 100% within each group.

Table 2

General synthesis of the selected studies

Collection indicators	Key findings
Type of species evaluated.	Laying hen – 13 (25%) Broiler – 39 (75%)
Environmental variables monitored.	Temperature – 52 (100%) Humidity – 49 (94.2%) Gases – 26 (50%) Others – 17 (32.7%)
Type of environmental sensor used.	DHT Series (Temperature/Humidity) – 29 (55.7%) SHT Series (Temperature/Humidity) – 3 (5.7%)

	MQ Series (gas) – 18 (34.6%) Others – 25 (48%) None – 6 (11.5%)
Type of hardware platform used.	ESP Series – 22 (42.3%) Arduino – 18 (34.6%) Raspberry – 9 (17.3%) Others – 10 (19.2%) None – 7 (13.4%)
Type of wireless data transmission network used.	Wi-Fi – 26 (50%) LoRa – 4 (7.7%) Mobile (3G/4G/5G) – 4 (7.7%) Others – 3 (5.7%) None – 18 (34.6%)
Type of artificial intelligence technique used.	Fuzzy logic – 19 (36.5%) Neural networks – 2 (3.8%) Decision trees – 2 (3.8%) Others – 10 (19.2%) None – 21 (40.3%)
Did you use a cloud data storage and/or consultation system?	Yes – 32 (61.5%) No – 20 (38.5%)
Did the system perform automatic actuator control?	Yes with Artificial Intelligence – 17 (32.7%) Yes without Artificial Intelligence – 21 (40.4%) Did not perform – 14 (26.9%)
Did the system make an environmental classification (e.g., good, moderate, critical)?	AI-powered Yes – 13 (25%) Yes without Artificial Intelligence – 5 (9.6%) Did not do so – 34 (65.4%)
Was there validation of the results with recognized environmental indexes?	Yes – 2 (3.8%) No – 50 (96.2%)

Source: Prepared by the authors.

The synthesis of the main indicators raised in the included studies allowed us to visualize the diversity of technological approaches applied to environmental monitoring in poultry systems. It was observed that several surveys used more than one hardware platform, environmental sensor, or communication technology simultaneously. Overall, temperature and humidity were the most monitored variables, followed by gas detection, while the ESP series and Arduino stood out among the hardware platforms employed. As for the sensors, the use of the DHT and MQ series predominated, although other environmental sensors were also applied. It was also found that the distribution of the studies shows a predominance of research carried out in broiler systems (75%), while only 25% directly address laying aviaries. This result points to a relevant gap in the scientific literature, indicating that, despite the economic and productive importance of laying poultry, there is less investment in research specifically aimed at automated monitoring of the environment in this production system.

The Wi-Fi network was the most recurrent means of data transmission, although some studies have explored LoRa communication or cellular connections. Fuzzy logic was the most used artificial intelligence technique, either for environmental classification or to support actuator control, while a portion of the studies were limited to monitoring without the application of an artificial intelligence method. In addition, it was observed that most of the systems incorporated cloud storage and that few studies validated their results with recognized ambience indexes. These findings provide a technological and methodological overview of the studies analyzed, serving as a basis for discussion in the following section.

4 DISCUSSION

The results of this scoping review show a significant growth in research involving fuzzy logic, sensing, and IoT technologies applied to monitoring the environment in poultry systems between 2020 and 2025. There was a gradual increase in the number of publications throughout the period, especially in 2024, which concentrated the largest number of studies included. This behavior suggests that the theme goes hand in hand with the recent expansion of digital and smart solutions in livestock production, as well as the growing interest in continuous monitoring systems and data-driven decision-making on commercial farms.

From a geoFigureical point of view, the distribution of studies revealed a strong concentration especially in Indonesia and China, followed by Brazil, India, Morocco and other countries. This predominance may be related to the economic importance of poultry farming in these regions, the advancement of policies to encourage agriculture 4.0, and the greater availability of technical labor for the development of prototypes and low-cost IoT platforms. At the same time, the lower representation of other egg and chicken meat producing countries indicates an opportunity to expand investigations in environmental and production contexts, particularly in laying systems.

Although the focus of this review is on laying aviaries, most of the studies included were conducted with broilers, as exemplified by Liani *et al*. (2021), Husein and Kharisma (2020) and Sanjaya and Fadlil (2023), among others. On the other hand, a smaller number of investigations addressed laying hens, as in the works of Liu *et al*. (2022), Perdanasari, Etikasari and Rukmi (2023) and Panagi *et al*. (2025). This asymmetry highlights an important gap, considering that the longevity of birds, their sensitivity to environmental variations, and the specific welfare demands in laying aviaries, justify the need to expand technological solutions dedicated to this segment.

Regarding the methodological design, field studies predominate, as demonstrated by Lashari *et al*. (2023), Fahrurrozi *et al*. (2024) and Mulya *et al*. (2024). Next, experimental research, carried out in controlled environments, as in Lehaa *et al*. (2025), Silva *et al*. (2025) and Adha *et al*. (2022). A case study was also identified (Malika *et al*., 2021) and another based on modeling and simulation (Elghardouf *et al*., 2024). This profile indicates that a large part of the technological proposals have been tested in real production conditions, which favors the practical validation of monitoring and control systems. At the same time, the relevant presence of experimental and simulation studies demonstrates the importance of prototyping and calibration steps in controlled environments, before implementation on a commercial scale. The combination of both designs strengthens the reliability of the results, but also highlights the need for detailed methodological descriptions to allow replication and comparison between studies.

With regard to the environmental variables monitored, it was observed that temperature and humidity are present in practically all studies, while the measurement of gases, such as ammonia and carbon dioxide, is even less frequent. This predominance was expected, as temperature and relative humidity are the main indicators of thermal comfort and are relatively simple to measure with widely available sensors. However, the lower emphasis on gas monitoring represents a critical point, since air quality is directly related to the respiratory health of birds, productive performance and the working conditions of employees. In this sense, the expansion of the use of specific sensors for NH_3, CO_2 and other contaminants, as well as the integration of these parameters in decision models, sets an important direction for future research.

The analysis of the types of sensors and the hardware platforms employed reveals a preference for widely available low-cost sensors, especially the DHT and MQ series, and for affordable microcontrollers, such as ESP32 and Arduino, as observed in Syafar, Anwar and Ridwansyah (2021), Nalendra *et al*. (2021) and Ishak *et al*. (2024). This combination reflects the search for affordable solutions, easy to program, and with good integration with wireless networks, which favors the construction of modular and scalable IoT systems. However, the adoption of more accurate SHT series sensors and more robust hardware architectures may be necessary in applications that require higher accuracy reliability, read stability, and service life.

In the field of communication technologies, the Wi-Fi network was the most widely used form of wireless transmission, appearing in studies such as that of Shanmugapriya, Sangeethadevi and Kalaivani (2022), Setiadi and Arifiandi (2024) and Prasetia, Dahlan and Lifwarda (2024). While long-range and low-consumption networks, such as LoRa, emerged in a much smaller proportion, being mentioned in few studies, such as the one by Liani *et al*. (2021), Santos and Borges (2022) and Rubio and Ortiz (2021). This scenario indicates that many systems still rely on the restricted-range local area network. The low adoption of LoRaWAN reveals room for advancement, especially in limited or extensive connectivity properties with multiple warehouses. Expanding the use of LoRa network or other technologies can help overcome these limitations and expand the coverage of real-time monitoring.

Following the example of Suprianto, Pristiyaningrum and Prasetyo (2022), Saputra *et al*. (2020) and Adek *et al*. (2024), fuzzy logic stood out as a widely used artificial intelligence technique, both for classifying environmental conditions and for supporting the automatic activation of actuators. Other intelligent models, such as neural networks and decision trees, appeared in much smaller quantities, recorded in Zhang, Ma and Khadka (2024), Reddy *et al*. (2024) and Pranta, Islam and Khan (2025). However, a significant number of studies did not use artificial intelligence, being limited to monitoring and automation by fixed rules, as in Susanto *et al*. (2023), Manju *et al*. (2024) and Zheng *et al*. (2021). This result shows that, although fuzzy logic is consolidated as a promising tool to treat uncertainties and translate the knowledge of experts in inference systems, its use is not yet predominant in the entire set of IoT applications in poultry farming, thus indicating that the transition to truly intelligent systems is still in progress. In addition, the integration between fuzzy logic and other artificial intelligence methods, such as predictive models based on time series or multivariate classification algorithms, appears in few studies, which opens space for more sophisticated hybrid proposals.

As demonstrated in Kandarsamy and Mashori (2024), Aulia and Kurniawan (2024) and Kaimujjaman, Hossain and Khatun (2023), it was found that most of the systems described in the studies perform automatic actuator control. Among these, a slightly larger portion employs artificial intelligence techniques to support the decision process, while another part performs the triggers only based on fixed temperature and humidity thresholds, without the use of artificial intelligence.

Regarding the environmental classification, identified in the research of Liu *et al*. (2022), Pranta, Islam and Khan (2025) and De-Sousa *et al*. (2023), only a small portion of the studies explicitly categorized the conditions, adopting terms such as "comfortable", "moderate" or "critical". Among these studies, some used artificial intelligence techniques, such as fuzzy logic or other models, while the others performed classification without the support of artificial intelligence. This gap is significant, as the translation of numerical data into understandable language classes is critical to support decision-making by technicians and producers. This process becomes even more efficient when carried out with the support of artificial intelligence techniques, which allow converting continuous information into interpretable categories in a consistent and adaptive way, in addition to facilitating the integration of these outputs into web interfaces and mobile applications.

Another point identified is that a very small number of studies validated the results with recognized indices of thermal comfort or environmental quality, as happened in the works of Wijaya and Hartati (2024) and Pranta, Islam and Khan (2025). Few studies have compared the responses of their systems with literature indexes, which limits comparability between approaches and makes it difficult to assess the real impact of the proposed technologies on animal welfare and productive performance.

Finally, it is noteworthy that most studies implemented some type of cloud data storage or consultation (Liani *et al*., 2021; Lashari *et al*., 2023; Silva *et al*., 2025), which reinforces the trend of digitization and centralization of environmental information on remotely accessible platforms. Still, an important fraction of the work remains limited to on-premise solutions, without remote exploitation of real-time data (Ali *et al*., 2024; Malika *et al*., 2021; Liu *et al*., 2022).

In general, the analyzed studies demonstrate significant advances in the area of environment in poultry sheds, but also reveal important challenges identified. Thus, the findings of this review provide a solid basis to guide and support future investigations in the development of intelligent environmental monitoring systems in poultry houses.

5 CONCLUSION

This scoping review highlighted three central quantitative findings. First, only 25% of the studies analyzed directly address laying aviaries, while 75% focus on broiler systems, indicating a relevant gap in the scientific literature specifically focused on egg production. Secondly, it was found that practically 100% of the studies monitor the environmental variables temperature and humidity, while 50% of the studies also monitor parameters related to air quality, such as gases and particulate matter, indicating a growing concern with environmental impacts and animal welfare. Finally, it was observed that about 40.3%

of the studies do not use artificial intelligence or machine learning techniques, being limited to descriptive analyses or monitoring systems without automated decision-making support.

In the technological field, it was verified the majority use of low-cost temperature, humidity and gas sensors, especially the DHT and MQ series, as well as accessible hardware platforms, such as ESP series microcontrollers and Arduino boards, usually associated with communication via Wi-Fi. Long-range and low-consumption data transmission technologies, such as the LoRa network, have been little explored, pointing to opportunities for advancement in rural scenarios with multiple warehouses and restricted connectivity. Fuzzy logic stood out as the most used artificial intelligence technique, however, a considerable number of systems still operate without using intelligent models for both automatic actuator control and environmental classification. Classification, in particular, was very little used in the studies analyzed, despite its importance for translating numerical data into understandable linguistic categories, such as "comfortable", "moderate" or "critical". This type of classification makes the reading of environmental conditions more intuitive for technicians and producers, strengthening the decision-making process. It was also observed that, although many of the systems integrate cloud data storage and consultation solutions, this practice is not yet universal among research. The implementation of cloud platforms enables remote monitoring in real time and favors historical data analysis, so the use of this technology is an important opportunity to strengthen the intelligent management of poultry houses.

Regarding the validation of the results by means of recognized indices of thermal comfort or environmental quality, it was found that this practice was practically absent among the studies analyzed. This gap compromises the comparability of approaches and makes it difficult to assess the real impact of solutions on animal welfare and productive performance.

In view of these findings, it is concluded that the objective of this scoping review, which consists of identifying, mapping and characterizing studies that integrate, in isolation or combination, fuzzy logic, environmental sensors and IoT technologies in the monitoring of the environment in laying aviaries, was achieved. However, it is recommended that future investigations prioritize: (i) the expansion of the monitoring of variables related to air quality; (ii) the integrated use of fuzzy logic with other artificial intelligence techniques for prediction, classification, and decision-making; (iii) the validation of systems with consolidated environmental indexes; and (iv) the development of specific solutions for laying aviaries, with a focus on low-cost IoT hardware, long-range wireless networks, full integration with cloud computing environments and intelligent data analysis. Such advances combined can contribute to consolidating intelligent environmental monitoring and control systems in laying poultry farming, promoting animal welfare, productive sustainability and greater efficiency in the use of resources.

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